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Laboratorium voor Analytische Scheikunde
Bestuurders : Prof. emer. J. HOSTE (tot 1986)
Prof. R. DAMS

THE k_0-STANDARDIZATION METHOD

A MOVE TO THE OPTIMIZATION OF NEUTRON ACTIVATION ANALYSIS

FRANS DE CORTE

In English
Nederlandse samenvatting - Résumé en français

Proefschrift voorgelegd tot het verkrijgen van de graad van
Geaggregeerde voor het Hoger Onderwijs - 1987

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"*Everyone* needs standards"

[Advertising slogan seen in London, July 1978, on my way to the 5th Symposium on the Recent Developments in Activation Analysis, held in St. Catherines College, Oxford]

Voor Igna

Aan mijn meter, Augusta De Corte
Aan mijn petekind, Bart De Corte

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CONTENTS

LIST OF SYMBOLS

a	= branching ratio
a (subscript)	= analyte (determinand)
A_{sp}	= specific count rate
b	= barn (10^{-24} cm^2)
c	= internal conversion factor [= $1/(1+\alpha_t)$]
c (subscript)	= comparator (coirradiated with standard for k_0-determination)
C	= "measurement" factor [= $(1-e^{-\lambda t_m})/\lambda t_m$]
Cd (subscript)	= epicadmium (i.e. related to irradiation under Cd-cover)
COI	= correction factor for true-coincidence effects
D	= decay factor (= $e^{-\lambda t_d}$)
e (subscript)	= epithermal (not in R_e, where it denotes "epicadmium")
E	= neutron energy
EC	= electron capture
E_{Cd}	= effective Cd cut-off energy (= 0.55 eV in standard conditions)
E_{eff}	= effective gamma energy
E_γ	= gamma energy
ENAA	= epicadmium neutron activation analysis
E_0	= 0.0253 eV (Maxwellian) neutron energy
E_r	= resonance energy
$\bar{E}_r$	= effective resonance energy
f	= subcadmium (thermal)-to-epithermal neutron flux ratio (= ϕ_s/ϕ_e)
F	= fractional decay factor
F_{att}	= correction factor for gamma-attenuation

F_{burn} = correction factor for burn-up

F_{Cd} = correction factor for Cd-transmission of epithermal neutrons

g = statistical weight factor

g (superscript) = ground state

G_e = correction factor for epithermal neutron self-shielding

geo (superscript) = counting geometry

G_{th} = correction factor for thermal neutron self-shielding

$g(T_n)$ = Westcott-factor at (Maxwellian) neutron temperature T_n

I_{abs} = neutron absorption resonance integral of the element

ic = internal comparator (for k_0 and Q_0 determination)

IC = internal conversion

INW = Instituut voor Nucleaire Wetenschappen (Institute for Nuclear Sciences, State University Gent/Belgium)

I_0 = resonance integral for a 1/E epithermal spectrum, integrated from E_{Cd} = 0.55 eV

$I_0(\alpha)$ = resonance integral for a $1/E^{1+\alpha}$ epithermal spectrum

IT = internal transition

$k\alpha_1$ [or α_2, β_1'...] = $K\alpha_1$ [or α_2, β_1' ...] relative emission rate (probability that KX-ray is $K\alpha_1$ [or α_2, β_1',...])

KFKI = Központi Fizikai Kutató Intézete (Central Research Institute for Physics, Budapest/Hungary)

$k_{0,x}(y)$ = k_0-factor of y versus x

m (subscript) = monitor (coirradiated with sample)

m (superscript) = metastable state (or states m_1, m_2,...)

M = molar mass

m_n = rest mass of neutron

N_A = Avogadro's number

NAA = reactor neutron activation analysis

N_p = number of counts in the full-energy peak corrected for pulse losses

N'_p = number of counts observed in the full-energy peak

n_s = subcadmium (thermal) neutron density

$n'(v)$ = neutron density per unit of velocity interval, at neutron velocity v

p_j = parameters on which a quantity Q is depending

P_K = probability that EC is K EC

P/T = peak-to-total ratio

Q = quantity depending on the parameters p_j

Q_0 = resonance integral (1/E) to 2200 m s^{-1} cross-section ratio ($= I_0/\sigma_0$)

$Q_0(\alpha)$ = resonance integral ($1/E^{1+\alpha}$) to 2200 m s^{-1} cross-section ratio [$= I_0(\alpha)/\sigma_0$]

r = thermal-to-epithermal flux ratio (f) monitor

R = (n,γ) reaction rate per nucleus

R_{Cd} = Cd-ratio [$= A_{sp}/(A_{sp})_{Cd}$]

R_e = epicadmium (n,γ) reaction rate per nucleus

ref (superscript) = reference counting geometry

s = uncertainty

s (subscript) = standard (not in ϕ_s, n_s and R_s, where it denotes "subcadmium")

S = saturation factor ($= 1-e^{-\lambda t_{irr}}$)

$s_Q(p_j)$ = uncertainty on quantity Q originating from parameter p_j

T = half-life

t_d = decay time

t_{irr} = irradiation time

T_1 = half-life of a nuclear level (in decay scheme)

t_m = measuring time

T_n = (Maxwellian) neutron temperature

T_0 = 293.59 K (Maxwellian) neutron temperature

v = neutron velocity

v_{Cd} = neutron velocity corresponding to E_{Cd}

v_0 = 2200 m s^{-1} (Maxwellian) neutron velocity

w = mass of element

W = mass of sample

Z = atomic number

$Z_Q(p_j)$ = propagation factor of error on parameter p_j towards quantity Q

α = parameter describing the $\varphi_e'(E) \sim 1/E^{1+\alpha}$ neutron flux distribution

$\alpha_{t[K, L,...]}$ = total [or K, L ...] internal conversion coefficient

γ = absolute gamma-intensity (gamma-emission probability)

Γ = total width of resonance

Γ_γ = radiative width of resonance

Γ_n = neutron width of resonance

ε = electron capture intensity

ε_p = full-energy peak detection efficiency, including gamma-attenuation

ε_t = total detection efficiency

θ = (fractional) isotopic abundance

λ = decay constant

ρ = concentration

$\bar{\sigma}$ = ^{235}U fission neutron averaged cross-section

σ_{abs} = thermal neutron absorption cross-section of the element

$\sigma(E)$ = (n,γ) cross-section at neutron energy E

σ_0 = $\sigma(v_0) = \sigma(E_0) = 2200$ m s^{-1} (n,γ) cross-section

$\sigma(v)$ = (n,γ) cross-section at neutron velocity v

τ = amplifier's pulse shaping time constant

T = peaking time of amplifier's output pulse

$\varphi'(E)$ = neutron flux per unit of energy interval, at neutron energy E

$\varphi'(v)$ = neutron flux per unit of velocity interval, at neutron velocity v

ϕ_e = conventional epithermal neutron flux

ϕ_f = (equivalent) fission neutron flux

ϕ_s = conventional subcadmium (thermal) neutron flux

ω_K = K-fluorescence yield

$\bar{\Omega}$ = effective solid angle

INTRODUCTION

Two features of (n,γ) reactor neutron activation analysis [NAA] are making its standardization (i.e. calibration) potentially easy and accurate: the high penetrability of matter for neutrons; and the existence of a delayed signal (besides the prompt gamma's), viz. the characteristic radiation emitted in the decay - with a specific half-life - of the unstable nuclei formed by (n,γ) reaction. Hence, standard and sample can be excited simultaneously - i.e. they can be coirradiated -, and the induced signals of both can be measured successively after a suited time following the end of irradiation.

Other consequences of these two features are that NAA is a bulk analysis method with multi-element capability, that the relation between element concentration and measured signal is nearly matrix-independent, that matrix preparation can be kept simple - thus minimizing the risk for loss and contamination -, and that treatment of sample (and standard) after irradiation is possible - thus enabling such operations as etching, dissolution and chemical separation with the addition of inert carriers and subsequent determination of the separation yield. If measurement of decay gamma's is performed - a procedure feasible for a vast majority of the elements -, the feature of matter being highly penetrable for this type of radiation leads the way to non-destructive analysis of many matrices - on condition that use is made of high-resolution gamma-spectrometry with a Ge-detector. This feature also implies that irradiation and counting of a multi-element standard of extended geometry is possible.

The above virtues of NAA are amplified by its excellent sensitivity (down to the ppm, ppb or even to the ppt level) attainable for many elements - though not all -, and by the solid theoretical foundation whereon it is based. This allows NAA to be classified as an extremely powerful analytical method for which all sources of systematic or random variation are identifiable and predictable down to the limits of detection, so that, among a variety of other applications, it is eminently suited for the certification of reference materials.

Every coin has two sides, however, and NAA is no exception. Some of its disadvantages are obvious, such as the dependence on an irradiation facility

(a nuclear reactor) and the threshold imposed by legal safety regulations for the manipulation of radioactive materials. Additional hindrance to its use - especially in case of industrial applications - is the comparatively lengthy analysis procedure. Indeed, in extreme trace analysis and if long-lived radionuclides are involved, irradiation periods of many hours or even days and measuring periods of tens of hours (per sample) are often required [not to forget the considerable decay periods which are occasionally necessary to reduce disturbing (matrix) activities when non-destructive work is carried out]. The only way to remedy these inconveniences is by turning to larger samples, higher neutron fluxes and more efficient counting devices (i.e. larger Ge-detectors) - if possible and financially justifiable. Not only the sample is present, however, but the standards are there as well, requiring - they too - manpower and time (and thus, money) for their preparation, counting and data processing, which is especially - but not uniquely - a nuisance in case of multi-element routine analysis. All this makes NAA a rather expensive, time-consuming, labour-intensive, yet very sensitive and accurate determination method. Thus, it should not be surprising that a serious challenge is emanating from other extreme trace analysis techniques with threatening acronyms such as GF-AAS [made considerably more accurate by using platform techniques, matrix modifiers, Zeeman compensation, and so on] and (ID-)ICP-MS [a very promising newcomer in the field].

Recognition of the drawbacks of NAA is not new, and already at the early stages in its development - at the late fourties - efforts have been spent to simplify the standardization procedure drastically. This is possible, indeed, because of the above mentioned features of NAA. Among these, it is important to recall its well-founded theoretical basis, meaning in fact that the phenomena of (n,γ) activation [signal excitation], radioactive decay and measurement of gamma-radiation [signal detection] are well-understood and can be accurately described. The consequences of this can be extrapolated to the extreme : all standards can be omitted and quantitative NAA is possible by neutron flux monitoring, absolute gamma-ray counting and direct calculation of weights from nuclear constants. This procedure of "absolute" standardization has been extensively dealt with by Girardi et al., among others [F.Girardi, G.Guzzi, J.Pauly, Anal.Chem., 36/8 (1964) 1588]. It was concluded that uncertainties in nuclear data taken from literature, especially those on decay schemes and activation cross-sections, may be responsible for systematic errors up to tens of

percents. Although the situation improved significantly ever since, even nowadays the uncertainties are too large to allow of analysis results of an accuracy comparable to that of relative standardization - as will be amply demonstrated in the present work. A less drastical approach is to determine experimentally the so called k-factors depending on nuclear constants by irradiating known weights of the elements under study with a neutron flux monitor (irradiating then the unknown samples with a similar flux monitor), instead of deriving them by calculation. This "single-comparator" method has been critically evaluated in 1965 by the above mentioned authors [Anal.Chem., 37/9 (1965) 1085] and it was proven that it is as accurate as the relative standardization. On the other hand, however, application of it is strictly bound to constant experimental parameters of activation and counting, thus resulting in an exorbitant rigidity.

Throughout the years many variants of the absolute and single-comparator methods have been proposed and applied, and no doubt should exist as to their usefulness in many fields of application of NAA. These efforts, however, did not lead to a procedure combining the merits of experimental simplicity, high accuracy, excellent flexibility (with respect to the irradiation and counting conditions) and suitability for computerization. These four aspects were actually the main topics of concern when in 1974 the idea of the k_0-standardization method - the subject of the present work - was ripening.

The k_0-standardization method was intended to be an absolute technique where the uncertain nuclear data are replaced by compound nuclear constants - the k_0-factors - which are experimentally determined with high accuracy. Basically, this determination is done as for the k-factors, which are then transformed into k_0's by lifting out the experimental parameters. k_0-Factors are thus generally applicable on condition that the activation analyst recombines them with the parameters of the local irradiation and counting conditions, in this way generating "his" k-factors; from this point of view, the k_0-method is a flexible single-comparator technique.

The above makes clear that the k_0-standardization stands or falls with the availability and especially the accuracy of k_0-factors, and the determination of those was therefore planned to be undertaken as a cooperation between the Institute for Nuclear Sciences (Gent) and the Central Research Institute for Physics (Budapest). Very soon, however, the k_0-factor turned out to be but one of the kernels of the enterprise, and this should not be aston-

ishing in view of the stringent goals aimed at. Thus, it was a necessity to develop new methods - or to adopt and optimize existing ones - and to evaluate nuclear data (by experiment or calculation), with regard to such phenomena as complex activation and decay, burn-up effects, detection efficiency, true-coincidence of cascading radiation, and the contribution of epithermal (n,γ) activation; not to forget specific problems caused by uncertainties on half-lives, primary interferences [(n,n') and (n,2n)], variability of neutron flux during irradiation, intermittent irradiation, and deviation from ideality of the cross-section versus energy dependence in the thermal neutron region. By choosing the Høgdahl-convention for the description of the (n,γ) reaction rate, correction for the deviation of the cross-section - although fundamentally feasible - was wittingly omitted in the here proposed methodology; indeed, with only some rare exceptions, the resulting inaccuracies are small to negligible, and the slight improvement that would result from adopting more sophisticated formalisms is not worth the sacrifice to the experimental simplicity.

The above mentioned efforts led to the possibility of evaluating the accuracy and traceability of the k_0-method, and of clearly marking out its applicability. Since the proof of the pudding is in the eating, however, it was essential to turn to practice, for which the development of computer programs was a prerequisite. Thus, it was felt mandatory to analyze a number of reference materials, in order to examine and assure the accuracy and compatibility of the k_0-based results; but, in addition, a survey is given of analyses taken from life.

CHAPTER I

FUNDAMENTALS

1. DESCRIPTION OF THE (n,γ) REACTION RATE

1.1. General formulation

Upon reactor neutron irradiation of a nuclide the (n,γ) reaction rate per nucleus (in s^{-1}) is given by :

$$R = \int_0^\infty \sigma(v)\ \varphi'(v)dv = \int_0^\infty \sigma(E)\ \varphi'(E)dE \qquad (I.1\text{-}1)$$

with $\sigma(v)$ = (n,γ) cross-section [in cm^2 ; 1 barn (b) = 10^{-24} cm^2] at neutron velocity v (in cm s^{-1}) ;

$\sigma(E)$ = (n,γ) cross-section (in cm^2) at neutron energy E (in eV) ;

$\varphi'(v)$ = neutron flux per unit of velocity interval (in cm^{-3}) at neutron velocity v ;

= n'(v)v, with n'(v) = neutron density per unit of velocity interval (in cm^{-4} s) at neutron velocity v ;

$\varphi'(E)$ = neutron flux per unit of energy interval (in cm^{-2} s^{-1} eV^{-1}) at neutron energy E.

In Eq. (I.1-1), $\sigma(v) = \sigma(E)$ with E (in erg = $6.2415.10^{11}$ eV) = 1/2 m_n v^2 [m_n = rest mass of the neutron = $1.6749.10^{-24}$ g]. Furthermore, per definition, $\varphi'(v)dv = \varphi'(E)dE$ [both in cm^{-2} s^{-1}].

1.2. (n,γ) Cross-section and neutron flux functions

In Eq. (I.1-1), the functions $\sigma(v)$ [$= \sigma(E)$] and $\varphi'(v)$ [or $\varphi'(E)$] are complex and are respectively depending on the (n,γ) reaction and on the irradiation site. Fortunately, introduction of some generally valid characteristics yields the possibility of avoiding the actual integration and of describing accurately the reaction rate in a relatively simple way by means of so-called formalisms or conventions. In short, these characteristics are :

- The (n,γ) cross-section function $\sigma(v)$ versus v can be interpreted as a $\sigma(v) \sim 1/v$ dependence, or $\sigma(E)$ versus E as a $\sigma(E) \sim 1/E^{1/2}$ dependence [log $\sigma(E)$ versus log E is linear with slope - 1/2], on which - above some eV - several resonances are superposed (Fig. I.1-1). These resonances, and also the "1/v-tail", are described by the Breit-Wigner equation [BREIT36]. Only a few (n,γ) reactions of interest in NAA show a significant deviation from the 1/v-dependence in the energy region below 1.5 eV (due to low-lying resonances). In some conventions for the description of the reaction rate, based on transformation of Eq. (I.1-1), these deviations are accounted for by introducing the Westcott $g(T_n)$-factor ($\neq 1$ in such cases) which is depending on the neutron temperature T_n (see below) [WESTCOTT55/58/58A/62 ; STOUGHTON59].
- The neutron flux distribution, e.g. $\varphi'(E)$ versus E, can be subdivided into three components (Fig. I.1-2) :

1. a fission or fast neutron spectrum, showing a maximum (i.e. most probably energy) at $\sim$ 0.7 MeV neutron energy, and frequently described by the semi-empiric Watt-representation [WATT52]. Since $\sigma(v)$ becomes very small in the MeV-region, the contribution of the fast neutron induced (n,γ) reaction rate can be neglected, also because in practical NAA irradiation conditions the fast neutron flux component is not dominant (and in most cases relatively small) ;
2. a spectrum of low-energetic neutrons which, after slowing-down or moderation (see sub 3.), are in thermal equilibrium with their environment (moderator). This spectrum can be described by a Maxwell-Boltzmann distribution [IAEA70]. In a $\varphi'(E)$ versus E or $n'(v)$ versus v representation the maximum of the curve (i.e. the most probable energy or velocity) is situated at $E(T_n) = kT_n$ or $v(T_n) = [2E(T_n)/m_n]^{1/2} = [2kT_n/m_n]^{1/2}$, respectively [k=Boltzmann's constant = $1.3807.10^{-16}$ erg K^{-1} ; T_n = neutron temperature, in K]. In standard conditions : T_0 = 293.59 K, E_0 = 0.0253 eV, $v_0 = 2.200.10^5$ cm s^{-1} = 2200 m s^{-1} ; the value $\sigma(v_0) = \sigma_0$ is referred to as the 2200 m s^{-1} cross-section ;
3. an epithermal (intermediate, moderation, slowing-down) neutron spectrum (index e), which can be described in the ideal case by a $\varphi'_e(E) \sim 1/E$ dependence. In actual irradiation sites, the latter can be replaced by a $\varphi'_e(E) \sim 1/E^{1+\alpha}$ dependence, with α ($\lesssim 0$) being to a first approximation independent of neutron energy (see V.1). For the present reasoning, one can

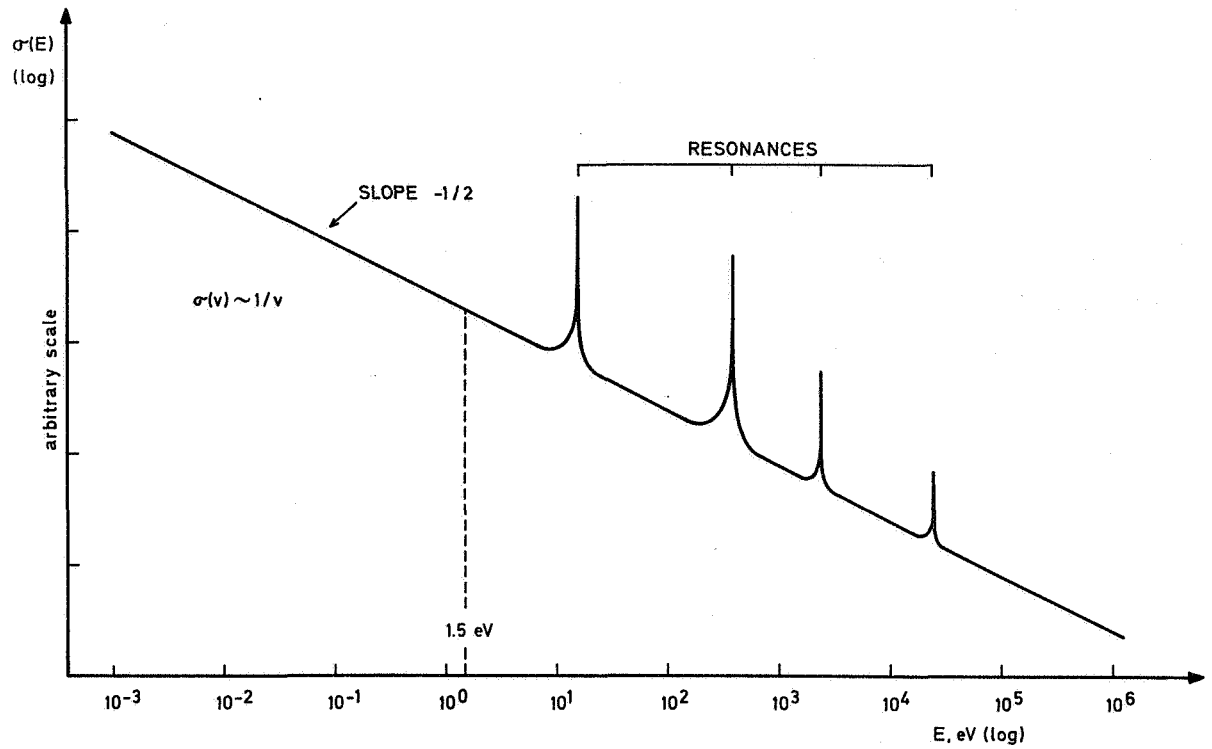


Fig. I.1-1 : Schematic representation of the (n,γ) cross-section function σ(E) versus E

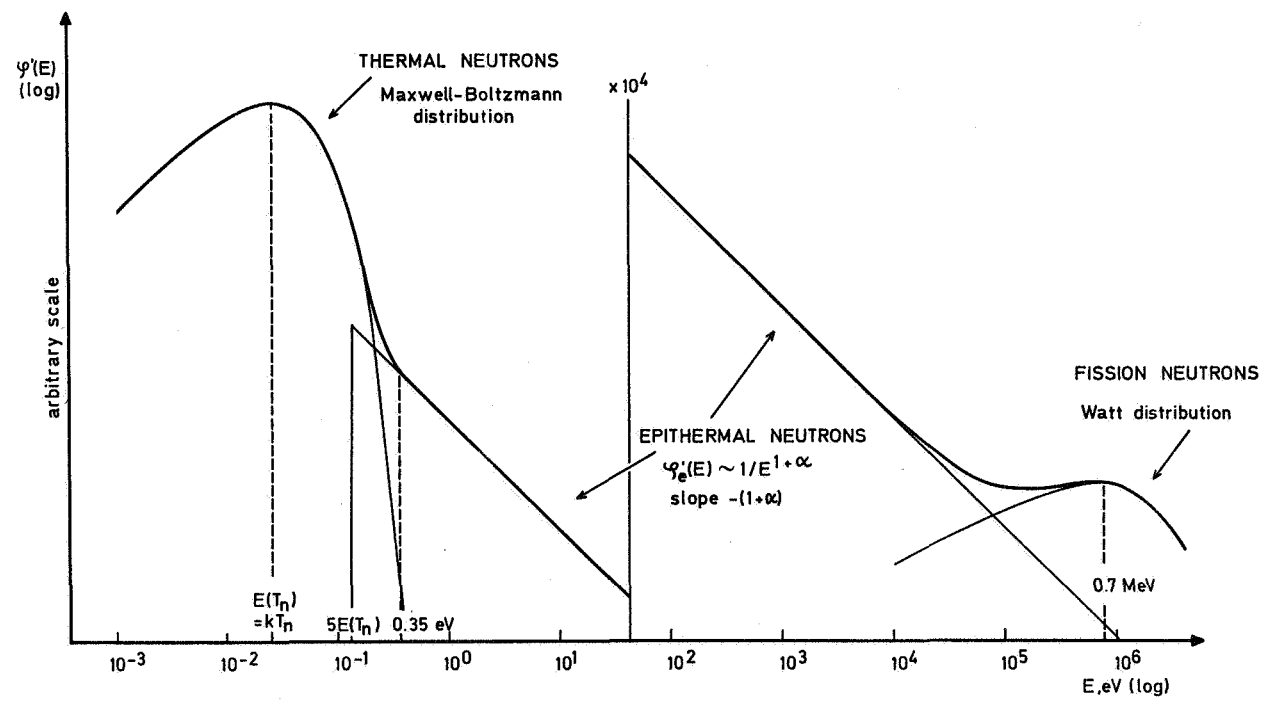


Fig. I.1-2 : Schematic representation of the reactor neutron flux distribution φ'(E) versus E

assume a sharp termination of the epithermal neutron flux at $5E(T_n)$ [STOUGHTON63]. In view of considerations with respect to the effective Cd cut-off energy (see I.3.2), it is important to remark that the Maxwellian neutron flux is practically not disturbing the epithermal neutron flux above $\sim$ 0.35 eV neutron energy. In principle, this could happen for "hot" Maxwellian spectra (high T_n), but the disturbance is counteracted because in practical NAA conditions the degree of thermalization is then lower (lower thermal-to-epithermal flux ratio). On the other hand, in view of the remark made above (sub 1.), the high-energy junction with the fission spectrum is irrelevant.

1.3. The Høgdahl convention

1.3.1. Choice of convention

Among the commonly adopted conventions, those of Westcott [WESTCOTT55/58/58A/62] and of Stoughton and Halperin [STOUGHTON59] are the most generally applicable ones, since they take into account possible deviations from the $\sigma(v) \sim 1/v$ dependence in the low-energy region. This implies the knowledge of the Westcott $g(T_n)$-factors, and hence a neutron temperature monitoring is required. Since, as said above, $g(T_n) = 1$ (independent of neutron temperature) for the large majority of analytically interesting (n,γ) reactions, the much simpler Høgdahl convention was adopted in the present work [HØGDAHL62/65]. Only the reactions $^{151}Eu(n,\gamma)$ and $^{176}Lu(n,\gamma)$, which are seriously violating the 1/v-dependence, are then excluded from being dealt with, at least if one tolerates analytical errors of 1-2% as induced by some other (n,γ) reactions with $g(T_n)$-factors slightly different from unity (see VII.4).

1.3.2. The effective cadmium cut-off energy

Before giving an outline of the Høgdahl convention, it is necessary to consider briefly the concept of the effective Cd cut-off energy.

When irradiating a nuclide under a Cd-cover, the (n,γ) reaction rate is drastically reduced in the low energy region, where the neutrons are largely absorbed by the Cd due to the very high $Cd(n,\gamma)$ cross-section (mainly caused by the $^{113}Cd(n,\gamma)$ resonance at 0.178 eV) [see Fig. I.1-3a]. A simplified Cd-

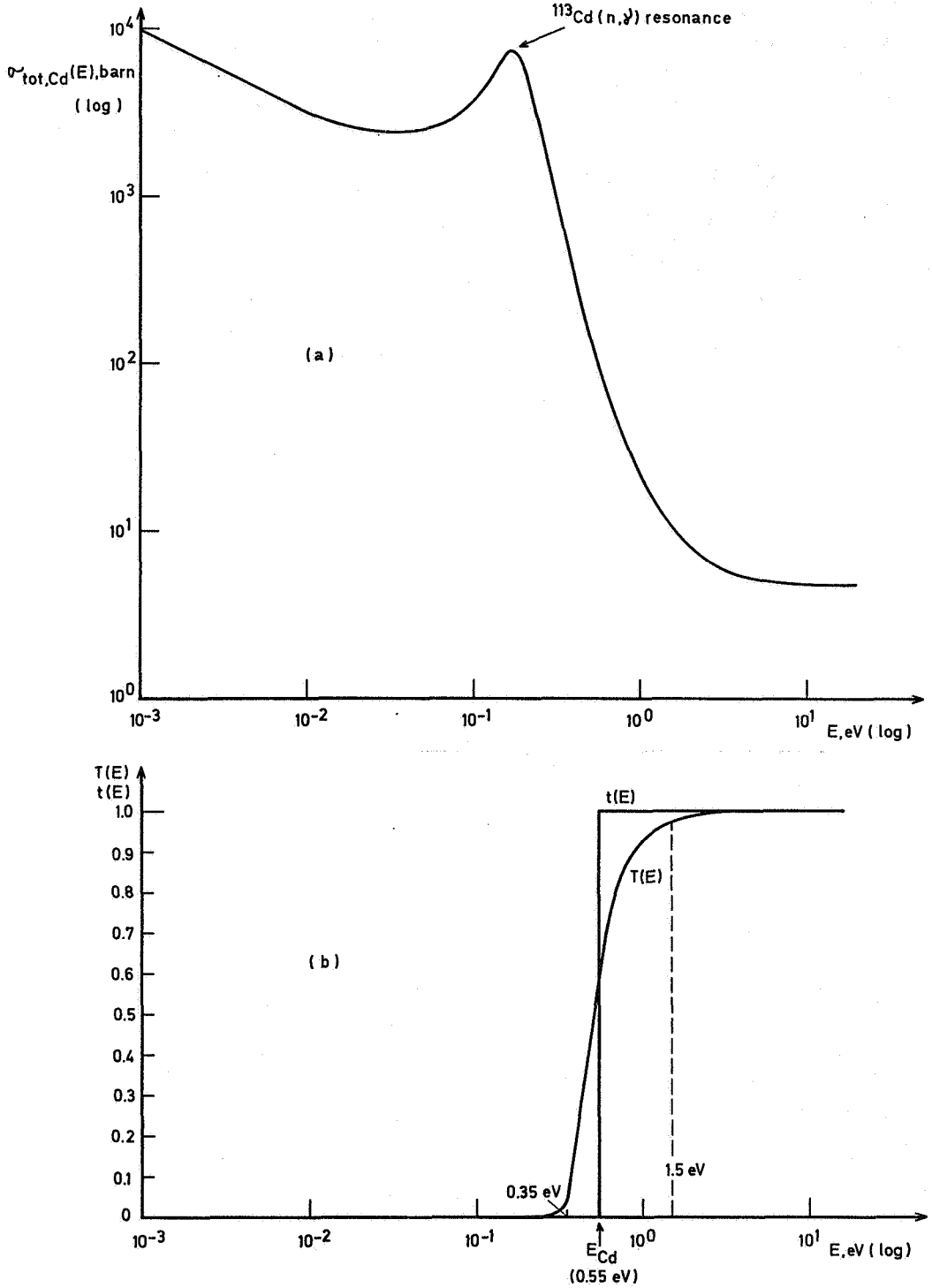


Fig. I.1-3 : a. Cd total cross-section curve, $\sigma_{tot,Cd}(E)$ versus E

b. Actual and idealized Cd neutron transmission functions, T(E) and t(E) versus E [MOENS81]

transmission function T(E) for a 1 mm-thick Cd-cover is shown in Fig. I.1-3b. It has been calculated as :

$$T(E) = e^{-\sigma_{tot,Cd}(E)\ \delta\ N_A 1_0/M} \qquad (I.1\text{-}2)$$

with δ = density of Cd = 8.642 g cm^{-3} ,

N_A = Avogadro's number = $6.0221.10^{23}$ mol^{-1} ,

1_0 = Cd-thickness = 0.1 cm ,

M = molar mass of Cd = 112.41 g mol^{-1} ,

$\sigma_{tot,Cd}(E)$ = cross-section function (Fig. I.1-3a), in cm^2 ,

where $T(E) \simeq 0$ for $E < 0.2$ eV and $T(E) \simeq 1$ for $E > 2$ eV.
In obtaining the T(E)-curve of Fig. I.1-3b, some simplifications were made, e.g. :

- geometry effects caused by sample and Cd-cover were neglected ;
- a monodirectional beam of neutrons, hitting a 1 mm-thick Cd-foil in a direction normal to its face, was considered.

It is possible to define an idealized transmission as a step function t(E) [see Fig. I.1-3b], situated at the so-called effective Cd cut-off energy E_{Cd} [i.e. with t(E) = 0 at $E < E_{Cd}$ and t(E) = 1 at $E > E_{Cd}$], so that the epi-cadmium reaction rate R_e can be written as :

$$\left.\begin{aligned} R_e &= \int_0^\infty \sigma(E)\ \varphi'(E)T(E)dE \\ &= \int_0^\infty \sigma(E)\ \varphi'(E)t(E)dE \\ &= \int_{E_{Cd}}^\infty \sigma(E)\ \varphi'(E)dE \end{aligned}\right| \qquad (I.1\text{-}3)$$

The internationally accepted "standard" E_{Cd} = 0.55 eV [GOLDSTEIN61] is bound to the following conditions :

1. The nuclide should have a $\sigma(v) \sim 1/v$ dependence up to $\sim$ 1.5 eV [where T(E) approaches unity ; see Fig. I.1-3b]. Small deviations do not cause E_{Cd} to differ significantly from 0.55 eV; e.g. for $^{197}Au(n,\gamma)$, with g (293.59 K) = 1.005, E_{Cd} is equal to 0.56 eV. As mentioned in I.1.3.1, $^{151}Eu(n,\gamma)$ and $^{176}Lu(n,\gamma)$ do not fulfil this requirement.

2. The neutron flux should be homogeneous and isotropic, with an epithermal neutron flux distribution following the 1/E-law down to ∿ 0.35 eV [where T(E) approaches zero ; see Fig. I.1-3b]. However, even for a $1/E^{1+\alpha}$ dependence with $\alpha = 0.1$ (which is a rather large deviation from ideality), E_{Cd} lowers only insignificantly to 0.54 eV. Disturbance of the epithermal by the Maxwellian neutron flux above ∿ 0.35 eV has to be feared especially in case of high T_n or of high thermalization. However, from calculations of Stoughton and Halperin [STOUGHTON63] it appears that at $T_0 = 293.59$ K ($E_0 = 0.0253$ eV) the E_{Cd}-value, reported to be 0.546 eV, does not change at all with the thermal-to-epithermal flux ratio (up to $\phi_s/\phi_e = 50$; see I.1.3.3 for definitions); also, for $\phi_s/\phi_e = 10$, E_{Cd} shows only a small decrease from 0.546 eV at $T_0 = 293.59$ K to 0.534 eV at $T_n = 580.22$ K. In addition to this it should be realized that the conditions of high T_n and high thermalization (high ϕ_s/ϕ_e) are contradictory.
3. The material to be irradiated should have a relatively small volume and should be positioned approximately in the center of a cylindrical Cd-box with 1 mm wall-thickness and a height/diameter ratio = 2.

1.3.3. Reaction rates and cadmium ratio

According to the Høgdahl convention, Eq. (I.1-1) - with the introduction of the E_{Cd}-concept - is split into :

$$R = \int_0^{v_{Cd}} \sigma(v)\, \varphi'(v)\, dv + \int_{E_{Cd}}^{\infty} \sigma(E)\, \varphi'(E)\, dE \qquad (I.1\text{-}4)$$

with $v_{Cd} = (2\, E_{Cd}/m_n)^{1/2}$.

Since $\sigma(v) \sim 1/v$ up to v_{Cd} (in fact, up to ∿ 1.5 eV), one can write in the left-hand integral $\sigma(v) = \sigma_0 v_0/v$, where the set v_0 and σ_0 is arbitrarily chosen. Since one can assume an undisturbed $\varphi_e'(E) \sim 1/E^{1+\alpha}$ [or $\varphi_e'(E) \sim 1/E$, if $\alpha = 0$] epithermal neutron spectrum down to E_{Cd} (in fact, down to ∿ 0.35 eV), one can write :

for a 1/E spectrum	for a $1/E^{1+\alpha}$ spectrum
$\varphi'_e(E) = \varphi'_e(1\ eV)\ 1\ eV/E$	$\varphi'_e(E) = \varphi'_e(1\ eV)\ 1\ eV^{1+\alpha}/E^{1+\alpha}$

with 1 eV = an arbitrarily chosen reference energy (see V.1.4).
By defining the conventional epithermal neutron flux ($cm^{-2}\ s^{-1}$) as $\phi_e = \varphi'_e(1\ eV)\ 1\ eV$, one obtains :

$\varphi'_e(E) = \phi_e/E$ (I.1-5a)	$\varphi'_e(E) = \phi_e\ 1\ eV^{\alpha}/E^{1+\alpha}$ (I.1-5b)
ϕ_e is often called the (true) epithermal neutron flux per unit lnE interval, since integration of Eq. (I.1-5a) yields	Here, ϕ_e is the (true) epithermal neutron flux per unit $(-E^{-\alpha}/\alpha).1\ eV^{\alpha}$ interval, since integration of Eq. (I.1-5b) yields
$\phi_e = \left[\int_{E_1}^{E_h} \varphi'_e(E)\,dE\right] \Big/ \left[\ln(E_h/E_1)\right]$	$\phi_e = \left[\int_{E_1}^{E_h} \varphi'_e(E)\,dE\right] \Big/ 1\ eV^{\alpha}\left[-E^{-\alpha}/\alpha\right]_{E_1}^{E_h}$

with E_h and E_1 the high and low boundaries of the epithermal spectrum.

Remembering that $\varphi'(v) = n'(v)v$, Eq. (I.1-4) can be transformed as :

$R = \sigma_0 v_0 \int_0^{v_{Cd}} n'(v)\,dv + \phi_e \int_{E_{Cd}}^{\infty} \sigma(E)\,dE/E$	$R = \sigma_0 v_0 \int_0^{v_{Cd}} n'(v)\,dv + \phi_e\, 1eV^{\alpha} \int_{E_{Cd}}^{\infty} \sigma(E)\,dE/E^{1+\alpha}$
$= \sigma_0 v_0 n_s + \phi_e I_0$	$= \sigma_0 v_0 n_s + \phi_e I_0(\alpha)$
$= \phi_s \sigma_0 + \phi_e I_0$ (I.1-6a)	$= \phi_s \sigma_0 + \phi_e I_0(\alpha)$ (I.1-6b)
with	with
$I_0 = \int_{E_{Cd}}^{\infty} \sigma(E)\,dE/E$ (I.1-7a)	$I_0(\alpha) = 1eV^{\alpha} \int_{E_{Cd}}^{\infty} \sigma(E)\,dE/E^{1+\alpha}$ (I.1-7b)
= resonance integral for a 1/E spectrum (cm^2)	= resonance integral for a $1/E^{1+\alpha}$ spectrum (cm^2)

and

$n_s = \int_0^{v_{Cd}} n'(v)\,dv$ = subcadmium neutron density (cm^{-3}) ;

$\phi_s = v_0 n_s$ = conventional subcadmium ("thermal") neutron flux ($cm^{-2}\ s^{-1}$).

The relation between I_0 and $I_0(\alpha)$, necessitating the introduction of the so-called effective resonance energy $\bar{E}_r$, will be dealt with in V.1.2.

Note that a direct experimental determination of the epicadmium reaction rate R_e is possible when irradiating a nuclide under a Cd-cover in the aforementioned standard conditions. R_e is simply described by :

$$R_e = \phi_e I_0(\alpha)$$

or

$$R_e = \phi_e I_0 \qquad \text{(I.1-8)}$$

The subcadmium reaction rate R_s is then the difference between the experimentally determined R and R_e values. R_s is described by :

$$R_s = \phi_s \sigma_0 \qquad \text{(I.1-9)}$$

Another useful quantity is the experimentally measured Cd-ratio R_{Cd} :

$$R_{Cd} = \frac{R}{R_e} = \frac{\phi_s \sigma_0 + \phi_e I_0(\alpha)}{\phi_e I_0(\alpha)} = [f/Q_0(\alpha)] + 1 \qquad \text{(I.1-10)}$$

or

$$R_{Cd} = \frac{\phi_s \sigma_0 + \phi_e I_0}{\phi_e I_0} = [f/Q_0] + 1 \qquad \text{(I.1-11)}$$

$f = (R_{Cd} - 1)\, Q_0(\alpha)$

with $f = \phi_s/\phi_e$ = subcadmium ("thermal") to epithermal neutron flux ratio ;

$Q_0(\alpha) = I_0(\alpha)/\sigma_0$

$Q_0 = I_0/\sigma_0$

= resonance integral to 2200 m s^{-1} cross-section ratio.

It should be remarked that R and R_e cannot be measured simultaneously by irradiating together a bare and Cd-covered nuclide, since Cd causes significant flux depressions in its vicinity [IAEA70]. Thus, subsequent irradiation is dictated.

1.3.4. Mechanism of the convention

Before giving an outline of the mechanism, it is interesting to remark that ϕ_s is related to the sum of Maxwellian neutrons up to E_{Cd} and of epithermal neutrons below E_{Cd}. However, from the above reasoning - and if all conditions are met - this appears to be irrelevant [see Eqs I.1-6a/b]. More specifically, it should be noted that the knowledge of the Maxwellian neutron flux distribution, especially of the neutron temperature T_n, and of the Maxwellian-epithermal spectrum junction is not required.

The mechanism of the Høgdahl convention is as follows :

1. first, one finds σ_0 and I_0 values for an ultimate cross-section standard by methods independent of reactor neutron activation [HOLDEN81]. The most common standard is $^{197}Au(n,\gamma)^{198}Au$, with the following recommended data (which are adopted in the present work) :

   $\sigma_0 = 98.65 \pm 0.09$ barn ($\pm$ 0.09%)

   $I_0 = 1550 \pm 28$ barn ($\pm$ 1.8%)

   and thus

   $Q_0 = 15.71 \pm 0.28$ ($\pm$ 1.8%)

   [HOLDEN81 ; MUGHABGHAB81/84 ; HOLDEN85];

2. then, by measuring R_{Au} and $R_{e,Au}$, one can determine ϕ_s, ϕ_e and f, for any irradiation site, from Eqs (I.1-8), (I.1-9) and (I.1-10), respectively, on condition that $I_{0,Au}$ has been converted to $I_{0,Au}(\alpha)$;

3. applying the same equations, one can finally determine σ_0, I_0 and Q_0 from R and R_e measurement for other (n,γ) reactions [after converting $I_0(\alpha)$ to I_0]. Evaluated σ_0 and I_0 data, mostly originating from such determinations, can be found in several compilations (see V.3.3 and APP.4.2).

1.3.5. Neutron self-shielding and Cd-transmission correction factors

Before linking the reaction rate to the signal obtained from reactor (n,γ) activation, it is necessary to introduce some correction factors in the equations describing R and R_e. These factors are :

- G_{th} (≤ 1), accounting for thermal neutron self-shielding which depends on the nucleus "density" (number of nuclei/cm^3 x target thickness, cm) and on σ_0. G_{th} has to be multiplied by $\phi_s\sigma_0$. For the calculation of G_{th}, see I.2.4.

- G_e (≤ 1), accounting for epithermal neutron self-shielding which depends on the nucleus "density" (see above) and on the resonance parameters. G_e has to be multiplied by $\phi_e I_0(\alpha)$ [or $\phi_e I_0$]. For the calculation of G_e, see I.2.4.

- F_{Cd}, the Cd-transmission factor for epithermal neutrons, which will be discussed in V.3.2.2. For most nuclides F_{Cd} is equal to unity; for some it is < 1 and exceptionally it can be > 1. F_{Cd} has to be multiplied by $\phi_e I_0(\alpha)$ [or $\phi_e I_0$], but - as a matter of course - only when an irradiation under Cd-cover is involved.

In view of the above, Eqs (I.1-6b), (I.1-8), (I.1-9) and (I.1-10) should be rewritten as :

$$R = G_{th}\,\phi_s\,\sigma_0 + G_e\,\phi_e\,I_0(\alpha) \qquad \text{(I.1-12)}$$

$$R_e = G_e\,F_{Cd}\,\phi_e\,I_0(\alpha) \qquad \text{(I.1-13)}$$

$$R_s = G_{th}\,\phi_s\,\sigma_0 \quad [\text{only if } F_{Cd} = 1\ !] \qquad \text{(I.1-14)}$$

$$F_{Cd}\,R_{Cd} = [G_{th} f/G_e\,Q_0(\alpha)] + 1 \qquad \text{(I.1-15)}$$

and similarly for $\alpha = 0$.

2. THE ACTIVATION EQUATION

2.1. Direct formation of measured radionuclide ; no burn-up

When combining reactor (n,γ) activation with subsequent gamma-spectrometry using a Ge-detector, the relation between the reaction rate and the number of counts (N_p) collected in the full-energy peak is as follows :

$$R = \frac{\frac{N_p/t_m}{SDCw}}{N_A\,\theta\,\varepsilon_p\,\gamma/M} \qquad \text{(I.2-1)}$$

or

$$R_e = \frac{\left(\frac{N_p/t_m}{SDCw}\right)_{Cd}}{N_A\,\theta\,\varepsilon_p\,\gamma/M} \qquad \text{(I.2-2)}$$

on condition that the measured radionuclide is directly formed by (n,γ), and that disappearance - by (n,γ) reaction - of target and formed nuclei is negligible (i.e. no burn-up effects).

In Eqs (I.2-1) and (I.2-2) :

N_p = number of counts in the full-energy peak, corrected for pulse losses (dead time, random and true coincidence) ;

t_m = measuring time (s) ;

S = saturation factor = $1-e^{-\lambda t_{irr}}$; λ = decay constant = $(\ln 2)/T$; with T = half-life ; t_{irr} = irradiation time (same units as T) ;

D = decay factor = $e^{-\lambda t_d}$; t_d = decay time (same units as T) ;

C = "measurement" factor = $(1-e^{-\lambda t_m})/\lambda t_m$ (with t_m in the same units as T) ;

w = mass of irradiated element (g) ;

θ = isotopic abundance (fraction) ;

ε_p = full-energy peak detection efficiency, including correction for gamma-attenuation ;

γ = absolute gamma-intensity (gamma-emission probability).

In the present work

$$A_{sp} = \frac{N_p/t_m}{SDCw} \qquad \text{(I.2-3)}$$

is denoted as the specific count rate ($s^{-1}\ g^{-1}$).

From combination of Eq. (I.2-3) with Eqs (I.1-12) and (I.2-1), or with (I.1-13) and (I.2-2), the activation equation is obtained (in conditions of stable ϕ_s, ϕ_e and α during t_{irr}) :

$$A_{sp} = \frac{N_A\ \theta\ \gamma}{M} \left[G_{th}\ \phi_s\ \sigma_0 + G_e\ \phi_e\ I_0(\alpha)\right]\ \varepsilon_p \qquad \text{(I.2-4)}$$

or

$$(A_{sp})_{Cd} = \frac{N_A\ \theta\ \gamma}{M}\ G_e\ F_{Cd}\ \phi_e\ I_0(\alpha)\ \varepsilon_p \qquad \text{(I.2-5)}$$

If in Eqs (I.2-4) and (I.2-5) the same ε_p-value is involved, one has :

$$A_{sp} - (A_{sp})_{Cd}/F_{Cd} = \frac{N_A\ \theta\ \gamma}{M}\ G_{th}\ \phi_s\ \sigma_0\ \varepsilon_p \qquad \text{(I.2-6)}$$

which in the present work is referred to as the Cd-subtraction or Cd-difference.

Finally, the experimentally measured Cd-ratio is simply obtained as (if the above mentioned condition with respect to ε_p is fulfilled) :

$$R_{Cd} = \frac{A_{sp}}{(A_{sp})_{Cd}} \qquad (I.2\text{-}7)$$

2.2. Branching activation and mother-daughter decay

Eqs (I.2-1) to (I.2-7) refer to the scheme :

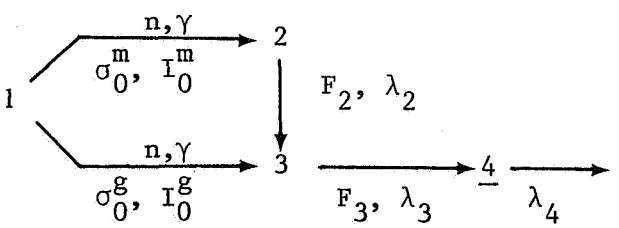
$$1 \xrightarrow[\sigma_0, I_0]{n,\gamma} \underline{2} \xrightarrow{\lambda_2}$$

where the measured radionuclide (underlined) is directly formed by (n,γ). Following this notation $A_{sp,2}$ should be written as :

$$A_{sp,2} = \frac{N_{p,2}/t_m}{S_2 D_2 C_2 w}$$

and γ should be denoted as γ_2 in Eqs (I.2-4) - (I.2-6).

It is, however, quite well possible that branching activation is involved - with formation of metastable and ground states (superscripts m and g, respectively) - and that the analytically interesting radionuclide is a daughter or granddaughter nuclide of the directly formed one(s), as for instance in the scheme :



where F_2 and F_3 stand for the fractional decay of nuclide 2 to 3 and nuclide 3 to 4, respectively.

In general, the definition of $A_{sp,4}$ is more complex in such cases, and Eqs (I.2-4) - (I.2-6) will contain the parameters σ_0^m, $I_0^m(\alpha)$, σ_0^g, $I_0^g(\alpha)$, λ_2, λ_3, λ_4, F_2, F_3 and γ_4.

Since in such cases the terms of the relevant expressions for A_{sp} as a function of nuclear data and experimental conditions [Eqs (I.2-4) and (I.2-5)] are strictly related to the definition and use of k_0-factors, a more detailed treatment is put off to I.3.4.2.

2.3. Burn-up effects

In the present work, burn-up is defined as the significant disappearance - by (n,γ) reaction - of target and/or formed nuclei, so that A_{sp} can no longer be described by Eq. (I.2-3). The following practical cases are considered.

2.3.1. Burn-up of target and/or directly formed nuclide

For the case below, where * refers to burn-up effect :

$$1^{*} \xrightarrow[\sigma_{0,1}, I_{0,1}]{n,\gamma} \underline{2}^{*} \xrightarrow{\lambda_2}$$

$$\Big\downarrow \; n,\gamma \quad \sigma_{0,2},\ I_{0,2}$$

the specific count rate of measured radionuclide 2 (underlined) can be written as :

$$A_{sp,2} = \frac{N_{p,2}/t_m}{S_2 D_2 C_2 w} \Big/ F_{burn}$$

with

$$F_{burn} = \frac{\lambda_2\, e^{-(\phi\sigma_1)t_{irr}} \left[1-e^{[(\phi\sigma_1)-(\phi\sigma_2)\ -\ \lambda_2]\ t_{irr}}\right]}{[(\phi\sigma_2) + \lambda_2 - (\phi\sigma_1)]\ [1-e^{-\lambda_2\ t_{irr}}]} \qquad \text{(I.2-8)}$$

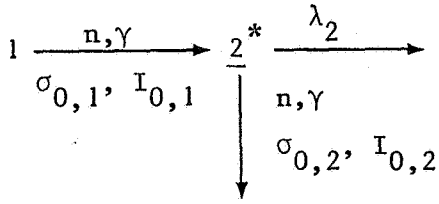
and

$$(\phi\sigma) = G_{th}\, \phi_s\, \sigma_0 + G_e\, \phi_e\, I_0(\alpha)$$

From Eq. (I.2-8) it is clear that the burn-up will be larger for increasing $(\phi\sigma)$, λ and t_{irr}. For low $(\phi\sigma)$ and/or t_{irr}, $F_{burn} \simeq 1$. The relevant equations for burn-up of the target nuclide, i.e.

$$1^{*} \xrightarrow[\sigma_{0,1},\ I_{0,1}]{n,\gamma} \underline{2} \xrightarrow{\lambda_2}$$

or of the directly formed nuclide, i.e.



are obtained by putting $(\phi\sigma_2) = 0$ or $(\phi\sigma_1) = 0$, respectively.

Some well-known cases are :

A. $^{164}Dy^* \xrightarrow[\sigma_{0,1}^{(m+g)} = 2723b;\ I_{0,1}^{(m+g)} = 517b]{n,\gamma} {}^{165}Dy^*$ (T = 2.334 h) $\xrightarrow{\lambda_2}$

$^{165}Dy^* \xrightarrow{n,\gamma} {}^{166}Dy^*$ ($\sigma_{0,2}$ = 3600b; $I_{0,2}$ = 22000b)

where (for $G_{th} = G_e = 1$) :

- $F_{burn} = 1.000$ [$F_{burn}(^{164}Dy^*) = 1.000$; $F_{burn}(^{165}Dy^*) = 1.000$], for t_{irr} = 7 h and $\phi_s = 1.6.10^{12}$ n cm^{-2} s^{-1}, $\phi_e = 6.8.10^{10}$ n cm^{-2} s^{-1}, $\alpha = 0.015$ [channel 3 of reactor THETIS/Gent, one of the channels used for k_0-determination] ;

- $F_{burn} = 0.996$ [$F_{burn}(^{164}Dy^*) = 0.997$; $F_{burn}(^{165}Dy^*) = 0.998$], for t_{irr} = 10 h and $\phi_s = 3.6.10^{13}$ n cm^{-2} s^{-1}, $\phi_e = 1.8.10^{12}$ n cm^{-2} s^{-1}, $\alpha \simeq 0$ [channel 17/2 of reactor WWR-M/Budapest, one of the channels used for k_0-determination];

- $F_{burn} = 0.712$ [$F_{burn}(^{164}Dy^*) = 0.717$; $F_{burn}(^{165}Dy^*) = 0.993$], for t_{irr} = 14 d and $\phi_s = 10^{14}$ n cm^{-2} s^{-1}, $\phi_e = 10^{13}$ n cm^{-2} s^{-1}, $\alpha \simeq 0$ [channel H323 of reactor BR-2/Mol].

B. $^{197}Au^* \xrightarrow[\sigma_{0,1} = 98.65b;\ I_{0,1} = 1550b]{n,\gamma} {}^{198}Au^*$ (T = 2.695 d) $\xrightarrow{\lambda_2}$

$^{198}Au^* \xrightarrow{n,\gamma} {}^{199}Au^*$ ($\sigma_{0,2}$ = 25800b; $I_{0,2}$ = 31031b)

where (for $G_{th} = G_e = 1$) :

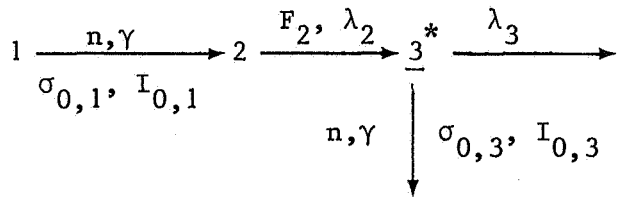
- $F_{burn} = 0.999$ [$F_{burn}(^{197}Au^*) = 1.000$; $F_{burn}(^{198}Au^*) = 0.999$], for t_{irr} = 7 h in channel 3 of reactor THETIS/Gent (flux parameters : see above) ;

- $F_{burn} = 0.983$ [F_{burn} ($^{197}Au^*$) = 1.000; F_{burn} ($^{198}Au^*$) = 0.983], for t_{irr} = 10 h in channel 17/2 of reactor WWR-M/Budapest (flux parameters : see above) ;
- $F_{burn} = 0.507$ [F_{burn} ($^{197}Au^*$) = 0.977; F_{burn} ($^{198}Au^*$) = 0.521], for t_{irr} = 14 d in channel H323 of reactor BR-2/Mol (flux parameters : see above).

Whenever relevant, σ_0 and I_0 values for burn-up of the formed radionuclide are listed in Table VIII.3-1 [e.g. for $^{181}Ta(n,\gamma)\underline{^{182}Ta}^*(n,\gamma)$] in order to enable calculation of F_{burn}.

2.3.2. Burn-up of daughter nuclide

For the case :



the specific count rate of measured radionuclide 3 can be written as :

$$A_{sp,3} = \frac{N_{p,3}/t_m}{(SDC)_{burn}\, w}$$

with

$$(SDC)_{burn} = \frac{\lambda_3}{\lambda_3-\lambda_2}\, S_2D_2C_2 + \left(\frac{\lambda_3(\Lambda_3S_2-\lambda_2\Sigma_3)}{\Lambda_3(\Lambda_3-\lambda_2)} - \frac{\lambda_3S_2}{\lambda_3-\lambda_2}\right) D_3C_3 \qquad \text{(I.2-9)}$$

and $\Lambda = \lambda + (\phi\sigma)$

$$\Sigma = 1-e^{-\Lambda\, t_{irr}}$$

When comparing this to the expression for negligible burn-up effect :

$$A_{sp,3} = \frac{N_{p,3}/t_m}{(SDC)\, w}$$

with

$$(SDC) = \frac{\lambda_3S_2D_2C_2 - \lambda_2S_3D_3C_3}{\lambda_3-\lambda_2} \qquad \text{[cf. Table I.3-1]}$$

a F_{burn}-factor (in practice negligibly depending on t_d and t_m) can be defined as :

$$F_{burn} = (SDC)_{burn} / (SDC)$$

The only analytically interesting case is :

$$^{148}Nd \xrightarrow[\sigma_{0,1},\ I_{0,1}]{n,\gamma} {}^{149}Nd\ (T = 1.72\ h) \xrightarrow[F_2=1]{\lambda_2} \underline{^{149}Pm^*}\ (T = 53.08\ h) \xrightarrow{\lambda_3}$$

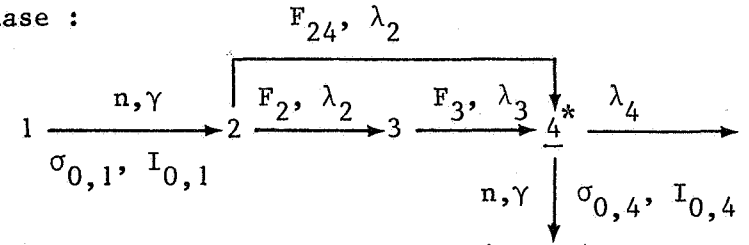
$$\underline{^{149}Pm^*} \xrightarrow{n,\gamma} \begin{cases} \sigma_{0,3} = 1400\ b \\ I_{0,3} \simeq 800\ b \end{cases}$$

where (for $G_{th} = G_e = 1$) :

- $F_{burn} = 1.000$, for $t_{irr} = 7$ h in channel 3 of reactor THETIS/Gent (flux parameters : see I.2.3.1);
- $F_{burn} = 0.999$, for $t_{irr} = 10$ h in channel 17/2 of reactor WWR-M/ Budapest (flux parameters : see I.2.3.1);
- $F_{burn} = 0.963$, for $t_{irr} = 14$ d in channel H323 of reactor BR-2/Mol (flux parameters : see I.2.3.1).

2.3.3. Burn-up of granddaughter nuclide

For the case :



the specific count rate of measured radionuclide 4 can be written as :

$$A_{sp,4} = \frac{N_{p,4}/t_m}{(SDC)_{burn}\, w}$$

with

$$\begin{aligned}(SDC)_{burn} = {} & \frac{\lambda_4}{\lambda_4-\lambda_2}\left(\frac{\lambda_3}{\lambda_3-\lambda_2} + \frac{F_{24}}{F_2F_3}\right) S_2D_2C_2 \\ & - \frac{\lambda_2\,\lambda_4}{(\lambda_3-\lambda_2)(\lambda_4-\lambda_3)}\, S_3D_3C_3 \\ & - \frac{(\Lambda_4-\lambda_4)\,\lambda_4}{(\Lambda_4-\lambda_2)(\lambda_4-\lambda_2)}\left(\frac{\lambda_3}{\lambda_3-\lambda_2} + \frac{F_{24}}{F_2F_3}\right) S_2D_4C_4 \\ & + \frac{\lambda_2\lambda_4(\Lambda_4-\lambda_4)}{(\lambda_3-\lambda_2)(\lambda_4-\lambda_3)(\Lambda_4-\lambda_3)}\, S_3D_4C_4 \\ & + \frac{\lambda_2\lambda_4}{\Lambda_4(\Lambda_4-\lambda_2)}\left(\frac{\lambda_3}{\Lambda_4-\lambda_3} - \frac{F_{24}}{F_2F_3}\right)\Sigma_4D_4C_4\end{aligned} \qquad \text{(I.2-10)}$$

When comparing this to the expression for negligible burn-up effect :

$$A_{sp,4} = \frac{N_{p,4}/t_m}{(SDC)w}$$

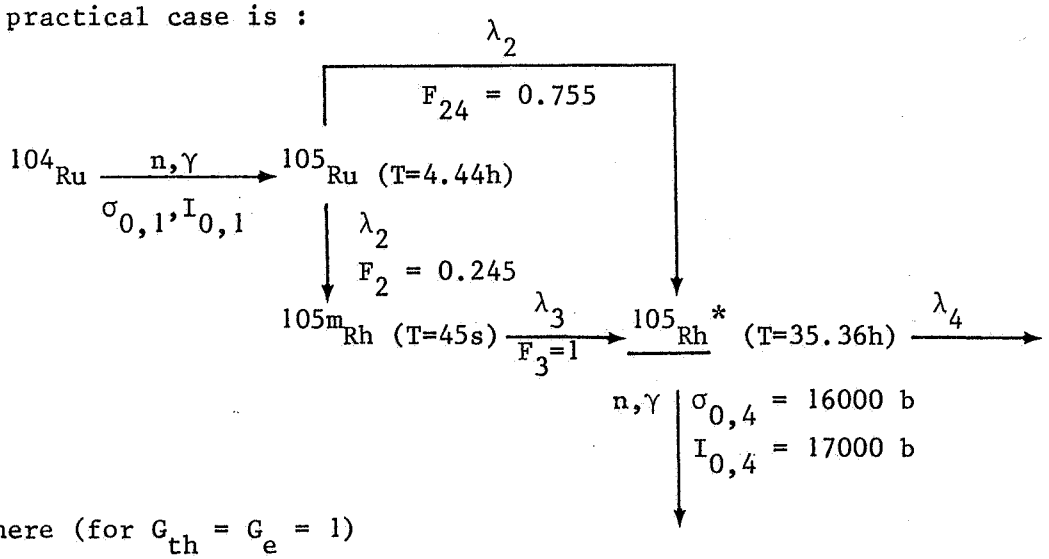
with

$$(SDC) = S_2D_2C_2 \frac{\lambda_4}{\lambda_4-\lambda_2}\left(\frac{\lambda_3}{\lambda_3-\lambda_2} + \frac{F_{24}}{F_2F_3}\right) - S_3D_3C_3 \frac{\lambda_2\lambda_4}{(\lambda_4-\lambda_3)(\lambda_3-\lambda_2)} + S_4D_4C_4 \frac{\lambda_2}{\lambda_4-\lambda_2}\left(\frac{\lambda_3}{\lambda_4-\lambda_3} - \frac{F_{24}}{F_2F_3}\right) \qquad [\text{cf. Table I.3-1}]$$

a F_{burn}-factor (slightly depending on t_d and t_m) can be defined as :

$$F_{burn} = (SDC)_{burn}/(SDC)$$

A practical case is :



where (for $G_{th} = G_e = 1$)

- $F_{burn} = 1.000$, for $t_{irr} = 7$ h in channel 3 of reactor THETIS/Gent (flux parameters : see I.2.3.1) and $t_d = t_m = 1000$ s ;
- $F_{burn} = 0.993$, for $t_{irr} = 10$ h in channel 17/2 of reactor WWR-M/Budapest (flux parameters : see I.2.3.1) and $t_d = t_m = 1000$ s ;
- $F_{burn} = 0.758$, for $t_{irr} = 14$ d in channel H323 of reactor BR-2/Mol (flux parameters : see I.2.3.1) and $t_d = t_m = 1000$ s.

Note that for $^{105}Ru/^{105m}Rh/\underline{^{105}Rh}^{*}$ the above equations can be simplified since $\lambda_3 >> \lambda_2$, $\lambda_3 >> \lambda_4$ and, in practice, $D_3 = 0$.

For a pure mother-granddaughter equilibrium, Eq. (I.2-10) can be simplified by putting $F_{24} = 0$.

2.4. Calculation of neutron self-shielding factors

As outlined in I.1.3.5, thermal and epithermal neutron self-shielding factors (G_{th} and G_e) are defined as correction terms to be multiplied by $\phi_s\sigma_0$ and $\phi_e\ I_0(\alpha)$, respectively, in order to obtain the observed reaction rates for actual samples [see Eq. (I.1-12)]. Historically, this has been interpreted in terms of the average thermal flux [$\bar{\phi}_s = G_{th}\ \phi_s$] inside a sample, or in terms of the effective resonance integral [$I_{eff}(\alpha) = G_e\ I_0(\alpha)$] of a material which is not infinitely diluted.

The best way to solve the problem of self-shielding is by avoiding it, e.g. by using thin wires or foils, by diluting fine powders with "inert" materials (i.e. of low absorption cross-section), or by dissolving chemical substances in inert solvents followed by micropipetting and drying spots on an inert carrier. Even then, of course, one should be able to judge whether self-shielding is negligible; this, together with the fact that in practice self-shielding is often inevitable, makes it necessary to have at one's disposal the relevant formulae for calculation of G_{th} and G_e.

Based on the work of Dwork et al. [DWORK55], Zweifel [ZWEIFEL60] and others, G_{th} for a homogeneous and isotropic Maxwellian neutron flux distribution can be calculated in case of simply shaped samples.

- for a sphere :

$$G_{th,\ sphere} = 1 - \frac{9}{8}\xi \qquad (\text{if } \xi \leq 0.003) \qquad \text{(I.2-11)}$$

$$G_{th,\ sphere} = \frac{3}{4y^3}\left[y^2 - \frac{1}{2} + \left(\frac{1}{2} + y\right)e^{-2y}\right] \qquad (\text{if } \xi > 0.003) \qquad \text{(I.2-12)}$$

with $y = \frac{3}{2}\xi$

$$\xi = \frac{2V}{S}\ \sum_i N_i\ \bar{\sigma}_{abs,i}$$

V = volume of the sample ($= \frac{4}{3}\pi r^3$; cm^3) ; r = radius of sphere (cm) ;

S = surface of the sample ($= 4\pi r^2$; cm^2); $2V/S = \frac{2}{3} r$;

N_i = atom density of element i (cm^{-3}) ;

$\bar{\sigma}_{abs} = \frac{\sigma_{abs}}{2} \sqrt{\frac{293.59\pi}{T_n}}$ (cm^2) [= average absorption cross-section];

σ_{abs} = 2200 m s^{-1} absorption-cross section (cm^2) of the element.

- for an infinite slab (foil) :

$$G_{th,foil} = \frac{1}{2\xi} (1-e^{-\xi} + \xi e^{-\xi} - \xi^2 \int_{\xi}^{\infty} \frac{e^{-u}}{u} du) \qquad (I.2-13)$$

with ξ defined as above [where $2V/S = h$; h = foil thickness, cm]

and $\int_{\xi}^{\infty} \frac{e^{-u}}{u} du = -\left(C + \ln \xi + \sum_{n=1}^{p} \frac{(-\xi)^n}{n.n!}\right)$

C = Eulers constant = 0.577215...

p = 5 if $\xi < 0.1$

p = 10 if $0.1 < \xi < 1$

p = (int 5ξ) + 5 if $\xi > 1$

- for an infinite cylinder (wire) [as a rough approximation] :

$$G_{th,wire} = 1 - \frac{4}{3} \xi \qquad (I.2-14)$$

with ξ defined as above [where $2V/S = r$; r = wire radius, cm].

- for a finite cylinder (e.g. short wire, thick foil) :

$$G_{th,cyl.} = G_{th,foil} + \left(8\xi^{1.4} e^{-3.72\xi} + 0.4 e^{8\xi}\right)\left(G_{th,sphere} - G_{th,foil}\right) \qquad (I.2-15)$$

where $G_{th,sphere}$ and $G_{th,foil}$ are respectively calculated from Eqs (I.2-11)/(I.2-12) and (I.2-13), with introduction of $(2V/S)_{cyl.} = rh/(r+h)$ [r = cylinder radius, cm ; h = cylinder height, cm].

In the above, $\bar{\sigma}_{abs}$ can be calculated from σ_{abs} as compiled in Table VIII.3-1 ; by putting arbitrarily T_n = 333.15 K (= 60°C), the maximum error on $\bar{\sigma}_{abs}$ is $\sim$ 6.5% in the temperature range 20-100°C, and the effect of this error is drastically reduced in all formulae for G_{th}-calculation.

Eqs (I.2-11) - (I.2-15) are obtained by assuming that scattering of neutrons in the sample and in the surrounding material is negligible. The justification of this no-scattering assumption has been proved by Gilat et al. [GILAT63].

Because of the $\sigma(v) \sim 1/v$ dependence in the thermal energy range, all nuclides of a homogeneous mixture undergo the same thermal shielding effect, and the same G_{th}-value (calculated from all elements in the mixture) should be applied to all (n,γ) reactions considered.

In general, the error in the calculation of self-shielding effects is estimated to be about 10% of the correction term, that is,

$$s_{G_{th}} \simeq 0.1 \ (1 - G_{th}) \qquad \text{(I.2-16)}$$

Calculation of the epithermal neutron self-shielding factor G_e is considerably more difficult. In case of one dominant resonance at energy E_r - with no Doppler broadening - use can be made of the approximations described by Chernick and Vernon [CHERNICK58].

$$G_e = \left[1 + \frac{\sigma(E_r)}{\sigma_p(\eta+1)} \left(1 - \frac{\Gamma_n}{\Gamma(\eta+1)}\right)\right]^{-1/2} \qquad \text{(I.2-17)}$$

$$\text{if} \quad \Gamma\left[\sigma(E_r)/\sigma_p\right]^{1/2} < (1 - \beta)\, E_r \ ,$$

or

$$G_e = \left[1 + \frac{\sigma(E_r)}{\sigma_p \eta} \frac{\Gamma_\gamma}{\Gamma}\right]^{-1/2} \qquad \text{(I.2-18)}$$

$$\text{if} \quad \Gamma\left[\sigma(E_r)/\sigma_p\right]^{1/2} > (1 - \beta)\, E_r$$

In the above equations :

$\beta = \left(\frac{A-1}{A+1}\right)^2$; A = atomic mass of nuclide considered ;

$\eta = \frac{\delta S}{4N\sigma_p m}$;

δ = density of sample (g cm^{-3}) ;

S = surface of sample (cm^2) ;

N = density of shielding nuclei (cm^{-3}) ;

σ_p = potential scattering cross-section (cm^2) $\simeq 4\pi R'^2$; R' = potential scattering radius (cm) ;

m = mass of sample (g) ;

$\sigma(E_r)$ = resonance peak (n,γ) cross-section (cm^2) ;

$$= \frac{2.608.10^6}{E_r} \left(\frac{A+1}{A}\right)^2 \frac{g\Gamma_n}{\Gamma} \quad ;$$

E_r = resonance energy (eV) ;

g = statistical weight factor ;

$= (2J+1)/[2(2I+1)]$; J = spin of resonance state ;

I = spin of target nucleus ;

Γ = total width of resonance (eV) ;

Γ_γ = radiative width of resonance (eV) ;

Γ_n = neutron width of resonance (eV).

For the relevant nuclear data, reference is made to MUGHABGHAB81/84.

Since the epithermal shielding is mainly caused by high resonance cross-sections (the underlying 1/v-tail being of minor importance), it remains specific for a particular nuclide, unless resonances of several nuclides are overlapping. The latter situation, which might occur in actual activation analysis, is a nuisance - especially if the overlapping of the resonance of a trace constituent with the resonance of a shielding major element is only partial. The most safe procedure is then, if dilution of the sample is not possible, to introduce for the trace constituent a G_e-factor as calculated from the major element - assigning however to G_e a percentile uncertainty of $(1-G_e)$ 100%.

In general, if accurate neutron self-shielding factors are required, it is advised to rely on experimental determination rather than calculation (see V.3.2.4).

3. (n,γ) ACTIVATION ANALYSIS : PRINCIPLES OF STANDARDIZATION

In (n,γ) activation analysis, the mass of the element to be determined (i.e. the analyte, index a) in the sample is obtained from Eqs (I.2-4) and (I.2-5), yielding respectively :

$$w_a = \frac{M_a}{N_A\,\theta_a\,\gamma_a}\;\frac{\left(\frac{N_p/t_m}{SDC}\right)_a}{[G_{th,a}\,\phi_s\,\sigma_{0,a} + G_{e,a}\,\phi_e\,I_{0,a}(\alpha)]\;\varepsilon_{p,a}} \qquad \text{(I.3-1)}$$

in NAA (neutron activation analysis), when the sample is irradiated in the whole reactor neutron spectrum,

and

$$w_a = \frac{M_a}{N_A\,\theta_a\,\gamma_a}\;\frac{\left[\left(\frac{N_p/t_m}{SDC}\right)_{Cd}\right]_a}{G_{e,a}\,F_{Cd,a}\,\phi_e\,I_{0,a}(\alpha)\;\varepsilon_{p,a}} \qquad \text{(I.3-2)}$$

in ENAA (epicadmium neutron activation analysis), when the sample is irradiated under a Cd-cover in standard conditions (see I.1.3.2).

In Eqs (I.3-1) and (I.3-2), the term SDC should be modified in case of branching activation and mother-daughter decay (see I.3.4.2).

The actual determination of w_a can be based on various standardization methods.

3.1. Relative standardization

In the relative standardization method, a chemical standard (index s) with known mass w_s of the element to be determined is coirradiated with the sample, and both are subsequently counted in the same geometrical configuration with respect to the Ge-detector. Thus, one can rewrite Eqs (I.3-1) and (I.3-2) for the standard, and combination leads to (for NAA and ENAA, respectively) :

$$w_a = \frac{\left(\frac{N_p/t_m}{DC}\right)_a}{\left(\frac{N_p/t_m}{DCw}\right)_s} \cdot \frac{G_{th,s}\,f + G_{e,s}\,Q_{0,s}(\alpha)}{G_{th,a}\,f + G_{e,a}\,Q_{0,a}(\alpha)} \cdot \frac{\varepsilon_{p,s}}{\varepsilon_{p,a}} \qquad \text{(I.3-3)}$$

$$w_a = \frac{\left[\left(\frac{N_p/t_m}{DC}\right)_{Cd}\right]_a}{\left[\left(\frac{N_p/t_m}{DCw}\right)_{Cd}\right]_s} \cdot \frac{G_{e,s}}{G_{e,a}} \cdot \frac{\varepsilon_{p,s}}{\varepsilon_{p,a}} \qquad \text{(I.3-4)}$$

since $S_a = S_s$, $M_a = M_s$, $\gamma_a = \gamma_s$, $\sigma_{0,a} = \sigma_{0,s}$, $I_{0,a} = I_{0,s}$ and $\theta_a = \theta_s$ [unless in case of natural isotopic variability (see VIII.2.2 and APP.2.1)]. In the above, it has been assumed that flux gradients between sample and standard location in the irradiation container are negligible or corrected for.

Furthermore, it should be noted that ε_p is still figuring in Eqs (I.3-3) and (I.3-4) in order to account for different gamma-attenuation in sample and standard; only in case of high gamma-energy and large source-detector separation, one can consider the gammas passing the source as a parallel beam normal to the detector face so that $\varepsilon_{p,s}/\varepsilon_{p,a}$ can be replaced by $F_{att,s}/F_{att,a}$ (with F_{att} = gamma-attenuation correction factor) without introduction of the detection efficiency. Furthermore, in Eq. (I.3-3) one can get rid of the f-factor only if :

- $G_{e,s}\, Q_{0,s}(\alpha) \ll G_{th,s} f$ and $G_{e,a}\, Q_{0,a}(\alpha) \ll G_{th,a}\, f$;
- or $G_{th,s} = G_{th,a} = G_{e,s} = G_{e,a} = 1$.

In the latter case and on condition that $F_{att,s} = F_{att,a} = 1$, one obtains the well-known simple expressions (for NAA and ENAA, respectively) :

$$w_a = \frac{\left(\frac{N_p/t_m}{DC}\right)_a}{\left(\frac{N_p/t_m}{DCw}\right)_s} \qquad \text{(I.3-5)}$$

$$w_a = \frac{\left[\left(\frac{N_p/t_m}{DC}\right)_{Cd}\right]_a}{\left[\left(\frac{N_p/t_m}{DCw}\right)_{Cd}\right]_s} \qquad \text{(I.3-6)}$$

and in terms of concentrations :

$$\rho_a,\text{ppm} = \frac{\left(\frac{N_p/t_m}{DCW}\right)_a}{\left(\frac{N_p/t_m}{DCw}\right)_s} \cdot 10^6 \qquad \text{(I.3-7)}$$

$$\rho_a,\text{ppm} = \frac{\left[\left(\frac{N_p/t_m}{DCW}\right)_{Cd}\right]_a}{\left[\left(\frac{N_p/t_m}{DCw}\right)_{Cd}\right]_s} \cdot 10^6 \qquad \text{(I.3-8)}$$

with W = sample mass (g).

Note that N_p in Eqs (I.3-3) - (I.3-8) should not be corrected for true-coincidence effects, since sample and standard are measured at the same source-detector separation.

Relative standardization can be performed by means of individual mono-element standards, or by using synthetic or natural multi-element standards. It is assumed that in favourable conditions its accuracy is of the order of 1-2%, although this should not be taken for granted. In particular, it must be remarked that the accuracy of standardization cannot be better than the accuracy on w_s ; in this context, one should not underestimate possible errors caused by non-stoichiometry of the standard element in the selected chemical substance, or by manipulations such as diluting and micropipetting - often inevitable to reduce or eliminate neutron self-shielding problems (see VI.2.1).

The obvious disadvantage of classical relative standardization lies in (routine) multi-element NAA, where preparation, counting and spectrum evaluation of the standards is laborious and irksome, not to speak about the loss of information in case of unexpected elements for which no standard has been coirradiated. Some of these problems can be obviated by using home-made multi-element standards, for which - if large quantities are produced and to be stored - attention should be paid, however, to homogeneity and stability of composition. As to commercial multi-element reference materials (e.g. USGS/ United States Geological Survey), standard reference materials (e.g. NBS-SRM/ National Bureau of Standards), certified reference materials (e.g. BCR-CRM/ Community Bureau of Reference) and the like, it must be remarked that - in view of the limited quantities available - their use for standardization on a routine basis cannot be justified (and they should be used only to assure the accuracy and compatibility of measurements); moreover, the accuracies quoted on the specified elemental concentrations are even in the best cases not better than $\sim$ 5%.

3.2. Single-comparator (monostandard) standardization

In its original concept [GIRARDI65], the NAA single-comparator method makes use of so-called k-factors, which are experimentally determined by co-irradiation of a standard and a single-comparator (monostandard; index c) :

$$k_c(s) = \frac{A_{sp,s}}{A_{sp,c}} \qquad \text{(I.3-9)}$$

From Eq. (I.2-4) it follows that $k_c(s)$ is in fact defined as :

$$k_c(s) = \frac{M_c\ \theta_s\ \gamma_s\ \sigma_{0,s}}{M_s\ \theta_c\ \gamma_c\ \sigma_{0,c}} \cdot \frac{G_{th,s} f + G_{e,s}\ Q_{0,s}(\alpha)}{G_{th,c} f + G_{e,c}\ Q_{0,c}(\alpha)} \cdot \frac{\varepsilon_{p,s}}{\varepsilon_{p,c}} \qquad \text{(I.3-10)}$$

Thus, the concentration of the analyte can be obtained from coirradiation of sample and single-comparator :

$$\rho_a, \text{ppm} = \frac{\left(\frac{N_p/t_m}{SDCW}\right)_a}{A_{sp,c}} \cdot 10^6/k_c(s) \qquad \text{(I.3-11)}$$

on condition that $\theta_a = \theta_s$, and :

- neutron self-shielding is essentially the same for respectively analyte/comparator and standard/comparator in the irradiation conditions of analysis and of $k_c(s)$-determination, i.e. $[G_{th,a}]_{anal.} = [G_{th,s}]_{k_c(s)}$, $[G_{e,a}]_{anal.} = [G_{e,s}]_{k_c(s)}$, $[G_{th,c}]_{anal.} = [G_{th,c}]_{k_c(s)}$ and $[G_{e,c}]_{anal.} = [G_{e,c}]_{k_c(s)}$. The most straightforward solution is to make in all cases $G_{th} = G_e = 1$;
- f and α show no significant difference in the irradiation conditions of analysis and $k_c(s)$-determination, i.e. $[f]_{anal.} = [f]_{k_c(s)}$ and $[\alpha]_{anal.} = [\alpha]_{k_c(s)}$. Thus, application of the method is bound to the irradiation position where $k_c(s)$ is determined. This condition can be dropped if $G_e\ Q_0(\alpha) \ll G_{th} f$ for standard/analyte and comparator and for both irradiation positions, which causes the parameters f and α to cancel in Eq. (I.3-10); in general, this holds for strongly thermalized neutron spectra (very high f) [LINEKIN73]. Furthermore, it is clear from Eq. (I.3-10) that variation of f [from the moment of $k_c(s)$-determination to the moment of analysis] will cause negligible errors if $Q_{0,s} \simeq Q_{0,c}$, but this observation is of course irrelevant in case of multi-element NAA. More detailed considerations in this context are to be found in Refs GIRARDI65, DE CORTE69, DAMSGAARD78 ;
- the detection efficiency, including gamma-attenuation, is essentially the same for analyte/comparator and standard/comparator in the counting conditions of analysis and $k_c(s)$-determination, respectively, i.e.

$[\varepsilon_{p,a}]_{anal.} = [\varepsilon_{p,s}]_{k_c(s)}$ and $[\varepsilon_{p,c}]_{anal.} = [\varepsilon_{p,c}]_{k_c(s)}$. Thus, application of the method is bound to the geometrical counting positions of $k_c(s)$-determination (note that $\varepsilon_{p,a}$ and $\varepsilon_{p,s} \neq \varepsilon_{p,c}$ is allowed) ;

- all flux parameters (ϕ_s, f and α) remain constant during irradiation, for both analysis and $k_c(s)$-determination [see VII.5].

Note that, as in the relative standardization method, the N_p-values do not have to be corrected for true-coincidence effects.

Evidently, the single-comparator method can be extended to ENAA as well, and the definition of $k_c(s)$ is then given by Eq. (I.3-10) with f = 0 and with multiplication of the $G_e\ Q_0(\alpha)$ terms by the corresponding F_{Cd}-factor.

In the extreme, if an excellent long-term stability of the reactor flux characteristics is proved, one can omit the use of a single-comparator, and the a priori determined $A_{sp,s}$ is equal to $A_{sp,a}$; this is the case in the SLOWPOKE reactor [BERGERIOUX79].

Some authors suggested to make the k-factors convertible with respect to the irradiation conditions [DECORTE69], requiring f and α-monitoring, or with respect to the counting conditions [DEBRUIN72], requiring ε_p-determination. In the context of the present work, these developments were of vital importance, since - among other considerations - they led to the concept of the experimentally determined k_0-factors (see I.3.4.1).

If performed properly, the accuracy of the single-comparator standardization can be estimated at ≃ 3% or less. Its obvious advantage is the experimental simplicity, on condition that k-factors are determined a priori; its use is beneficial in routine analysis of long series of similar samples. On the other hand, a serious drawback is the rigidity of the k-factors which are strictly bound to local and "personal" experimental conditions, sometimes with awkward consequences : if a Ge-detector gets out of use, for instance, the painful work of k-determination has to be done over again.

3.3. Absolute (parametric) standardization

When writing down Eq. (I.2-4) for the analyte and for a flux monitor (index m) coirradiated with the sample, combination leads to :

$$\rho_a,ppm = \frac{\left(\frac{N_p/t_m}{SDCW}\right)_a}{A_{sp,m}} \cdot \frac{M_a\ \theta_m\ \gamma_m\ \sigma_{0,m}}{M_m\ \theta_a\ \gamma_a\ \sigma_{0,a}} \cdot \frac{G_{th,m} f + G_{e,m}\ Q_{0,m}(\alpha)}{G_{th,a} f + G_{e,a}\ Q_{0,a}(\alpha)} \cdot \frac{\varepsilon_{p,m}}{\varepsilon_{p,a}} \cdot 10^6 \qquad \text{(I.3-12)}$$

on condition that ϕ_s, f and α remain constant during irradiation (see VII.5).

The absolute standardization method, experimentally very simple, requires the accurate knowledge of the parameters M, θ, γ and σ_0 for both analyte and monitor. In principle, these nuclear data can be found in literature, but it will be shown that this might lead to a deterioration of accuracy (see APPENDIX) and traceability (VIII.2.2) of the analytical results. Indeed σ_0, γ and θ (in order of decreasing importance) can be sources of considerable errors or uncertainties. Next to the remark made in I.3.2, the above considerations were also highly stimulating the development of the k_0-standardization method.

In addition to the usual corrections for G_{th} and G_e, to be applied in principle in all standardization methods, absolute standardization requires not only the knowledge of M, θ, γ and σ_0, but also of f, $Q_0(\alpha)$ and ε_p, and the N_p-values should be corrected for true-coincidence effects as well. These extra parameters, which are essentially the same as in the k_0-standardization method, will be extensively dealt with in later chapters.

Many researchers have published on the development and application of the absolute standardization method (not necessarily adopting the Høgdahl-convention), and a good deal of them have compiled the "best" absolute nuclear data set to be introduced in the equation for concentration calculation-leading to remarkable inconsistencies for many (n,γ) reactions (see e.g. HEFT79, TAKEUCHI81, KIM81). Not all of the authors have always taken into account all parameters (α, ε_p, true-coincidence, etc.) mentioned above. Several researchers have reported on the application of the absolute method in case of strongly thermalized neutron spectra (high f), which makes the $G_e\ Q_0(\alpha)$-terms dropping in Eq. (I.3-12). On the other hand, extension of the method to ENAA is possible as well; then, Eq. (I.3-12) should be modified by putting f = 0 and multiplying $G_e\ Q_0(\alpha)$ by the corresponding F_{Cd}-factor.

3.4. k_0-Standardization

3.4.1. Basic concepts

The concept of the NAA k_0-standardization method, which was launched in 1975 [SIMONITS75], can be approached in two different ways :

A. If the experimentally determined k-factors of the single-comparator method are normalized for the experimental conditions of irradiation (f, α) and counting (ε_p), one obtains from Eq. (I.3-9) :

$$k_{0,c}(s) = k_c(s) \cdot \frac{G_{th,c} f + G_{e,c} Q_{0,c}(\alpha)}{G_{th,s} f + G_{e,s} Q_{0,s}(\alpha)} \cdot \frac{\varepsilon_{p,c}}{\varepsilon_{p,s}}$$

$$= \frac{A_{sp,s}}{A_{sp,c}} \cdot \frac{G_{th,c} f + G_{e,c} Q_{0,c}(\alpha)}{G_{th,s} f + G_{e,s} Q_{0,s}(\alpha)} \cdot \frac{\varepsilon_{p,c}}{\varepsilon_{p,s}} \qquad \text{(I.3-13)}$$

In view of Eq. (I.3-10), the $k_{0,c}(s)$-factor is thus defined as a composite nuclear constant :

$$k_{0,c}(s) = \frac{M_c \theta_s \sigma_{0,s} \gamma_s}{M_s \theta_c \sigma_{0,c} \gamma_c} \qquad \text{(I.3-14)}$$

which can be tabulated and published in literature as a generally useful parameter.

Suppose now that a sample is coirradiated with a monitor (m), for which an experimentally determined $k_{0,c}(m)$-factor is available [replace s by m in Eq. (I.3-13) and in definition (I.3-14)]. Then, by converting $k_{0,c}(s)/k_{0,c}(m) = k_{0,m}(s)$ to the analysis conditions of irradiation (f,α) and counting (ε_p), the analyte concentration can be obtained as [with $k_{0,c}(s) = k_{0,c}(a)$] :

$$\rho_a, ppm = \frac{\left(\frac{N_p/t_m}{SDCW}\right)_a}{A_{sp,m}} \cdot \frac{k_{0,c}(m)}{k_{0,c}(a)} \cdot \frac{G_{th,m} f + G_{e,m} Q_{0,m}(\alpha)}{G_{th,a} f + G_{e,a} Q_{0,a}(\alpha)} \cdot \frac{\varepsilon_{p,m}}{\varepsilon_{p,a}} \cdot 10^6 \qquad \text{(I.3-15)}$$

on condition that $\theta_a = \theta_s$ (no natural isotopic variability).

Note that in Eqs (I.3-13) and (I.3-15) the parameters f, α and ε_p refer unambiguously to the experimental conditions of k_0-determination and analysis, respectively.

According to the above reasoning, the k_0-method can be interpreted as a single-comparator standardization which is made completely versatile with respect to both irradiation and counting conditions.

B. If in the absolute standardization method the nuclear data set $[M_m\ \theta_a\ \gamma_a\ \sigma_{0,a}/M_a\ \theta_m\ \gamma_m\ \sigma_{0,m}]$ of Eq. (I.3-12) is replaced by one single composite nuclear constant $k_{0,m}(a)$, one obtains

$$\rho_a,\text{ppm} = \frac{\left(\frac{N_p/t_m}{SDCW}\right)_a}{A_{sp,m}} \cdot \frac{1}{k_{0,m}(a)} \cdot \frac{G_{th,m} f + G_{e,m}\, Q_{0,m}(\alpha)}{G_{th,a} f + G_{e,a}\, Q_{0,a}(\alpha)} \cdot \frac{\varepsilon_{p,m}}{\varepsilon_{p,a}} .10^6 \qquad \text{(I.3-16)}$$

With $k_{0,m}(a) = k_{0,c}(a)/k_{0,c}(m)$ [from definition (I.3-14)], this leads to Eq. (I.3-15), and Eq. (I.3-13) enables the experimental determination of $k_{0,c}(a) = k_{0,c}(s)$ and $k_{0,c}(m)$ [for the latter, replacing s by m in Eq. (I.3-13)].

It should be remarked that the above holds only on condition that all relevant flux parameters (ϕ_s, f and α) remain constant during irradiation (see VII.5). As in the absolute method, all N_p-values involved should be corrected for true-coincidence effects (see Chapter IV).

According to the above reasoning, the k_0-method can be interpreted as an absolute standardization with substitution of the absolute nuclear data for experimentally determined k_0-factors. This eliminates systematic errors due to unreliability and uncertainty of nuclear data, on condition that the experimentally determined k_0-factors are accurate. In order to reach an accuracy of better than 2%, it was felt necessary to perform the k_0-determination in a parallel but independent way at the Institute for Nuclear Sciences (INW, Gent) and the Central Research Institute for Physics (KFKI, Budapest) [see VI.2.1].

It is important to remark that experimental k_0-determination is also possible using the Cd-subtraction technique, by irradiating standard and comparator with and without Cd-cover. Based on Eq. (I.2-6) one obtains :

$$k_{0,c}(s) = \frac{\left[A_{sp,s} - [(A_{sp})_{Cd}]_s/F_{Cd,s}\right]/G_{th,s}}{\left[A_{sp,c} - [(A_{sp})_{Cd}]_c/F_{Cd,c}\right]/G_{th,c}} \cdot \frac{\varepsilon_{p,c}}{\varepsilon_{p,s}} \qquad \text{(I.3-17)}$$

thus avoiding the necessity of introducing f and $Q_0(\alpha)$ [cf. Eq. (I.3-13)].

Evidently, the k_0-method can be applied to ENAA as well, by simply putting f = 0 in Eq. (I.3-15) [or Eq. (I.3-16)] and multiplying $G_e\ Q_0(\alpha)$ by the corresponding F_{Cd}-factor.

Summarizing, the fundamentals of the k_0-standardization method are :

SPECIALIZED LABORATORIES (INW/KFKI)

$$k_{0,c}(s) = \frac{A_{sp,s}}{A_{sp,c}} \cdot \frac{G_{th,c} f + G_{e,c}\ Q_{0,c}(\alpha)}{G_{th,s} f + G_{e,s}\ Q_{0,s}(\alpha)} \cdot \frac{\varepsilon_{p,c}}{\varepsilon_{p,s}} \qquad \text{(I.3-18)}$$

and/or :

$$k_{0,c}(s) = \frac{\left[A_{sp,s} - [(A_{sp})_{Cd}]_s / F_{Cd,s}\right] / G_{th,s}}{\left[A_{sp,c} - [(A_{sp})_{Cd}]_c / F_{Cd,c}\right] / G_{th,c}} \cdot \frac{\varepsilon_{p,c}}{\varepsilon_{p,s}} \qquad \text{(I.3-19)}$$

(s = standard ; c = coirradiated comparator)

→ recommended k_0-factors

ANALYST

NAA :

$$\rho_a, \text{ppm} = \frac{\left(\frac{N_p / t_m}{SDCW}\right)_a}{A_{sp,m}} \cdot \frac{k_{0,c}(m)}{k_{0,c}(a)} \cdot \frac{G_{th,m} f + G_{e,m}\ Q_{0,m}(\alpha)}{G_{th,a} f + G_{e,a}\ Q_{0,a}(\alpha)} \cdot \frac{\varepsilon_{p,m}}{\varepsilon_{p,a}} \cdot 10^6 \qquad \text{(I.3-20)}$$

ENAA :

$$\rho_a, \text{ppm} = \frac{\left[\left(\frac{N_p / t_m}{SDCW}\right)_{Cd}\right]_a}{[(A_{sp})_{Cd}]_m} \cdot \frac{k_{0,c}(m)}{k_{0,c}(a)} \cdot \frac{F_{Cd,m}\ G_{e,m}\ Q_{0,m}(\alpha)}{F_{Cd,a}\ G_{e,a}\ Q_{0,a}(\alpha)} \cdot \frac{\varepsilon_{p,m}}{\varepsilon_{p,a}} \cdot 10^6 \qquad \text{(I.3-21)}$$

[a = analyte in sample, with $k_{0,c}(a) = k_{0,c}(s)$;
m = coirradiated monitor, with experimentally determined $k_{0,c}(m)$;
if m = c , $k_{0,c}(m) \equiv 1$].

3.4.2. Modifications in case of complex activation-decay

As mentioned in I.2.2, the expressions (I.2-1) to (I.2-6) should be modified in case of branching activation and mother-daughter decay, and this will have implications on the definition and use of k_0-factors.

TABLE I.3-1 : Activation-decay types and relevant expressions for the parameters involved in the k_0-method

Activation-decay type	Activation-decay scheme	$\frac{\theta\sigma_0\gamma}{M}$ in k_0-definition [Eq.(I.3-14)]	Q_0 in Eqs (I.3-18) (I.3-20) (I.3-21)	$\frac{N_p/t_m}{SDC}$ in Eqs (I.3-18) - (I.3-21), to be divided by w for obtaining A_{sp} in Eqs (I.3-18) - (I.3-21)
I	1 $\xrightarrow[\sigma_0, I_0]{n,\gamma}$ 2 $\xrightarrow{\lambda_2}$ [e.g. $^{75}As(n,\gamma)\underline{^{76}As}$]	$\frac{\theta\sigma_0\gamma_2}{M}$	$\frac{I_0}{\sigma_0}$	$\frac{N_{p,2}/t_m}{S_2 D_2 C_2}$
II/a	1 $\xrightarrow[\sigma_0, I_0]{n,\gamma}$ 2 $\xrightarrow{F_2,\lambda_2}$ 3 $\xrightarrow{\lambda_3}$ [e.g. $\underline{^{101}Tc}$ from $^{100}Mo(n,\gamma)$]	$\frac{\theta\sigma_0 F_2\gamma_3}{M}$	$\frac{I_0}{\sigma_0}$	$\frac{N_{p,3}}{t_m} \cdot \frac{(\lambda_3-\lambda_2)}{\lambda_3 S_2 D_2 C_2 - \lambda_2 S_3 D_3 C_3}$
II/b	Special case : $\lambda_2 \gg \lambda_3$ and $D_2 = 0$ [e.g. $\underline{^{233}Pa}$ from $^{232}Th(n,\gamma)$]	"	"	$\frac{N_{p,3}/t_m}{S_3 D_3 C_3}$
II/c	Special case : $\lambda_2 < \lambda_3$ and $D_3 = 0$	"	"	$\frac{\lambda_3-\lambda_2}{\lambda_3} \cdot \frac{N_{p,3}/t_m}{S_2 D_2 C_2}$
II/d *	Special case : measurement of the 140.5 keV line of $\underline{^{99}Mo}/\underline{^{99m}Tc}$ [from $^{98}Mo(n,\gamma)$]	"	"	$\frac{N_{p,2+3}/t_m}{\frac{\lambda_3 S_2 D_2 C_2 - \lambda_2 S_3 D_3 C_3}{\lambda_3 - \lambda_2} + \frac{\gamma_2}{F_2\gamma_3} S_2 D_2 C_2}$
III/a	1 $\xrightarrow[\sigma_0, I_0]{n,\gamma}$ 2 $\xrightarrow{F_2,\lambda_2}$ 3 $\xrightarrow{F_3,\lambda_3}$ 4 $\xrightarrow{\lambda_4}$; 2 $\xrightarrow{F_{24},\lambda_2}$ 4 [e.g. $\underline{^{97}Nb}$ from $^{96}Zr(n,\gamma)$]	$\frac{\theta\sigma_0 F_2 F_3 \gamma_4}{M}$	$\frac{I_0}{\sigma_0}$	$(N_{p,4}/t_m)\cdot\left[S_2 D_2 C_2 \frac{\lambda_4}{\lambda_4-\lambda_2}\left(\frac{\lambda_3}{\lambda_3-\lambda_2} + \frac{F_{24}}{F_2 F_3}\right) - S_3 D_3 C_3 \frac{\lambda_2\lambda_4}{(\lambda_4-\lambda_3)(\lambda_3-\lambda_2)} + S_4 D_4 C_4 \frac{\lambda_2}{\lambda_4-\lambda_2}\left(\frac{\lambda_3}{\lambda_4-\lambda_3} - \frac{F_{24}}{F_2 F_3}\right)\right]^{-1}$

TABLE I.3-1 : (continued)

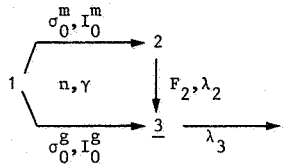
Activation-decay type	Activation-decay scheme	$\frac{\theta\sigma_0\gamma}{M}$ in k_0-definition [Eq.(I.3-14)]	Q_0 in Eqs (I.3-18) (I.3-20) (I.3-21)	$\frac{N_p/t_m}{SDC}$ in Eqs (I.3-18) - (I.3-21), to be divided by w for obtaining A_{sp} in Eqs (I.3-18) - (I.3-21)
III/b	Special case : $F_{24} = 0$	$\frac{\theta\,\sigma_0 F_2 F_3 \gamma_4}{M}$	$\frac{I_0}{\sigma_0}$	$(N_{p,4}/t_m)\cdot\left[S_2D_2C_2\,\frac{\lambda_4\lambda_3}{(\lambda_4-\lambda_2)(\lambda_3-\lambda_2)} - S_3D_3C_3\,\frac{\lambda_2\lambda_4}{(\lambda_4-\lambda_3)(\lambda_3-\lambda_2)} + S_4D_4C_4\,\frac{\lambda_2\lambda_3}{(\lambda_4-\lambda_2)(\lambda_4-\lambda_3)}\right]^{-1}$
III/c	Special case : $\lambda_3 \gg \lambda_2$ and λ_4, $D_3 = 0$ $F_3 = 1$, $F_2 + F_{24} = 1$ [e.g. $\underline{^{105}Rh}$ from $^{104}Ru(n,\gamma)$]	$\frac{\theta\,\sigma_0\gamma_4}{M}$	"	$(N_{p,4}/t_m)\cdot\frac{\lambda_4-\lambda_2}{\lambda_4 S_2D_2C_2 - \lambda_2 S_4D_4C_4}$
IV/a ** **	 [e.g. $\underline{^{80}Br}$ from $^{79}Br(n,\gamma)$]	$\frac{\theta\,\sigma_0^g\gamma_3}{M}$	$\frac{I_0^g}{\sigma_0^g}$	$(N_{p,3}/t_m)\cdot\left[\frac{F_2\sigma_0^m}{\sigma_0^g}\,\frac{f+Q_0^m(\alpha)}{f+Q_0^g(\alpha)}\,\frac{\lambda_3 S_2D_2C_2 - \lambda_2 S_3D_3C_3}{\lambda_3-\lambda_2} + S_3D_3C_3\right]^{-1}$ $= (N_{p,3}/t_m)\cdot\left[\frac{k_0^m}{k_0^g}\,\frac{f+Q_0^m(\alpha)}{f+Q_0^g(\alpha)}\,\frac{\lambda_3 S_2D_2C_2 - \lambda_2 S_3D_3C_3}{\lambda_3-\lambda_2} + S_3D_3C_3\right]^{-1}$
IV/b	Special case : $\lambda_2 \gg \lambda_3$ and $D_2 = 0$ [e.g. $\underline{^{60}Co}$ from $^{59}Co(n,\gamma)$]	$\frac{\theta(F_2\sigma_0^m + \sigma_0^g)\gamma_3}{M}$	$\frac{F_2 I_0^m + I_0^g}{F_2\sigma_0^m + \sigma_0^g}$	$\frac{N_{p,3}/t_m}{S_3D_3C_3}$
IV/c	Special case : $\lambda_2 < \lambda_3$ and $D_3 = 0$	$\frac{\theta\,F_2\sigma_0^m\gamma_3}{M}$	$\frac{I_0^m}{\sigma_0^m}$	$\frac{\lambda_3-\lambda_2}{\lambda_3}\,\frac{N_{p,3}/t_m}{S_2D_2C_2}$

TABLE I.3-1 : (continued)

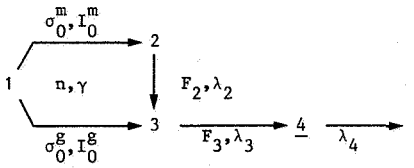
Activation-decay type	Activation-decay scheme	"$\frac{\theta\sigma_0\gamma}{M}$" in k_0-definition [Eq.(I.3-14)]	"Q_0" in Eqs (I.3-18) (I.3-20) (I.3-21)	"$\frac{N_p/t_m}{SDC}$" in Eqs (I.3-18) - (I.3-21), to be divided by w for obtaining A_{sp} in Eqs (I.3-18) - (I.3-21)
IV/d	Special case : measurement of the 112.9 keV and 208.4 keV lines of $\underline{^{177m}Lu}/^{177}Lu$ [from $^{176}Lu(n,\gamma)$]	$\frac{\theta\,\sigma_0^g\gamma_3}{M}$	$\frac{I_0^g}{\sigma_0^g}$	$(N_{p,2+3}/t_m)\cdot\left[\frac{\sigma_0^m\gamma_2}{\sigma_0^g\gamma_3}\,\frac{f+Q_0^m(\alpha)}{f+Q_0^g(\alpha)}\,(S_2D_2C_2 + \frac{F_2\gamma_3}{\gamma_2}\,\frac{\lambda_3S_2D_2C_2-\lambda_2S_3D_3C_3}{\lambda_3-\lambda_2} + S_3D_3C_3\right]^{-1}$
V/a ***		$\frac{\theta\,\sigma_0^g F_3\gamma_4}{M}$	$\frac{I_0^g}{\sigma_0^g}$	$(N_{p,4}/t_m)\cdot\left\{\frac{k_0^m}{k_0^g}\,\frac{f+Q_0^m(\alpha)}{f+Q_0^g(\alpha)}\left[S_2D_2C_2\,\frac{\lambda_4\lambda_3}{(\lambda_4-\lambda_2)(\lambda_3-\lambda_2)} - S_3D_3C_3\,\frac{\lambda_2\lambda_4}{(\lambda_4-\lambda_3)(\lambda_3-\lambda_2)} + S_4D_4C_4\,\frac{\lambda_2\lambda_3}{(\lambda_4-\lambda_2)(\lambda_4-\lambda_3)}\right] + \frac{\lambda_4S_3D_3C_3-\lambda_3S_4D_4C_4}{\lambda_4-\lambda_3}\right\}^{-1}$
V/b	Special case : $\lambda_4 \ll \lambda_2$ and λ_3 [e.g. $\underline{^{199}Au}$ from $^{198}Pt(n,\gamma)$]	$\frac{\theta(F_2\sigma_0^m+\sigma_0^g)F_3\gamma_4}{M}$	$\frac{F_2I_0^m+I_0^g}{F_2\sigma_0^m+\sigma_0^g}$	$\frac{N_{p,4}/t_m}{S_4D_4C_4}$
V/c	Special case : $\lambda_3 \ll \lambda_2$ and λ_4 $D_2 = D_4 = 0$ [e.g. $\underline{^{113m}In}$ from $^{112}Sn(n,\gamma)$]	"	"	$\frac{N_{p,4}/t_m}{S_3D_3C_3}$

TABLE I.3-1 : (continued)

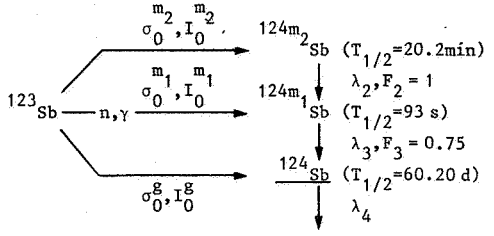
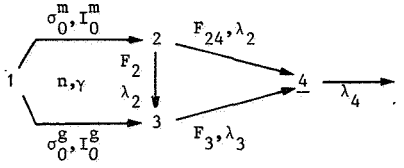
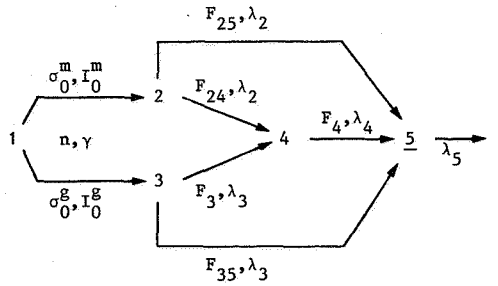
Activation-decay type	Activation-decay scheme	$\frac{\theta\sigma_0\gamma}{M}$ in k_0-definition [Eq.(I.3-14)]	Q_0 in Eqs (I.3-18) (I.3-20) (I.3-21)	$\frac{N_p/t_m}{SDC}$ in Eqs (I.3-18) - (I.3-21), to be divided by w for obtaining A_{sp} in Eqs (I.3-18) - (I.3-21)
VI	Special case : measurement of $\underline{^{124}Sb}$ [from $^{123}Sb(n,\gamma)$] after long decay time ($D_2 = D_3 = 0$) 	$\frac{\theta[F_3(\sigma_0^{m_1}+\sigma_0^{m_2})+\sigma_0^g]\gamma_4}{M}$	$\frac{F_3(I_0^{m_1}+I_0^{m_2})+I_0^g}{F_3(\sigma_0^{m_1}+\sigma_0^{m_2})+\sigma_0^g}$	$\frac{N_{p,4}/t_m}{S_4D_4C_4}$
VII/a		$\frac{\theta F_3 \sigma_0^g \gamma_4}{M}$	$\frac{I_0^g}{\sigma_0^g}$	$(N_{p,4}/t_m)\cdot\left\{\frac{\sigma_0^m F_{24}}{\sigma_0^g F_3}\frac{f+Q_0^m(\alpha)}{f+Q_0^g(\alpha)}\frac{\lambda_4 S_2 D_2 C_2 - \lambda_2 S_4 D_4 C_4}{\lambda_4-\lambda_2} + \frac{\lambda_4 S_3 D_3 C_3 - \lambda_3 S_4 D_4 C_4}{\lambda_4-\lambda_3} + \frac{\sigma_0^m F_2}{\sigma_0^g}\frac{f+Q_0^m(\alpha)}{f+Q_0^g(\alpha)}\left[S_2 D_2 C_2 \frac{\lambda_4\lambda_3}{(\lambda_4-\lambda_2)(\lambda_3-\lambda_2)} - S_3 D_3 C_3 \frac{\lambda_2\lambda_4}{(\lambda_4-\lambda_3)(\lambda_3-\lambda_2)} + S_4 D_4 C_4 \frac{\lambda_2\lambda_3}{(\lambda_4-\lambda_2)(\lambda_4-\lambda_3)}\right]\right\}^{-1}$
VII/b	Special case : $F_2 = 0$ [e.g. $\underline{^{125}Sb}$ from $^{124}Sn(n,\gamma)$]	"	"	$(N_{p,4}/t_m)\cdot\left[\frac{\sigma_0^m F_{24}}{\sigma_0^g F_3}\frac{f+Q_0^m(\alpha)}{f+Q_0^g(\alpha)}\frac{\lambda_4 S_2 D_2 C_2 - \lambda_2 S_4 D_4 C_4}{\lambda_4-\lambda_2} + \frac{\lambda_4 S_3 D_3 C_3 - \lambda_3 S_4 D_4 C_4}{\lambda_4-\lambda_3}\right]^{-1}$

TABLE I.3-1 : (continued)

Activation-decay type	Activation-decay scheme	$\frac{\theta\sigma_0\gamma}{M}$ in k_0-definition [Eq.(I.3-14)]	Q_0 in Eqs (I.3-18), (I.3-20), (I.3-21)	$\frac{N_p/t_m}{SDC}$ in Eqs (I.3-18) - (I.3-21), to be divided by w for obtaining A_{sp} in Eqs (I.3-18) - (I.3-21)
VIII	 [e.g. $\underline{^{117}In}$ from $^{116}Cd(n,\gamma)$]	$\frac{\theta F_{24} F_3 F_4 \sigma_0^g \gamma_5}{M}$	$\frac{I_0^g}{\sigma_0^g}$	$(N_{p,5}/t_m) \cdot \left\{ \frac{1}{F_{24}} \left[S_3 D_3 C_3 \frac{\lambda_5}{\lambda_5-\lambda_3} \left(\frac{\lambda_4}{\lambda_4-\lambda_3} + \frac{F_{35}}{F_3 F_4} \right) - S_4 D_4 C_4 \frac{\lambda_3 \lambda_5}{(\lambda_5-\lambda_4)(\lambda_4-\lambda_3)} + S_5 D_5 C_5 \frac{\lambda_3}{\lambda_5-\lambda_3} \left(\frac{\lambda_4}{\lambda_5-\lambda_4} - \frac{F_{35}}{F_3 F_4} \right) \right] + \frac{\sigma_0^m}{\sigma_0^g} \frac{f+Q_0^m(\alpha)}{f+Q_0^g(\alpha)} \left[S_2 D_2 C_2 \frac{\lambda_5}{\lambda_5-\lambda_2} \left(\frac{\lambda_4}{\lambda_4-\lambda_2} + \frac{F_{25}}{F_{24} F_4} \right) - S_4 D_4 C_4 \frac{\lambda_2 \lambda_5}{(\lambda_5-\lambda_4)(\lambda_4-\lambda_2)} + S_5 D_5 C_5 \frac{\lambda_2}{\lambda_5-\lambda_2} \left(\frac{\lambda_4}{\lambda_5-\lambda_4} - \frac{F_{25}}{F_{24} F_4} \right) \right] \right\}^{-1}$

* γ_2 : 140.5 keV (^{99}Mo)

γ_3 : 140.5 keV (^{99m}Tc)

$\gamma_2/F_2\gamma_3 = 0.0675$

** $\frac{\theta\sigma_0\gamma}{M}$ in definition of

$k_0^g : \frac{\theta\sigma_0^g\gamma_3}{M}$

$k_0^m : \frac{\theta F_2 \sigma_0^m \gamma_3}{M}$

k_0^m/k_0^g is experimentally determined for $^{80m}Br/^{80}Br$ and $^{104m}Rh/^{104}Rh$ (see VII.2.2.)

*** $\frac{\theta\sigma_0\gamma}{M}$ in definition of

$k_0^g : \frac{\theta\sigma_0^g\gamma_4}{M}$

$k_0^m : \frac{\theta F_2 \sigma_0^m \gamma_4}{M}$

Table I.3-1 summarizes the practical activation-decay cases encountered in (n,γ) activation analysis, together with relevant expressions for the parameters involved. Note that, so as to obtain the actual definition of k_0, "$\theta\ \sigma_0\ \gamma/M$" (third row) should be multiplied by "$(M/\theta\ \sigma_0\ \gamma)_c$", thus allowing in principle for a comparator showing a complex activation-decay scheme. However, in the present work $^{197}Au(n,\gamma)^{198}Au$ was chosen as the comparator, for which the simple expressions of activation-decay type I should be applied.

It should be remarked that the expressions for $\frac{"N_p/t_m"}{SDC}$ are not at all specific to the k_0-method, but are to be used inevitably in all types of standardization, the relative method included. This implies that, also there, such data as $\gamma_2/F_2\gamma_3$ (type II/d), F_{24}/F_2F_3 (type III/a), $F_2\sigma_0^m/\sigma_0^g$ and $[f + Q_0^m(\alpha)]/[f + Q_0^g(\alpha)]$ (type IV/a), etc., have to be known occasionally.

3.4.3. Parameters of the k_0-method

From Eqs (I.3-18) - (I.3-21) it follows that, for development and application of the k_0-standardization method, the following topics have to be dealt with :

A. Experimental determination of k_0-factors (see Chapter VI), for which, in addition to the next items (B - G), all parameters relevant to preparation, irradiation and counting of standards (as in the relative method) should be taken into account; this includes for instance calculation or experimental determination of G_{th}- and G_e-factors (see I.2.4) ;

B. Contribution of epithermal activation (see Chapter V), including :
   a. experimental determination of f ;
   b. experimental determination of α ;
   c. calculation or experimental determination of $\bar{E}_r$ [for $Q_0 \rightarrow Q_0(\alpha)$ conversion] ;
   d. evaluation or experimental determination of F_{Cd} ;
   e. experimental determination or evaluation of Q_0 ;

C. Experimental determination and conversion of ε_p, including gamma-attenuation (see Chapter III) ;

D. Correction of N_p for :
   a. true-coincidence effects (see Chapter IV) ;
   b. burn-up effects (see I.2.3) ;
   c. primary interferences [fast-neutron induced (n,n') and (n,2n) reactions](see VII.3) ;

E. Small deviations of $g(T_n)$ from unity (see VII.4) ;
F. Intermittent irradiation (see VII.6) ;
G. Constancy of flux parameters (ϕ_s, f, α) during irradiation (see VII.5).

The above parameters are discussed in the present work. It is possible to transfer most of the concepts, statements and conclusions as such to the absolute standardization method, and some of them to the single-comparator method (and even to the relative method) as well.

3.4.4. Uncertainties, error propagation and mean values

In view of the evaluation of the k_0-standardization method with respect to its accuracy (VIII.1) and traceability (VIII.2), it is essential to attribute uncertainties to the parameters mentioned in I.3.4.3 and to consider the propagation of these uncertainties (commonly called error propagation) towards quantities derived from these parameters - such as k_0-factors and analytical results.

According to the definition given by the National Bureau of Standards [NBS85], "uncertainty" should be understood as the best estimate of possible inaccuracy due to random and systematic error.

In general, a quantity to be determined (Q) is dependent on a number of parameters (p_j), each of them associated with an uncertainty (s_{p_j}) which is propagated towards this quantity. These parameters and uncertainties can be classified as follows :

- parameters with a random uncertainty, which can be described by the laws of probability. These parameters influence the precision of the determination. A typical example in NAA is the number of counts collected in the full-energy peak, at least if only the uncertainty from counting statistics is considered ;
- parameters with a systematic uncertainty which cannot be reduced in a given situation. These parameters influence the intrinsic accuracy of the determination. An obvious example in k_0-standardized NAA (from the analyst's standpoint) is the k_0-factor with its quoted uncertainty ;
- parameters with a systematic uncertainty which can in principle be reduced. These parameters influence the experimental accuracy of the method. An example in k_0-standardized NAA is the detection efficiency ratio $\varepsilon_{p,m}/\varepsilon_{p,a}$ in

Eqs (I.3-20) and (I.3-21), the uncertainty of which can be minimized by counting sample and monitor at the same distance to the Ge-detector.

Note that a parameter can have a random and a systematic uncertainty. For instance, the number of counts collected in the full-energy peak is associated with a random uncertainty from counting statistics and a systematic uncertainty from peak area evaluation.

If the function relating Q and p_j is written implicitly as :

$$F(Q,p_j) = 0 \qquad \text{(I.3-22)}$$

partial derivation yields :

$$\frac{\delta F}{\delta Q}\, dQ + \frac{\delta F}{\delta p_j}\, dp_j = 0 \qquad \text{(I.3-23)}$$

When expressing the uncertainties in terms of differentials, one obtains :

$$Z_Q(p_j) = \left| \frac{dQ}{Q} \Big/ \frac{dp_j}{p_j} \right| \qquad \text{(I.3-24)}$$

$$= \left| \frac{p_j}{Q} \cdot \frac{\delta F}{\delta p_j} \Big/ \frac{\delta F}{\delta Q} \right| \qquad \text{(I.3-25)}$$

where $Z_Q(p_j)$ denotes the "partial" error propagation factor for Q, with respect to the relative uncertainty on p_j; otherwise said, $Z_Q(p_j)$ is the multiplier of the relative uncertainty on p_j to obtain the associated relative uncertainty on Q, i.e. :

$$s_Q(p_j),\ \% = Z_Q(p_j).s_{p_j},\ \% \qquad \text{(I.3-26)}$$

If Q can be written as an explicit function of p_j :

$$Q = F(p_j) \qquad \text{(I.3-27)}$$

the above becomes :

$$Z_Q(p_j) = \left| \frac{p_j}{Q} \cdot \frac{\delta Q}{\delta p_j} \right| \qquad \text{(I.3-28)}$$

It should be noted that the validity of Eqs (I.3-25) and (I.3-28) is in principle restricted to moderate s_{p_j}-values or to F-functions which do not deviate dramatically from linearity. For the practical cases encountered

in the present work, the above expressions can be considered as acceptable approximations.

With the aid of Eqs (I.3-26) and (I.3-25) [or (I.3-28)] it is thus possible to calculate, for the quantity Q to be determined, the "partial" uncertainty contributions $s_Q(p_j)$, %, which are either of random or systematic nature. The crucial questions are then : should these uncertainties be combined to arrive at a total uncertainty ?; and how should such a combination be performed ? The answer to the first question is certainly affirmative. Indeed, if later the quantity Q becomes a parameter in the determination of a quantity Q^*, one must be able to apply the error propagation theory $[s_{Q^*}(Q),\% = Z_{Q^*}(Q).s_Q,\%]$ and this requires the knowledge of the total uncertainty on Q ; whether the latter is (partly) random or systematic in nature has no importance at that moment, since it contributes anyhow as a systematic error in the determination of Q^*. As an answer to the second question, a practical procedure has been recommended [KAARLS80] by the Working Group on the Statement of Uncertainties, organized by the Bureau International des Poids et Mesures (BIPM). In October 1981 it has been approved by the CIPM, the Comité International des Poids et Mesures [MULLER84, MULLER84A], and it is now applied in several national standardizing laboratories. This procedure recommends that the combined (total) uncertainty should be characterized by the numerical value obtained by applying the usual method for the combination of variances, whereby the combined uncertainty and its components should be expressed in the form of "standard deviations". Thus, according to this recommendation - which is followed in the present work - the total uncertainty on the quantity Q is :

$$s_Q,\% = \left\{ \sum_j \left[Z_Q(p_j) \cdot s_{p_j},\% \right]^2 \right\}^{1/2} \qquad \text{(I.3-29)}$$

In the above, nothing has been said about correlations and covariances. However, such effects will be mentioned and/or taken into account throughout this work whenever necessary.

When determining a quantity Q from N independent repetitions (1, 2,...i ...N), for which the associated uncertainties (s_{Q_i}) are estimated to be of equal magnitude, an unweighted average is calculated as :

$$\bar{Q} = \frac{1}{N} \sum_i^N Q_i \qquad \text{(I.3-30)}$$

with an uncertainty on the average :

$$s_{\bar{Q}} = \left\{ \frac{\sum_{i}^{N} [Q_i - \bar{Q}]^2}{N(N-1)} \right\}^{1/2} \qquad \text{(I.3-31)}$$

to which common systematic uncertainties can then be added in quadrature. This is the case for instance when calculating recommended k_0-factors as an average from independent experimental determinations [according to Eq. (I.3-18)] carried out in various irradiation channels of the THETIS and WWR-M reactor in Gent and Budapest (see VI.2.1).

When determining a quantity Q from N independent repetitions (1, 2, ... i ...N) for which the associated uncertainties (s_{Q_i}) are known to be largely different, a weighted average is calculated as :

$$\bar{\bar{Q}} = \left[\sum_{i}^{N} w_i Q_i\right] \Big/ \left[\sum_{i}^{N} w_i\right] \qquad \text{(I.3-32)}$$

with $w_i = 1/s_{Q_i}^2$ (I.3-33)

Then, the internal and external uncertainties (usually called internal and external errors) are calculated as :

$$s_{\bar{\bar{Q}},\text{int}} = \left(\sum_{i}^{N} w_i\right)^{-1/2} \qquad \text{(I.3-34)}$$

$$s_{\bar{\bar{Q}},\text{ext}} = \left\{ \frac{\sum_{i}^{N} w_i [Q_i - \bar{\bar{Q}}]^2}{(N-1)\sum_{i}^{N} w_i} \right\}^{1/2} \qquad \text{(I.3-35)}$$

In Eq. (I.3-33), s_{Q_i} should not contain common systematic uncertainties, which should be added afterwards in quadrature to the internal and external errors.

Comparison of the internal and external error, calculated from Eqs (I.3-34) and (I.3-35), is interesting because it reveals the statistical (in)consistency of the spread of the Q_i values with respect to their uncertainties s_{Q_i}. Consistency is achieved on condition that $s_{\bar{\bar{Q}},\text{int}} \simeq s_{\bar{\bar{Q}},\text{ext}}$. $s_{\bar{\bar{Q}},\text{int}} >> s_{\bar{\bar{Q}},\text{ext}}$ indicates that the estimated s_{Q_i} values contain common syste-

matic uncertainties or that the Q_i results are biased or manipulated, e.g. by unjustly removing " outliers ". $s_{\bar{Q},ext} >> s_{\bar{Q},int}$ suggests that one or more uncommon uncertainties were not taken into account when estimating the s_{Q_i} values.

Weighted averages and associated uncertainties are for instance calculated for Q_0-determination (V.3.3) and for k_0-determination according to the Cd-subtraction method [Eq. (I.3-19)], where the magnitude of the $s_{Q_{0,i}}$ - and $s_{k_{0,i}}$-values is largely influenced by the thermal-to-epithermal neutron flux ratio (of irradiation position i); and also for the calculation of σ_0-values from recommended k_0-factors (see APP.4) where $s_{\sigma_{0,i}}$ is proportional to the uncertainty on the introduced value of the gamma-intensity (of gamma-line i).

In all cases, the uncertainty quoted on the weighted average is the larger of the internal and external errors, to which common systematic uncertainties are quadratically added, as explained above.

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CHAPTER II

INSTRUMENTATION

1. IRRADIATION FACILITIES

1.1. Reactor Thetis (INW, Gent/Belgium)

At the Institute for Nuclear Sciences (INW, Gent/Belgium), irradiations for the determination of k_0, Q_0, etc. were carried out in reactor Thetis. This is a research reactor of the swimming-pool type, uniquely designed for neutron activation analysis and operated at a steady-state power of 250 kW. The horizontal cross-section is shown in Fig. II.1-1. The core consists of a lattice of fuel-elements, each of them (except one) containing 25 fuel pins (5% enriched UO_2 cladded with stainless steel). The core is surrounded from four sides by eight graphite blocks, acting as reflector and also as moderator with respect to the 16 pneumatically operated irradiation channels located in the graphite. The whole is immersed in a large light-water tank. One of the elements (central bottom in Fig. II.1-1) contains only eight fuel pins ;

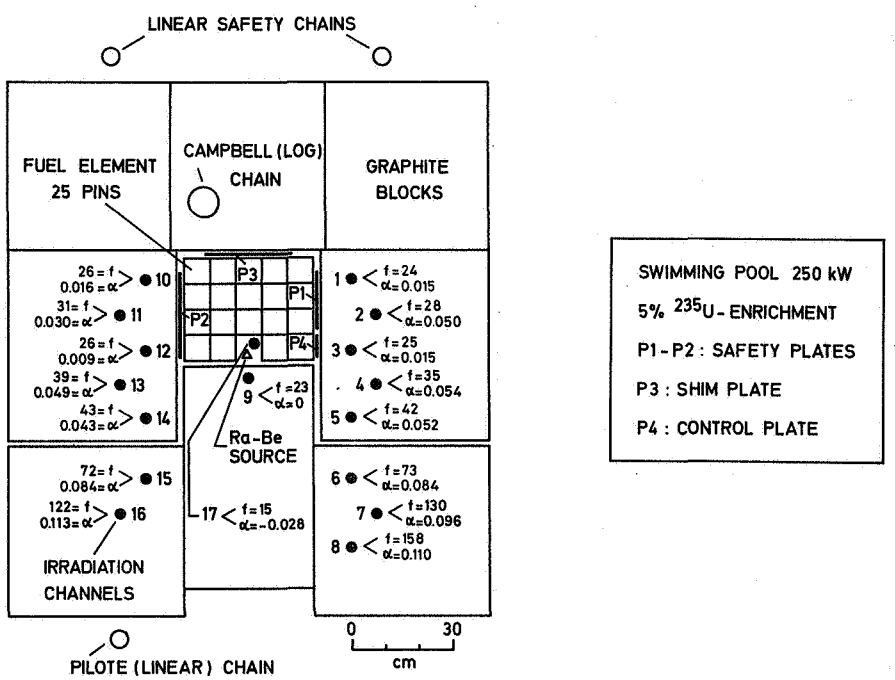

Fig. II.1-1 : Horizontal cross-section of reactor Thetis (INW, Gent/Belgium). The configuration and the data shown for f and α refer to before March 1981 (see text)

its vacant space is occupied by channel 17 (pneumatically served as well) and by the Ra-Be source to start up the reactor. The installation of these 8 extra fuel pins, requiring the moving up of channel 17, was done in March 1981 - in the course of the experiments described in the present work. This small change of the configuration had a marked influence on the magnitude of the parameters f and α (thus requiring a recalibration), and this explains the apparent inconsistencies which might be observed throughout this work.

The reactor is controlled by four vertically movable Cd-In-Ag alloy plates - two safety plates, one shim plate and one fine regulating (control) plate - which are installed at three outer sides of the core, between the core and the graphite reflector. At the fourth side, the graphite reflector is directly contiguous to the fuel elements. The control plate is steered by both the Campbell and the linear control chain, and on the signal of the latter the linear plot of the reactor power versus time (recorded as part of the logbook) is based as well. A typical recording during one irradiation cycle (7 hours) is shown in Fig. II.1-2a. Evidently, it gives no precise information on flux

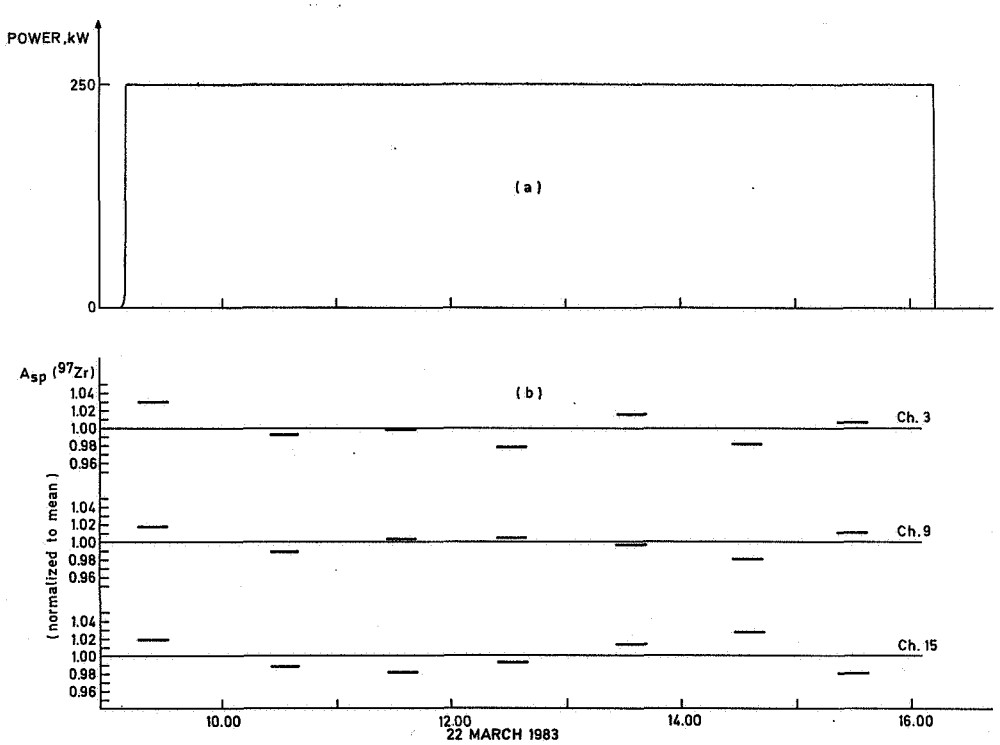

Fig. II.1-2a : Linear plot of the power of reactor Thetis (INW, Gent/Belgium) as recorded during one irradiation cycle (7 hours)

b : Flux variation in channels 3, 9 and 15, measured by irradiating at regular intervals Zr-monitors for 15 min-periods

variations in a particular irradiation position. Short-term flux variations (i.e. in the course of one irradiation cycle) have been studied repeatedly in several channels, by irradiating at regular intervals Zr-monitors for 15 min-periods, followed by counting the induced $^{97}Zr/^{97m}Nb$ activity with a Ge-detector. Typical results for channels 3, 9 and 15 are shown in Fig. II.1-2b. The maximum flux variation was never exceeding $\sim$ 5%, and the average deviation from the mean amounts to $\sim$ 1.2% for channel 3, $\sim$ 1.0% for channel 9, and $\sim$ 1.7% for channel 17. It is important to remark that sample loading and unloading was always performed during the steady-state operation of the reactor.

The long-term variability of the parameters f and α is shown in Fig. II.1-3 for channels 7 and 16. The maximum variation of f amounts to $\sim$ 12% in both channels, and the maximum deviation from the mean is $\sim$ 8% in channel 7 and $\sim$ 6% in channel 16. The maximum variation of α amounts to $\sim$ 20% in channel 7 and $\sim$ 23% in channel 16, and the maximum deviation from the mean is $\sim$ 10% in channel 7 and $\sim$ 11% in channel 16. It can be reasonably expected that the short-term variability (i.e. in the course of one irradiation cycle) is smaller. As will be demonstrated in VII.5, such moderate variabilities of the flux, and of f and α, have but a negligible effect on the accuracy of k_0-factors, analytical results, etc.

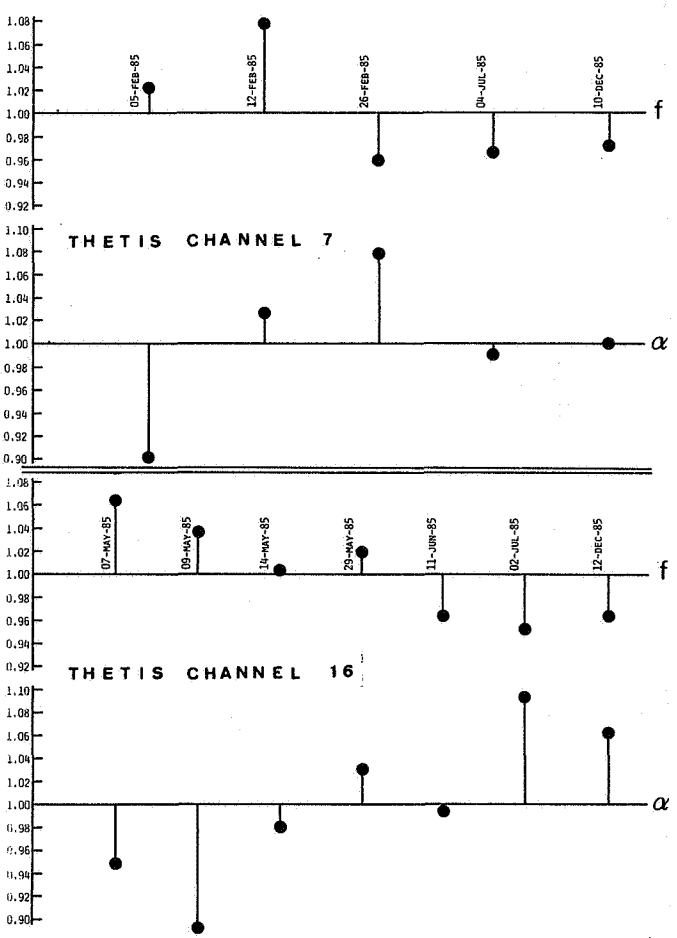

Fig. II.1-3 : Long-term variability of f and α (normalized) in 2 channels of reactor Thetis

The set of 17 irradiation channels, with varying distance to the core, offers a broad

choice of available neutron fluxes [ϕ_s is ranging from $\sim 1.7.10^{11}$n cm^{-2} s^{-1} (Ch.8) to $\sim 4.6.10^{12}$n cm^{-2} s^{-1} (Ch.17)], thermal-to-epithermal flux ratios [f is ranging from $\sim$ 15 (Ch.17) to $\sim$ 160 (Ch.8)], and α-values [ranging from $\sim$ -0.03 (Ch.17) to $\sim$ 0.11 (Ch.8, Ch.16)]. The parameters f and α, relevant in the k_0-standardization method, are shown in Fig. II.1-1 (data before March 1981). In addition to the above, the range of available thermal-to-fast flux ratios [from $\sim$ 1.6 (Ch.17) to $\sim$ 120 (Ch.8)] is interesting to mention as well; it allows to select a suited irradiation channel in case of disturbing, fast-neutron induced reactions, such as primary interferences [(n,n'), (n,2n)].

In the present work, most of the irradiations for experimental k_0 and Q_0 determination were done in :

- channels 3 and 15 for long-lived radionuclides, with irradiation times ranging from 1 to 7 hours [Ch.3 : $\phi_s \simeq 1.6.10^{12}$n cm^{-2} s^{-1}, thermal-to-fast flux ratio $\simeq$ 7 ; Ch.15 : $\phi_s \simeq 4.9.10^{11}$n cm^{-2} s^{-1}, thermal-to-fast flux ratio $\simeq$ 58];
- channels 8 and 9 (or 17) for short-lived radionuclides, with irradiation times ranging from 2 to 15 minutes [Ch.8 : $\phi_s \simeq 1.7.10^{11}$n cm^{-2} s^{-1}, thermal-to-fast flux ratio $\simeq$ 120 ; Ch.9 : $\phi_s \simeq 2.6.10^{12}$n cm^{-2} s^{-1}, thermal-to-fast flux ratio $\simeq$ 4.6 ; Ch.17 : $\phi_s \simeq 4.6.10^{12}$n cm^{-2} s^{-1}, thermal-to-fast flux ratio $\simeq$ 1.6].

Occasionally, as in the case of k_0-determination of the Zr-isotopes, use was made of other (and more) irradiation channels.

1.2. Other reactors

1.2.1. Reactor WWR-M (KFKI, Budapest/Hungary)

As mentioned in I.3.4.1, most of the results reported in the present work were obtained from parallel, but independent experimental determinations in Gent and Budapest.

At the Central Research Institute for Physics (KFKI, Budapest/Hungary), irradiations were carried out in a WWR-M type reactor. This is a research reactor of the "water boiler" type, operated at a power of 2 MW (in the course of the experiments increased to 5 MW). The fuel consists of 36% enriched UO_2.

The moderator is light water, and the reflector is beryllium. The ground plan is shown in Ref. SIMONITS80 .

The most frequently used irradiation channels were :

- channels "MILA" ($f \simeq 35$; $\alpha \simeq 0.016$) and "CSÖPI" ($f \simeq 18$; $\alpha \simeq -0.007$), for short irradiations of $\sim$ 3-5 minutes [Ch."MILA" : $\phi_s \simeq 3.10^{13}$ n cm^{-2} s^{-1}, thermal-to-fast flux ratio $\simeq$ 40 ; Ch."CSÖPI" : $\phi_s \simeq 3.6.10^{13}$ n cm^{-2} s^{-1}, thermal-to-fast flux ratio $\simeq$ 13];
- channels 17/2 ($f \simeq 20$; $\alpha \simeq 0.00$) and 15/2 ($f \simeq 30$; $\alpha \simeq -0.01$), for long irradiations of $\sim$ 10 hours [Ch.17/2 : $\phi_s \simeq 3.6.10^{13}$ n cm^{-2} s^{-1}, thermal-to-fast flux ratio $\simeq$ 13 ; Ch.15/2 : $\phi_s \simeq 3.10^{13}$ n cm^{-2} s^{-1}, thermal-to-fast flux ratio $\simeq$ 40].

Note that, due to the concept and construction of the reactor, f and α had to be redetermined for every irradiation run. Here also, the flux parameters were found to be sufficiently stable during irradiation.

1.2.2. Reactor DR-3 (Risø/Denmark)

For some k_0 and Q_0-determinations (e.g. of the Zr-isotopes; see VI.2.2 and V.3.2.4), irradiations were performed in reactor DR-3 of the Risø National Laboratory (Denmark). This is a 10 MW heavy-water cooled and moderated research reactor with 80% enriched U-Al fuel elements.

Use was made of irradiation channel R4V4, with $\phi_s \simeq 2.5.10^{13}$ n cm^{-2} s^{-1}, $f \simeq 320$, $\alpha \simeq 0.17$. The thermal-to-fast flux ratio is of the order of 600. The irradiations were performed for 0.5 and 2 hours during four subsequent days in December 1984. The day-to-day variation of ϕ_s, f and α was found to be sufficiently small so as to estimate the variability during the irradiations as having negligible effects.

1.2.3. Reactor BR-2 (SCK, Mol/Belgium)

In VII.3.4 and VII.5.2 some results are reported based on irradiations in reactor BR-2 of the Belgian Nuclear Study Centre (SCK, Mol/Belgium). This is a $\sim$ 60 MW light-water cooled and moderated reactor with 90% enriched fuel.

Use was made for instance of irradiation channel H323, with $\phi_s \simeq 1.10^{14}$ n cm^{-2} s^{-1}, $f \simeq 10$, $\alpha \simeq 0$, and a thermal-to-fast flux ratio $\simeq$ 4. Irradiation times were 7-14 days.

2. COUNTING EQUIPMENT

2.1. Ge gamma-ray spectrometers at the INW, Gent/Belgium

At the INW, use was made of several Ge(Li) gamma-ray spectrometer systems, the basic characteristics of which are compiled in Table II.2-1. Since mid-1983, only Canberra S40 multi-channel analysers are in use. As shown,

TABLE II.2-1 : Characteristics of the Ge(Li) gamma-ray spectrometer systems used at the INW, Gent (* amplifier/pulse pile-up rejector ; ** Bartošek-system [BARTOSEK72A/72B])

Code name	DET.4	DET.5	MK7	DET.6	MK4
Detector type	Ge(Li) single open ended (pseudo coaxial)				
Origin	Philips	Philips		Canberra	Canberra
Active volume cm^3	53	75		104	101
Efficiency (at 1332.5 keV),%	10.9	15.6		22.0	18.7
Resolution FWHM (at 1332.5 keV),keV	2.0	2.0		1.84	1.94
Preamplifier	Philips 56056	Philips 56056		Canberra 2001	
Amplifier	Canberra 1413	Canberra 1413	Canberra 1413 or 2010 or 2020*	Canberra 2010	Canberra 2010 or 2020*
MCA	Didac 4000		Canberra S40	Didac 4000	Canberra S40
ADC	C44B (100MHz)		Canberra (100MHz)	C44B (100MHz)	Canberra (100MHz)
Dead-time correction	Live-time circuit of MCA or Dead-time stabilizer ** in true-time mode				

dead-time corrections were performed by means of the live-time circuit of the multi-channel analyzer, or - in case of short-lived radionuclides - a dead time stabilizer (DTS) was applied while measuring in true-time mode [BARTOSEK72A/72B]. Even when using a Canberra 2020 amplifier/pile-up rejector, dead times were kept below ∿ 25%. When using other amplifiers, the counting rates were kept sufficiently small so as to make random coincidence effects (pulse pile-up) negligible, i.e. the product τN_t was kept below 5.10^{-3} (τ = pulse shaping time constant ; N_t = total counting rate).

A plexiglass source support was mounted on each detector so as to ensure easy and reproducible source positioning. Since some of the results shown in the present work refer to the geometric source-detector configuration of MK4 and MK7 (see Chapters III and IV), the relevant parameters are shown in Fig. II.2-1. Note that throughout this work, quoted source-detector separations refer to the distance from the source base to the detector's active volume.

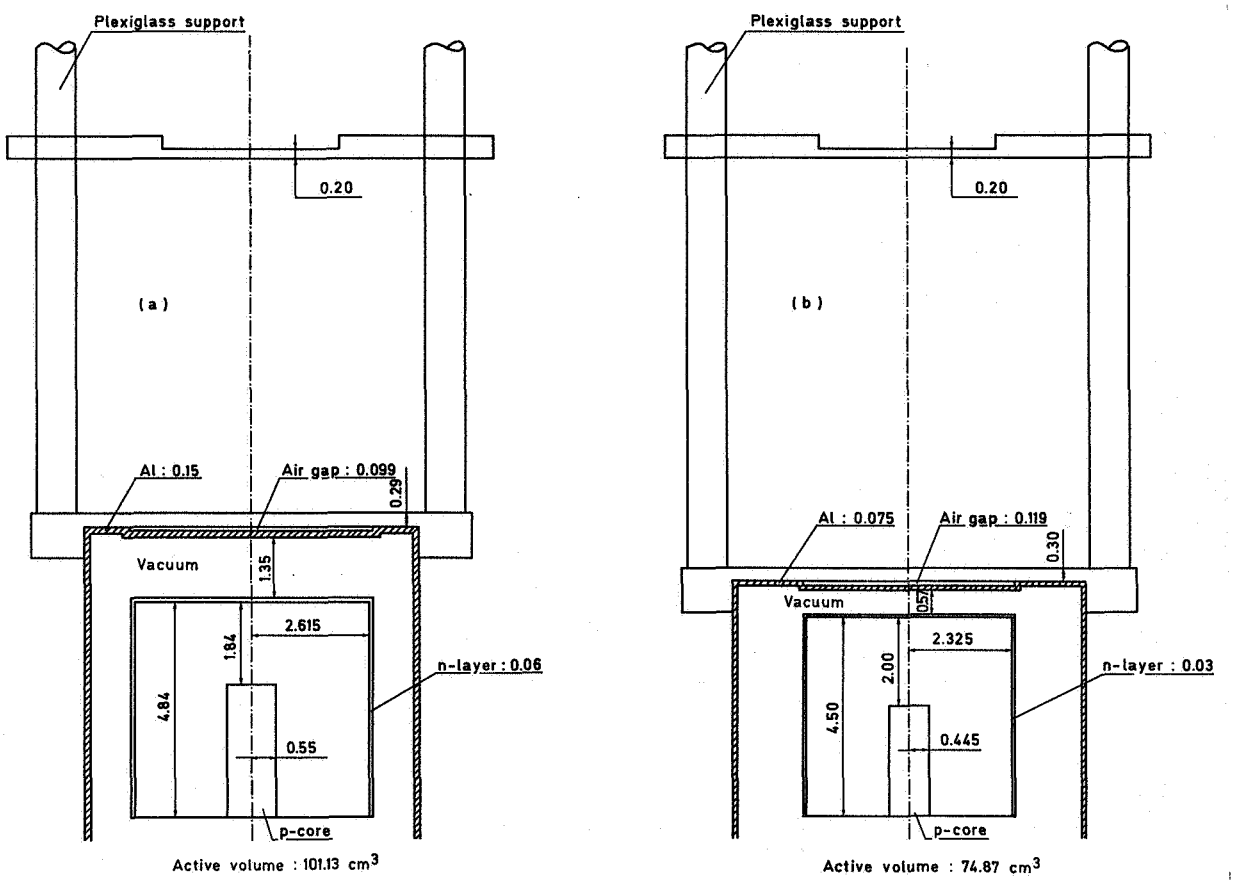

Fig. II.2-1 : Geometric configuration of detector and plexiglass source support : a. detector MK4 ; b. detector MK7 (measures in cm)

2.2. Ge gamma-ray spectrometers at the KFKI, Budapest/Hungary and at Risø/Denmark

The characteristics of the Ge gamma-ray spectrometer systems used at the KFKI and at Risø are shown in Table II.2-2. Note that simultaneous correction for pulse pile-up and dead time was performed by means of the pulser method, at the same time keeping the counting time below one tenth of the half-life of the measured radionuclide.

TABLE II.2-2 : Characteristics of the Ge gamma-ray spectrometer systems at the KFKI, Budapest and at Risø [* with Al-window (thickness : 0.5 mm)]

Institute	KFKI		Risø
Code name	CANB.77	CANB.79	GAMMA-X
Detector type	Ge(Li) single open ended (pseudo coaxial)		HPGe Coaxial*
Origin	Canberra		EG&G Ortec
Active volume cm^3	83	67	59
Efficiency (at 1332.5 keV),%	15.7	13.0	10.5
Resolution FWHM (at 1332.5 keV),keV	1.72	1.82	1.62
Preamplifier	Canberra 2001		Cooled FET
Amplifier	Canberra 2010 or 2020		Canberra 2010
MCA	ICA-70 (KFKI)		Nuclear Data 660 + Nuclear Data-66 (analyzer-terminal)
ADC	100 MHz		
Dead-time correction	fixed pulser BNC PB-4 or random pulser BNC DB-2		research pulser Ortec 448

3. COMPUTATIONAL

3.1. Hardware

At the INW, the available computer operating systems changed considerably in the course of the present work, from a PDP-09, over a PDP-11/45, to a VAX 11/780 machine. The latter has 1.25 Mbyte main memory (MOS), is equiped with two RM03 disk drives of 67 Mbyte capacity each and one 9900 Controller (System Industries) disk drive of 420 Mbyte capacity, and is using VMS operation system. Via a Canberra Serial Adapter 1656, the memory content of the Canberra S40 MCA's can be transferred either to the CPU of the VAX 11/780 or to a digital cassette recorder. Data can be stored on magtape (Dec Magtape TE16, 9 channel). Input data can be given via a Digital Decwriter II or via several videoterminals (VT 100; VT 102; Facit). A line printer (Digital LP5) and a plotting machine (CØMPLØT DP-8) are available for data output.

At the KFKI, a TPA-1140 (PDP-11/40) and an IBM 360 computer were available.

In addition to the computer systems, use was made of the programmable calculators HP-97 and HP-41C.

3.2. Software

At the INW, use was made of the following programs written for, or adapted to, the VAX 11/780 computer. Most of the programs are in FORTRAN IV or IV+.

- SEQAL [OPDEBEECK76], for routine calculation of gamma-ray peak areas; detection limits can be derived from it as well ;
- TRAP [DEWISPELAERE], mostly used for calculation of (widened) 511 keV β^+-annihilation peak areas, based on the trapezoidal method (see e.g. CANBERRA6) ;
- SAMP080 [KOSKELO81], used in case of doubt for evaluation of multiplet gamma-ray peak areas (after comparison with results from SEQAL and MARKER/CAOS) ;

- MARKER/CAOS [WESTMEIER], used in case of doubt for evaluation of multiplet gamma-ray peak areas (after comparison with results from SEQAL and SAMPO80); this program contains subroutines in MACRO language ;
- ABSORP [DEWISPELAERE], for calculation of thermal and epithermal neutron self-shielding factors, according to the formulae given in I.2.4 ;
- SOLANG [MOENS81], for calculation of effective solid angles needed for ε_p-conversion (see Chaptér III) ;
- QØCALC [DEWISPELAERE], for calculation of Q_0 from R_{Cd}-measurements (see V.3.2.1); it contains subroutines POINEF, OMEGA and SPECAC (see program SINGCOMP) ;
- KØCALC [DEWISPELAERE], for calculation of experimentally determined k_0-factors (see I.3.4.1 and VI.2.1); it contains the same subroutines as program QØCALC ;
- PTTCALC [DEWISPELAERE], for calculation of peak-to-total ratios (needed for true-coincidence correction) from spectra of coincidence-free gamma-emitters (see Chapter IV); it contains the subroutine POLYNO ;
- ALFACALC [DEWISPELAERE], for calculation of α-factors according to the "Cd-ratio for multi-monitor"-method (see V.1.5.2) ;
- ER [JOVANOVIC84], for calculation of effective resonance energies from resonance parameter data (see V.1.2) ;
- POLYNO [DEDONDER], for least-squares polynomial fitting of experimentally determined detection efficiencies and peak-to-total ratios versus gamma-energy (see Chapters III and IV) ;
- SINGCOMP [DEWISPELAERE], replacing the former program SINGCOM [LINXILEI84]. This program calculates concentrations based on the k_0-standardization method; it contains the following subroutines :
  - GENSINCOM : creates the command file to run SINGCOMP ;
  - GENDAT : reads in the data base ;
  - OMEGA : calculates ratios of effective solid angles (see Chapter III) from interpolation (according to Aitkens's method [ABRAMOWITZ70]) of data provided by program SOLANG (see above) ;
  - POINEF : calculates ε_p (for a particular gamma-energy) for experimental "reference" conditions (see Chapter III) from the polynomial fitting coefficients provided by program POLYNO ;
  - FALFA : calculates f (from the "bare bi-isotopic monitor"-method) and α (from the "bare triple-monitor"-method) [see Chapter V];

- SPECAC : calculates specific count rates for all activation/decay types (see I.3.4.2) ;
- PTOTOT : calculates peak-to-total ratios (for a particular gamma-energy), based on the polynomial fitting coefficients provided by program PTTCALC (see Chapter IV) ;
- EPSTOT : calculates total detection efficiencies (see Chapter IV) from data provided by OMEGA, POINEF and PTOTOT ;
- COIN : calculates true-coincidence correction factors according to the formulae in Chapter IV; it contains several subroutines for handling γ-γ coincidence summing, γ-γ coincidence loss, γ-KX(IC) coincidence loss, etc.

Program SINGCOMP corrects for spectral interferences, which should, however, be identified by the analyst.

At present, a new program for "k_0-based" concentration calculation is being developed [MOENS87]. It will include nuclide identification, automatic correction for spectral interferences, and concentration calculation from all relevant gamma-lines of a radionuclide based on least-squares.

At the KFKI, programs HYPERMET [PHILLIPS76/79] and TRAP were used for peak area evaluation, and program SPECTRUM [DEMETER86] was developed for concentration calculation. Evaluation of the gamma-spectra measured at Risø was based on programs SAMPO80, SEQAL, TRAP and on the built-in NUCLEAR DATA program.

In addition to the above, many small but useful programs were written for the HP-97 and HP-41C calculators. Among others, mention can be made of programs for the calculation of burn-up factors (see I.2.3), weighted averages and associated uncertainties (see I.3.4.4) and various error propagation factors (see I.3.4.4).

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CHAPTER III

FULL-ENERGY PEAK DETECTION EFFICIENCY (ε_p)

1. ε_p^{ref} IN REFERENCE CONDITIONS

1.1. Experimental determination

The full-energy peak detection efficiency (ε_p) has to be introduced in the relevant equations for experimental k_0-measurement [Eqs (I.3-18) and (I.3-19)], for determination of the analyte concentration [Eqs (I.3-20) and (I.3-21)], and also for f and α determination (see Chapter V) and true-coincidence correction (see Chapter IV).

For the determination of k_0, f and α, optimal so called "reference" counting conditions are selected (superscript "ref"). This implies that measurement of quasi-point sources is performed at large source-detector distance (e.g. 15-20 cm), where true-coincidence effects are negligible. Occasionally, these conditions can be realized in analytical practice as well. Then, use can be made of an experimentally determined log ε_p^{ref} versus log E_γ curve. As shown elsewhere [SIMONITS80,MOENS81,LIN81], such a curve - ranging from $\sim$ 55 keV to $\sim$ 2450 keV - can be constructed readily by measuring a number of absolutely calibrated multi- and single-gamma point sources (^{152}Eu, ^{226}Ra, etc.). The most useful radionuclides and their relevant nuclear data (E_γ, T and γ) are listed in Table III.1-1. As seen in Figs III.1-1 and III.1-2, a linear fitting is possible in the medium energy range, from 650 keV to 1500 keV for Ge-detector MK4 and from 560 to 1240 keV for Ge-detector MK7; this can serve as a reference line to obtain additional points in the low- and high-energy region, from measurement of secondary (home-made) multi-gamma point sources, such as ^{72}Ga, ^{182}Ta and ^{24}Na (see Table III.1-2). In this way it is possible to extend the ε_p^{ref}-curve up to $\sim$ 2850 keV. In principle, further extension to energies > 3000 keV is possible by measuring ^{56}Co.
In Figs III.1-1 and III.1-2 the polynomials $\log \varepsilon_p = a_0 + a_1 \log E_\gamma + \ldots + a_n (\log E_\gamma)^n$ are shown, which are giving the best fitting to the experimental points in four distinct energy regions. So as to obtain a smooth joining between the regions, the fitting in each region includes 1 or 2 nearestby points of the neighbouring region(s).

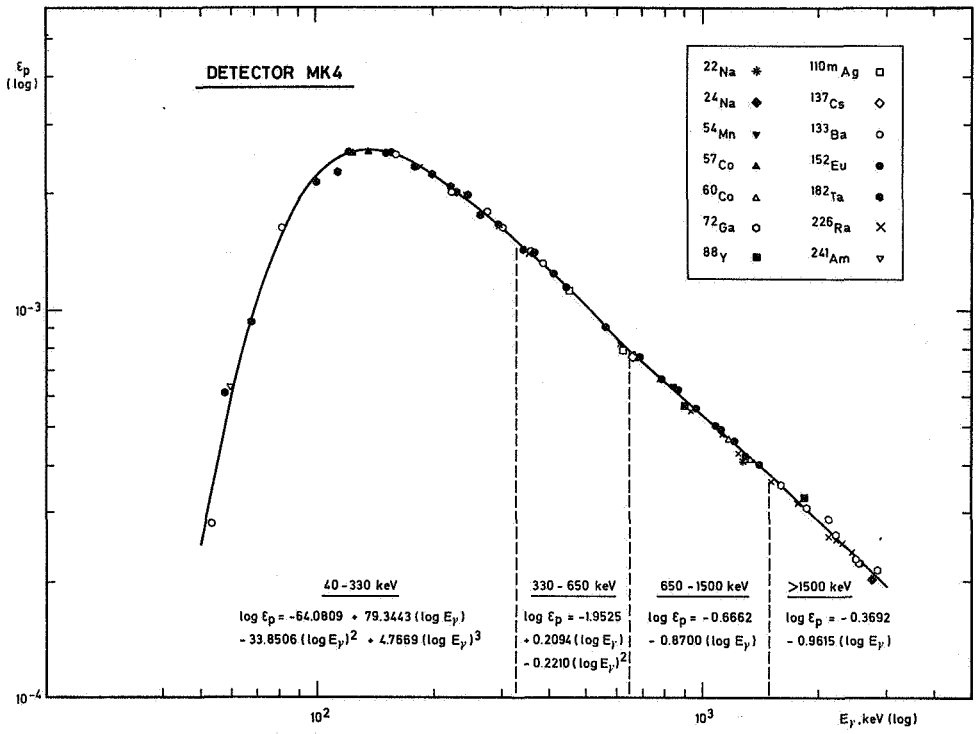

Fig. III.1-1 : ε_p^{ref}-curve for Ge(Li) detector MK4 (see II.2.1); "ref" = point-geometry at 17.27 cm source-detector distance

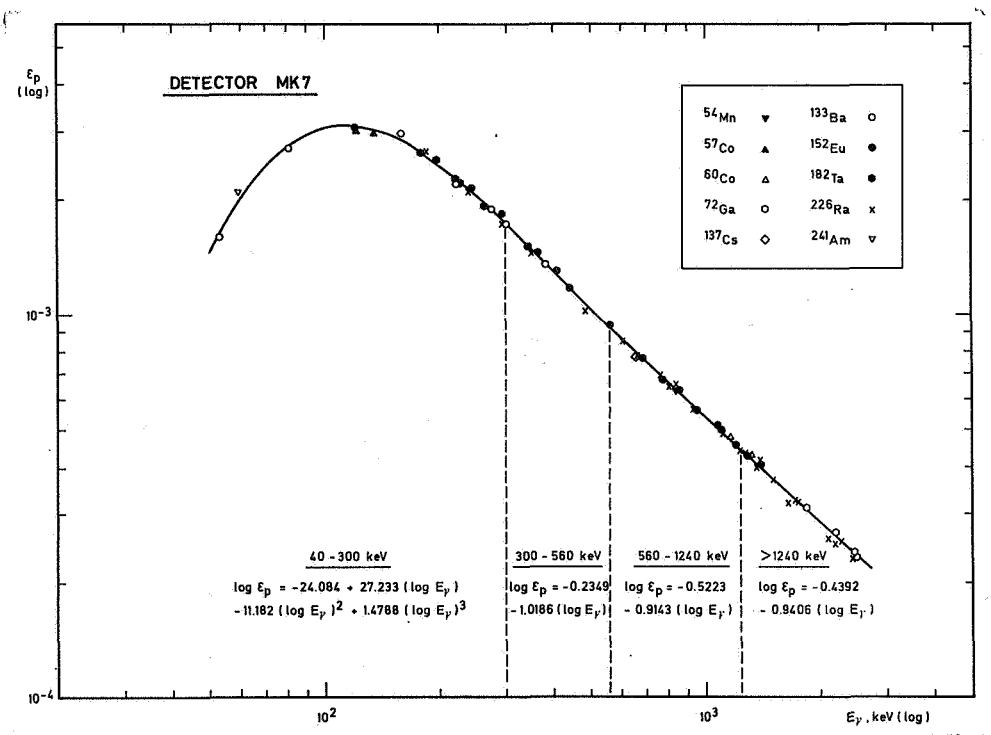

Fig. III.1-2 : ε_p^{ref}-curve for Ge(Li) detector MK7 (see II.2.1); "ref" = point-geometry at 16.37 cm source-detector distance

TABLE III.1-1 : Nuclear data of some useful absolutely calibrated point-sources; the data are collected from recent references and are consistent with Ref. LORENTZ83

Radio-nuclide	T	E_γ,keV	γ,%	Radio-nuclide	T	E_γ,keV	γ,%
^{241}Am	432.2 y	59.5	35.30	^{54}Mn	312.2 d	834.8	99.98
^{133}Ba	10.54 y	53.1[5]	2.20	^{22}Na	2.604 y	1274.5	99.95
		81.0*	36.94	^{226}Ra	1600 y	186.0	3.408
		160.6	0.62			241.9	7.082
		223.2[5]	0.47			274.5*	0.5178
		276.4	7.12			295.2	18.10
		302.9	18.3			351.9	35.10
		356.0	62.1			487.1	0.4342
		383.9	8.92			609.3	44.26
^{109}Cd	461.9 d	88.1	3.61			665.4[5]	1.492
^{57}Co	271.73 d	122.1	85.54			768.4	4.739
		136.5	10.66			806.2	1.208
^{60}Co	5.271 y	1173.2	99.88			839.0	0.5577
		1332.5	99.98			934.0[5]	3.054
^{137}Cs	30.18 y	661.6	84.62			1120.3	14.69
^{152}Eu	13.5 y	121.8	28.21			1155.2	1.633
		244.7*	7.423			1238.1	5.710
		295.9	0.4231			1281.0	1.385
		344.3	26.41			1377.6[5]	3.868
		367.8	0.8401			1385.3	0.7923
		411.3*	2.301			1401.5	1.301
		444.0*	3.077			1509.2	2.080
		564.5*	0.6133			1661.3	1.076
		688.6*	0.8493			1729.6	2.833
		778.9	13.00			1764.5	15.09
		867.4	4.161			2118.5	1.177
		964.0*	14.48			2204.1	4.957
		1086.4*	11.84			2293.4	0.2988
		1112.0*	13.55	^{88}Y	106.6 d	2447.7	1.514
		1212.9	1.390			898.0	93.40
		1298.7	1.743			1836.1	99.40
		1408.0	20.71				

* Effective γ-energies calculated as : $E_{eff} = \sum_i \gamma_i E_{\gamma,i} / \sum_i \gamma_i$

^{133}Ba : 81.0 keV = E_{eff} of 79.65 & 81.03;

^{152}Eu : 244.7 keV = E_{eff} of 244.69 & 251.76;
411.3 keV = E_{eff} of 411.12 & 416.04;
444.0 keV = E_{eff} of 443.98 & 444.0;
564.5 keV = E_{eff} of 564.02 & 566.36;
688.6 keV = E_{eff} of 686.4 & 688.69;
964.0 keV = E_{eff} of 963.43 & 964.05;
1086.4 keV = E_{eff} of 1085.83 & 1089.72;
1112.0 keV = E_{eff} of 1109.2 & 1112.08;
1298.7 keV = E_{eff} of 1292.86 & 1299.13

^{226}Ra : 274.5 keV = E_{eff} of 273.70 & 274.53

TABLE III-1-2 : Nuclear data of possible secondary calibration sources (*57.1 keV=E_{eff} of 56.28(Kα2) & 57.535 keV(Kα1); 65.6 keV=E_{eff} of 65.14(Kβ1) & 67.254 keV(Kβ2); 114.1 keV=E_{eff} of 113.67 & 116.42 keV; 153.5 keV=E_{eff} of 152.43 & 156.39 keV)

Radio-nuclide	E_γ,keV	γ,%
^{72}Ga	reference points	
	834.0	95.65
	894.2	9.85
	1050.8	6.93
	calibration points	
	1596.7	4.24
	1861.1	5.23
	2109.5	1.034
	2201.7	26.1
	2507.8	12.8
	2844.1	0.410
^{24}Na	reference point	
	1368.6	99.99
	calibration point	
	2754.0	99.88
^{110m}Ag	reference points	
	763.9	22.29
	884.7	72.7
	937.5	34.37
	1384.3	24.34
	calibration points	
	446.8	3.72
	620.4	2.802
^{182}Ta	reference points	
	1121.3	35.30
	1189.3	16.44
	1221.4	27.17
	1231.0	11.58
	calibration points	
	57.1*	73.6 ?!
	65.6*	19.5 ?!
	100.1	14.23
	114.1*	2.315
	153.5*	9.58
	179.4	3.09
	198.4	1.44
	222.1	7.50
	229.3	3.64
	264.1	3.62

1.2. Accuracy and error propagation

The accuracy of a properly determined ε_p^{ref}-curve can be estimated at 1-2% (including the accuracy of the gamma-emission rate), except in the energy regions below 100 keV and above 2500 keV, where it can go up to 3-4%. It is in fact the uncertainty on $\varepsilon_{p,c}^{ref}/\varepsilon_{p,s}^{ref}$ or $\varepsilon_{p,m}^{ref}/\varepsilon_{p,a}^{ref}$ which is transferred to the k_0-factors or the analytical results, respectively [cf. Eqs (I.3-18) - (I.3-21)]. This uncertainty on the efficiency ratio is of the or-

der of 0-2%, depending on the difference in gamma-energies. The ε_p^{ref} error propagation factors towards f and α will be discussed in Chapter V.

In case of k_0-determination, small geometry differences between comparator and standard can be accounted for by making use of an internal comparator technique (see VI.2.1) [or by actually converting the experimentally determined ε_p^{ref}-values to ε_p^{geo} (see below)].

It goes without saying that it is strongly recommended to check the ε_p^{ref}-curve at regular time intervals, e.g. by measuring some calibrated point sources with low, medium and high gamma-energy (for instance ^{133}Ba, ^{137}Cs and ^{60}Co).

2. ε_p^{geo} IN PRACTICAL GEOMETRIC CONDITIONS

2.1. Conversion of ε_p^{ref} to ε_p^{geo}, including gamma-attenuation

In actual activation analysis it is often inevitable to measure an extended sample close to the detector. Apart from correction for true-coincidence effects (see Chapter IV), this requires the introduction in Eqs (I.3-20) and (I.3-21) of ε_p^{geo}, the detection efficiency for the actual geometric configuration.

In principle, experimental determination of ε_p^{geo} versus E_γ could be performed by measuring a number of "coincidence-free" sources (^{109}Cd, ^{51}Cr, ^{137}Cs, ^{65}Zn, etc.), which should have the same geometry and major element composition as the samples to be analysed. Because of inflexibility and other difficulties encountered in such experimental detector calibration, the interest for computational techniques has increased during the last years.

A procedure for conversion of ε_p^{ref} to other counting configurations, including correction for gamma-attenuation, has been elaborated and tested by Moens et al., for both Ge(Li) and HPGe (hyperpure Ge) detectors [MOENS81/81A/82/83]. In short, this conversion proceeds as follows. The relation between ε_p^{geo} and ε_p^{ref} can be written as :

$$\varepsilon_p^{geo} = \varepsilon_p^{ref} \cdot \frac{\bar{\Omega}^{geo}}{\bar{\Omega}^{ref}} \cdot \frac{(p/t)^{geo}}{(p/t)^{ref}} \qquad \text{(III.2-1)}$$

where $\bar{\Omega}$ is the "effective" solid angle subtended at the source by the detector (see below). The parameter p/t is the "virtual" peak-to-total ratio. It

differs fundamentally from the peak-to-total ratio (P/T : see Chapter IV) that would be measured in an actual counting arrangement; in fact it refers to a hypothetical, bare and isolated detector crystal. As beared out by experimental test, it can be assumed that p/t is a constant of a detector crystal and thus is independent of source geometry and composition as well as of source-detector distance; similar conclusions were drawn earlier for NaI(Tl) detectors [RIEPP074]. Thus, Eq. (III.2-1) can be simplified to :

$$\varepsilon_p^{geo} = \varepsilon_p^{ref} \cdot \frac{\bar{\Omega}^{geo}}{\bar{\Omega}^{ref}} \qquad \text{(III.2-2)}$$

The basic concepts, formalae and calculation methods of the effective solid angle $\bar{\Omega}$ were extensively discussed elsewhere [MOENS81, MOENS81A]. It was shown that only simultaneous treatment of geometry, detector response and gamma-attenuation is principally correct. In summary it can be said that $\bar{\Omega}$ is obtained from numerical integration of the "weighted" solid angle element $d\bar{\Omega}$ over the volumes of source and detector. In general this can be expressed as :

$$\bar{\Omega} = \int_{\substack{source \\ detector}} d\bar{\Omega} = \int_{\substack{source \\ detector}} F_{eff}\, F_{att}\, d\Omega \qquad \text{(III.2-3)}$$

The first "weighing" factor F_{eff} (response factor) is the probability for a photon with energy E_γ, emitted within $d\Omega$ and impinging on the detector, to interact incoherently with the detector material. F_{att} accounts for gamma-attenuation caused by incoherent interaction in the absorbing materials interposed between source and detector body (source container, support, detector can, Ge dead layer, etc.). It is possible to express $d\Omega$, F_{eff} and F_{att} as a function of source and detector dimensions and - for sources with a symmetry axis coincident with the detector axis - as a function of not more than four (for cylinders) independent variables. For the numerical integration of the appropriate multiple integral [Eq. (III.2-3)], use is made of the Gauss-Legendre Quadrature. With an increasing number of base points this integration procedure is rapidly converging so that for a typical counting arrangement only 16-24 base points are required (for each relevant variable) for points, disks and cylinders. The procedure is available as the computer code SOLANG written in FORTRAN IV+ on a VAX 11/780 machine. Also a BASIC version was designed [FOGLIOPARA83] as well as an extended version in ALGOL [LIPPERT83].

The program SOLANG requires input data for the source and detector dimensions, source-detector distance, thickness of all interposed absorbers and finally for the needed γ-energies and corresponding absorption coefficients in all materials involved. A number of base points varying from 1 to 96 can be chosen for each variable. With the 16-24 base points mentioned above, cpu computing times required for the calculation of a 17 points $\bar{\Omega}$ vs E_γ-curve (between 40 keV and 3.5 MeV) are as follows : 54 s for points, 6 min 16 s for disks and 51 min 48 s for cylinders.

2.2. Applicability of the conversion

In principle, the applicability of the above described ε_p^{ref}-conversion procedure is bound to the following conditions :

a) The detector body must be cylindric and concentric with its housing, and its geometric parameters must be known. This means in practice that, so as to reach ∿ 2% accuracy on the conversion, the detector diameter should be known to within 1-2%, the diffuse n-layer thickness [for a Ge(Li)] to within 5% (important for low gamma-energies), whereas for the other parameters (detector height, dimensions of p-core or coaxial cavity) an uncertainty of 10-20% can be tolerated; the detector-Al (or Be) window separation should be known to within 0.1 mm.

b) The method applies to cylindrically symmetrical sources (cylinders, disks, points) with a rotation axis coincident with the detector axis and a radius not larger than the detector radius. The source-Al (or Be) window distance should be measured to within 0.1 mm. The source composition with respect to the major elements should be known approximately.

c) The thickness and major element composition of all absorbing layers interposed between the source and the detector body should be known [n-layer, Al (or Be) window, polythene or plexiglass holders, etc.].

As to conditions b) and c) : in the long practice at the INW and the KFKI, dealing with a large variety of samples with different physical and chemical structure, not any insuperable situation has been encountered which was obstructing application of the ε_p-conversion. The reason is, of course, obvious : many samples - biological, environmental, geological, etc. - are composed of low-Z elements, and the exact knowledge of the major element composition is

thus far from critical; in other cases, e.g. trace element determination in high-purity metals, no problem exists at all. In fact, the problem differs in nothing from the situation in relative standardization where the standard should be matched to the sample.

Much more serious is condition a) : the use of a cylindrical detector with known geometric parameters. The geometric parameters are specified in the detector's measuring certificate, information sheet or test report provided by the manufacturer. If the dimensions of the p-core or coaxial cavity are not quoted, one can safely assume the following figures : height p-core or cavity/height detector = 0.63 and diameter p-core or cavity/diameter detector = 0.22. These ratios are averages of some 10 detectors studied, and the extreme divergences from the average were not larger than $\pm$ 15%, thus fulfilling the condition mentioned above sub a). Nevertheless, notwithstanding this observation, this does not give an answer to the crucial questions : can the cylindricity of the detector be assumed, and are the measures quoted for the detector diameter, n-layer thickness and window-detector separation sufficiently accurate so as to achieve an accurate ε_p-conversion ? These topics will be dealt with below.

2.3. Accuracy and error propagation

The accuracy of the above outlined ε_p-conversion procedure, based on the geometric parameters as quoted by the manufacturer, has been tested extensively for several Ge(Li) and HPGe detectors by measuring point, disk and cylinder sources (with coincidence-free gamma-lines) at different detector distances down to the top of the detector [LIN81, MOENS81/81A/82/83]. This comes to the investigation of the validity of Eq. (III.2-2) written as :

$$\left(\frac{\varepsilon_p^{geo}}{\varepsilon_p^{ref}}\right)_{exp.} = \left(\frac{\bar{\Omega}^{geo}}{\bar{\Omega}^{ref}}\right)_{calc.} \qquad \text{(III.2-4)}$$

It was proved that from $\sim$ 80 keV (^{170}Tm) to $\sim$ 1800 keV (^{28}Al) the accuracy of the conversion is generally better than $\sim$ 2%, even for high (i.e. close-in) counting geometries.

Evidently, it would be dangerous to generalize these findings, and for every detector the validity and accuracy of the ε_p-conversion should be examined. If a detector is put into operation, it is strongly recommended to test the ε_p-conversion by counting some coincidence-free point sources (from low to high E_γ) at large (e.g. reference) and small distance to the detector. Systematic differences between the measured ε_p- and the calculated $\bar{\Omega}$-ratios [Eq. (III.2-4)] can then be easily eliminated by a trial-and-error adjustment of the specified detector parameters which are most critical : detector diameter, n-layer thickness and window-detector separation. An example of such an adjustment is shown in Table III.2-1 for Ge(Li)detector MK7 (see II.2.1), based on measurement of point sources at 1.29 cm and 16.37 cm (reference) detector distance. As seen, introduction of a value of 1000 µm for the n-layer thickness, as it was specified by the manufacturer, leads to systematic negative ($\bar{\Omega}^{1.29}/\bar{\Omega}^{16.37}$ versus $\varepsilon_p^{1.29}/\varepsilon_p^{16.37}$)-discrepancies which are becoming more serious at low gamma-energy. Finally, assuming a n-layer thickness of 300 µm reduces the discrepancies to maximum 2%, which is now a satisfactory situation.

TABLE III.2-1 : Adjustment of the value of the n-layer thickness [Ge(Li) detector MK7] based on comparison of calculated and experimentally determined efficiency ratios for "coincidence-free" point sources (measured at 1.29 and 16.37 cm detector distances) with a broad gamma-energy range

Isotope	E_γ,keV	measured $\varepsilon_p^{1.29}/\varepsilon_p^{16.37}$	n-layer(specified)=1000µm		n-layer(assumed)=300µm	
			$\bar{\Omega}^{1.29}/\bar{\Omega}^{16.37}$	Δ,%	$\bar{\Omega}^{1.29}/\bar{\Omega}^{16.37}$	Δ,%
^{241}Am	59.5	43.94	34.33	- 21.9	43.06	- 2.0
^{57}Co	122.1	42.96	41.10	- 4.3	42.87	- 0.2
	136.5	41.70	40.51	- 2.9	41.84	+ 0.3
^{51}Cr	320.1	34.48	33.52	- 2.8	33.79	- 2.0
^{137}Cs	661.6	34.13	33.88	- 0.7	33.99	- 0.4
^{54}Mn	834.8	33.75	33.66	- 0.3	33.83	+ 0.2
^{28}Al	1778.9	32.25	32.30	- 0.2	32.42	+ 0.5

In the context of the applicability of the ε_p-conversion procedure, it should be realized that the above mentioned conditions a) - c) (III.2.2), being rather stringent with respect to the conversion itself, are to be softened in actual activation analysis, for the following reasons :

- As it will be outlined in Chapter IV, the formulae for true-coincidence correction of N_p contain ε_p^{geo} [given by Eq. (III.2-2)], the uncertainty of which, however, is considerably reduced. In the worst case, for measurements on top of a large Ge-detector, the error reduction factor is still ≥ 3 ;
- In the formulae for f- and α-determination (see Chapter V), and also for k_0 and concentration calculation [Eqs (I.3-18) - (I.3-21)], only ε_p-ratios are involved. For instance in Eqs (I.3-20) and (I.3-21) one has to introduce :

$$\varepsilon_{p,m}^{geo}/\varepsilon_{p,a}^{geo} = (\varepsilon_{p,m}^{ref}/\varepsilon_{p,a}^{ref}) \cdot (\bar{\Omega}_m^{geo}/\bar{\Omega}_m^{ref})/(\bar{\Omega}_a^{geo}/\bar{\Omega}_a^{ref}) \qquad \text{(III.2-5)}$$

If the monitor is counted as a quasi-point source at the reference position, $\bar{\Omega}_m^{geo}/\bar{\Omega}_m^{ref} \simeq 1$ with negligible uncertainty, and only the uncertainty on $\bar{\Omega}_a^{geo}/\bar{\Omega}_a^{ref}$ plays a role (see above). It is, however, strongly recommended to count the monitor at the same distance to the detector as the sample. Then, the uncertainty on the $(\bar{\Omega}_m^{geo}/\bar{\Omega}_m^{ref})/(\bar{\Omega}_a^{geo}/\bar{\Omega}_a^{ref})$-ratio is reduced with at least a factor 4 as compared to the uncertainty on $\bar{\Omega}_a^{geo}/\bar{\Omega}_a^{ref}$, depending on the difference in gamma-energies between m and a. This is illustrated in Fig. III.2-1. For the analyte (a) being a point-source, emitting 100, 500 and 2000 keV gamma's, measured at distances to detector MK7 ranging from 1.29 cm to 31.4 cm, it shows the errors induced on both $\bar{\Omega}_a^{geo}/\bar{\Omega}_a^{ref}$ and $(\bar{\Omega}_m^{geo}/\bar{\Omega}_m^{ref})/(\bar{\Omega}_a^{geo}/\bar{\Omega}_a^{ref})$ [with m being a ^{198}Au point source (411.8 keV); ref = 16.37 cm] by an error as large as 1 mm on these distances (caused by a 1 mm error on the window-detector separation specified by the manufacturer). The reduced errors in the second situation prove the advantage of measuring monitor and sample (even when bulky) at the same distance to the detector. Otherwise said, it is clear that the requirements with respect to the detector (cylindricity, etc.) are then far from critical (see also MOENS81).

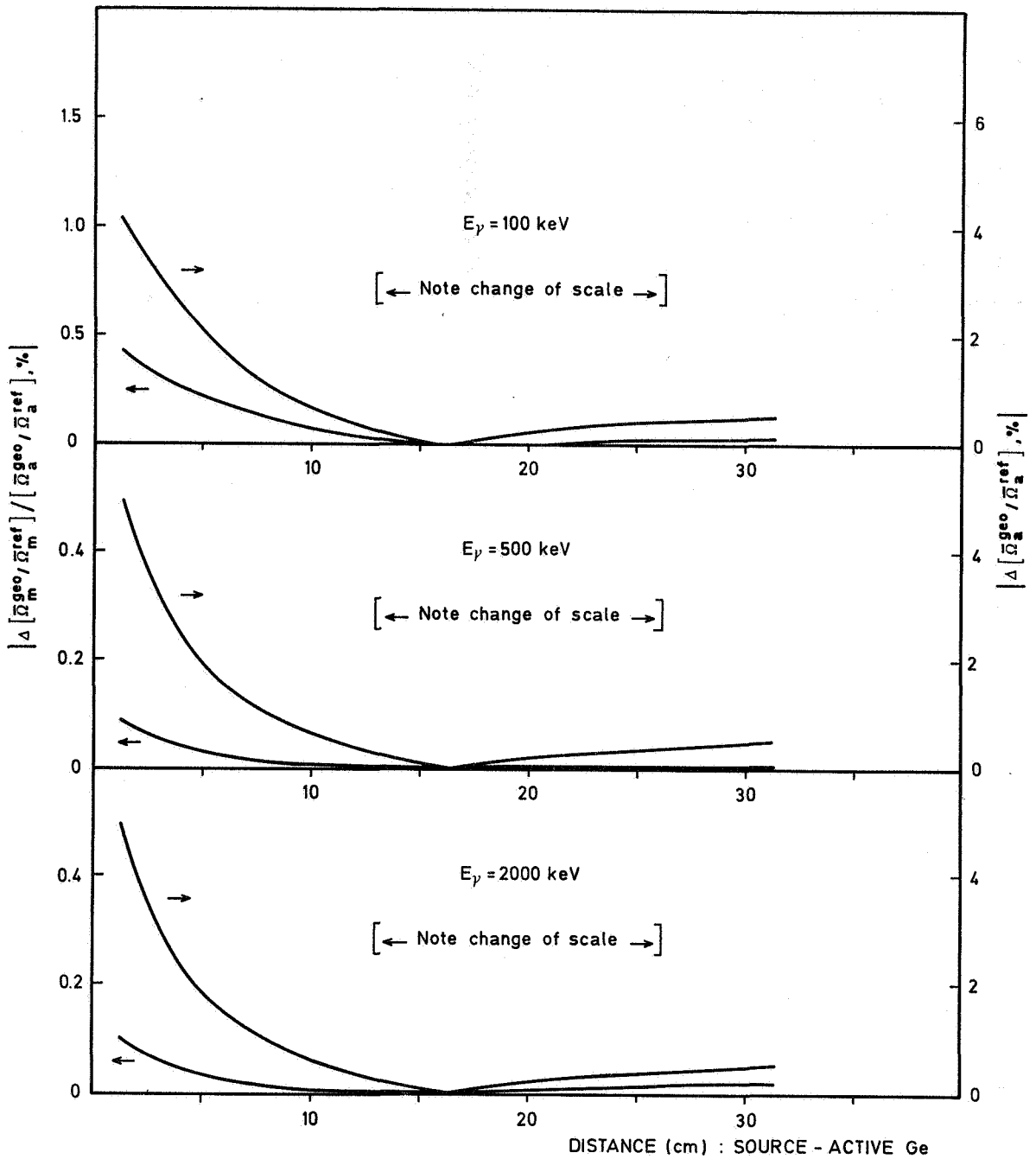

Fig. III.2-1 : Errors induced on the efficiency conversion for 100, 500 and 2000 keV gamma's by a 1 mm error on the assumed window-detector separation (MK7).
$|\Delta[\bar{\Omega}_a^{geo}/\bar{\Omega}_a^{ref}],\%|$ refers to a quasi-point sample (analyte) measured at "geo" position (ranging from 1.29 cm to 31.4 cm detector distance) and a quasi-point monitor measured at "ref" position (^{198}Au 411.8 keV ; "ref" = 16.37 cm) ;
$|\Delta[(\bar{\Omega}_m^{geo}/\bar{\Omega}_m^{ref})/(\bar{\Omega}_a^{geo}/\bar{\Omega}_a^{ref})],\%|$ refers to counting of both sample and monitor at "geo" position.

2.4. Need for cylindric Ge-detectors with well-defined geometric parameters

It goes without arguing that, with respect to the instrumentation, the best solution is to have at one's disposal a Ge-detector approaching as close as possible a cylindrical shape and with an accurately specified geometric configuration. Since 1981, efforts have been made to convince manufacturers about the need of this type of detectors. This campaign involved a INW/KFKI-Report [DECORTE81] sent to the different firms, a paper by Moens and Debertin [MOENS85] in the framework of the International Committee for Radionuclide Metrology, and a good deal of discussions with company-representatives. Attention was paid not only to NAA, but to other applications as well, e.g. neutron metrology, isotope production, environmental radioactivity monitoring, etc. Some further arguments were :

- flexibility of ε_p^{geo}-determination with respect to gamma-energy, source-detector distance, and source composition and dimensions ;
- simplicity of ε_p^{geo}-determination, which is experimentally only based on measurement of an ε_p^{ref}-curve (from counting of calibrated point sources at large detector distance) ;
- accuracy of a calculated ε_p^{geo}-curve (versus E_γ) when compared to experimental determination; in the latter case, the curve is based on a limited number of calibration points from measurement of "coincidence-free" sources with extended geometry, the preparation of which is a laborious task ;
- excellent suitability for programming on a computer.

Obviously, these efforts were fruitful, since cylindrical detectors with specified dimensions are nowadays available at a price hardly exceeding that for other detectors of comparable quality.

2.5. Isolated correction for gamma-attenuation

As mentioned in III.2.1, correction for gamma-attenuation, based on the assumption that the gammas pass the source and enter the absorbers in a direction normal to the detector face, turns out to fail to more or less extent especially for low gamma-energies and close-in geometries. Therefore, the correction is included in the above outlined ε_p-conversion procedure (see III.2.3).

Only in case of moderate to high-energy gamma emitters, measured as quasi-point sources at reference distance to the detector, can the correction for gamma-attenuation be isolated from the efficiency conversion, thus yielding :

$$\varepsilon_p^{geo} = \varepsilon_p^{ref} \cdot F_{att} \qquad \text{(III.2-6)}$$

where, it should be stressed, "geo" refers to a quasi-point source (a wire, foil or cylinder of very small dimensions), causing gamma-attenuation and measured at reference position.

The relevant correction formulae are [DIXON51] :

- small foil or cylinder, base facing to the detector :

$$F_{att} = \frac{1}{\mu h} (1-e^{-\mu h}) \qquad \text{(III.2-7)}$$

with μ = linear absorption coefficient (cm^{-1}) ;
h = thickness of foil or height of cylinder (cm).

- small cylindrical wire, axis parallel with detector face :

$$F_{att} = 1 - \frac{8}{3\pi} \mu r + \frac{1}{2} (\mu r)^2 - \frac{32}{45\pi} (\mu r)^3 + \ldots \qquad \text{(III.2-8)}$$

with r = radius of wire (cm).

It should be mentioned that this type of isolated correction is common practice in relative standardization, where the standard and the sample - although counted in the same geometric configuration - may have a different composition and density and hence exhibit a different gamma-attenuation. As said above, this leads to inaccuracies in case of low gamma-energies and/or small source-detector separations. The only correct way is then to incorporate the gamma-attenuation correction in an ε_p-conversion, as done in the present work.

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CHAPTER IV

CORRECTION FOR TRUE-COINCIDENCE EFFECTS

1. FUNDAMENTALS

1.1. Survey of analytically relevant true-coincidence effects and corrections

In general, true-coincidence effects occur when two or more cascading radiations - emitted in the decay of a radionuclide with negligible time delay - give rise to a total or partial energy deposition in the Ge-crystal. The special situation of "delayed gamma-gamma emission", i.e. of gamma's emitted in the same nuclear decay but separated in time due to an intermediate nuclear state of finite lifetime, will be discussed in IV.2.4.

Table IV.1-1 gives a survey of the analytically relevant true-coincidence effects in case of gamma-ray measurements performed on pseudo-coaxial Ge(Li) or p-type HPGe detectors (well-type excluded), for which the detection efficiency curve has a similar shape as shown in Figs III.1-1 and III.1-2. Such detectors are for instance : ORTEC "HPGe Coax (GEM series)" ; PGT "Ge(Li) Coax" or "Intrinsic Coax" ; CANBERRA "Coaxial Ge" [see respective catalogues]. Coincidence effects with β-rays (assumed to be absorbed before they can reach the sensitive detector body) or with bremsstrahlung are considered to be negligible. It should be realized that the considerable bremsstrahlung observed in gamma-ray spectra of ^{42}K, ^{66}Cu, ^{70}Ga, ^{142}Pr, etc. is mainly caused by a high-energy β^--transition to the ground state, which is thus not coincident with any gamma-emission. In the daily practice of multi-element neutron activation analysis, gamma-rays measured with the above mentioned detector types (i.e. gamma-rays A in Table IV.1-1) are to be regarded as analytically important only if their energy is higher than ∿ 100 keV. The main reasons for this are the presence of the accumulated high Compton "background" from high-energy photons and the considerable decrease of the detection efficiency below ∿ 100 keV photon energy (see Figs III.1-1 and III.1-2) due to the presence of attenuating layers (diffused n-type contact, Al-window). The latter effect also makes that only cascading gamma- or KX-rays with an energy higher than 50-60 keV can cause

TABLE IV.1-1 : Survey of analytically relevant true-coincidence effects. The full-energy peak area (N_p) of emitted gamma-ray A ($E_\gamma \gtrsim 100$ keV) is measured with a pseudo-coaxial Ge-detector [conventional Ge(Li) or p-type HPGe; well-type excluded]

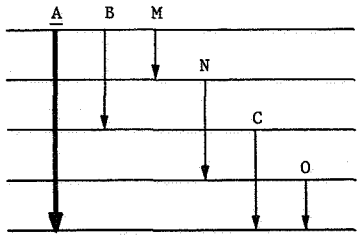
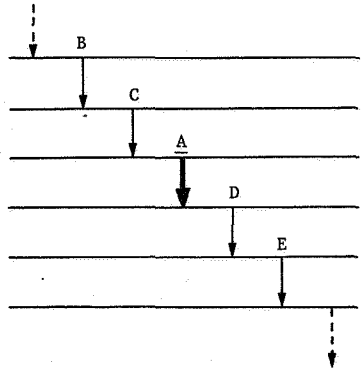
DECAY SCHEME	EFFECT	NOTES
	I. γ-γ COINCIDENCE SUMMING increase of $N_{p,A}$ due to total-energy deposition of the emitted cascading gamma-rays B+C and M+N+O	1. the effect can only be significant if the energy of all cascading gamma-rays (in the cascades B+C or M+N+O) is higher than 50-60 keV (see text); 2. for analytically interesting gamma-rays A, the effect caused by triple cascades is in many cases negligible, and quadruple and higher order cascades should not be taken into account at all.
	II. γ-γ COINCIDENCE LOSS decrease of $N_{p,A}$ due to total- or partial-energy deposition of the emitted gamma-rays ---B-C and D-E---	1. a cascading gamma-ray (--B,C,D,E--) can only cause a significant effect if its energy is higher than 50-60 keV (see text); 2. in principle, any physically possible energy deposition originating from an emitted cascading photon causes a decrease of $N_{p,A}$, i.e. counts in : full-energy peak, Compton continuum, single and double escape peaks, backscatter peak, 511 keV peak (in-scattering of 511 keV photons following external pair production), X-ray peaks from surrounding materials (especially Pb KX-rays), Ge KX escape peak, etc.; 3. possible sequences are : --A-B-C-D-E--, --B-A-C-D-E--, --B-C-A-D-E-- (shown), --B-C-D-A-E--, and B-C-D-E-A--; for analytically interesting gamma-rays A, the effect caused by gamma-ray cascades with more than five components (including A) is generally negligible.

TABLE IV.1-1 : continued

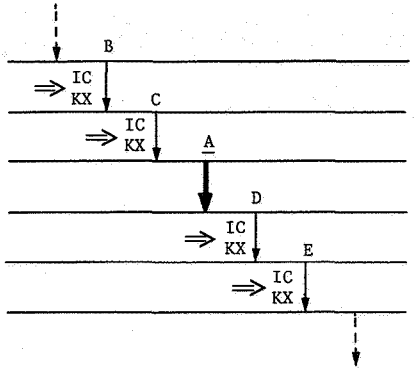
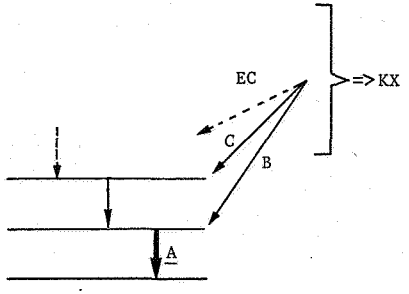
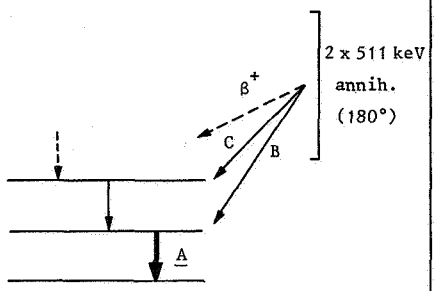
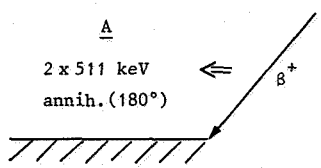
DECAY SCHEME	EFFECT	NOTES
	III. γ-KX(IC) COINCIDENCE LOSS decrease of $N_{p,\underline{A}}$ due to total or partial energy deposition of emitted cascading KX-rays --KX(B)-KX(C) and KX(D)-KX(E)---, which are following internal conversion (IC) of ---B,C,D,E---	1. the effect can only be significant for KX-rays with an energy higher than 50-60 keV (see text), i.e. for $Z \geqslant 70$ (from ^{175}Hf onwards); 2. cf. note II.2; 3. other sequences are possible; cf. note II.3.
	IV. γ-KX(EC) COINCIDENCE LOSS decrease of $N_{p,\underline{A}}$ due to total or partial energy deposition of emitted cascading X-rays KX(EC,B), KX(EC,C)--, which are following electron capture (EC)	1. cf. note III.1; 2. cf. note II.2; 3. among the analytically important radionuclides, this effect should only be considered for ^{175}Hf and ^{185}Os.

TABLE IV.1-1 : continued

DECAY SCHEME	EFFECT	NOTES
	V. γ-511 keV (β^+) COINCIDENCE LOSS decrease of $N_{p,\underline{A}}$ due to total or partial energy deposition of emitted 511 keV annihilation radiation, which is following β^+-decay (B,C,---)	1. except for well-type detectors, only one of both 511 keV annihilation photons (emitted at 180°) can cause a decrease of $N_{p,\underline{A}}$ (reasonably assuming that annihilation occurs completely in an external absorber); 2. cf. note II.2; 3. among the analytically interesting radionuclides/ gamma-rays, this effect occurs only in a few cases (e.g. for the 121.8 keV and 244.7 keV ^{152}Eu-lines), but in general it is negligible.
	VI. 511 keV (β^+) - 511 keV (β^+) COINCIDENCE LOSS none	1. except for well-type detectors; 2. the "undetected" 511 keV photon gives a small secondary energy deposition (backscatter peak, X-rays produced in surrounding materials); it can be reasonably assumed that this results in a negligible decrease of $N_{p,\underline{A}}$; 3. only considered for ^{64}Cu.

a significant coincidence effect, as mentioned in the "Notes" of Table IV.1-1. Eventually, it should be remarked that the different types of coincidence, headed as I, II, III, etc. in Table IV.1-1, can occur simultaneously. For instance, A can be subject to γ-γ coincidence summing (I), leading on the one side to an increase of $N_{p,A}$, and can further be in a cascade with other emitted gamma-rays (II) and/or KX-rays (III), leading on the other hand to γ-γ and/or γ-KX(IC) coincidence losses and thus to a decrease of $N_{p,A}$.

In classical relative NAA, the sample and the coirradiated standards are measured at the same source-detector separation. Hence, any true-coincidence effect is cancelled in the equation for concentration calculation, i.e. in the $N_{p,a}/N_{p,s}$-ratio [Eqs (I.3-3) and (I.3-4)]. This is however not the case in the k_0-standardization technique (or in any absolute or single-comparator method showing versatility with respect to the counting conditions), where the $N_{p,a}$ and $N_{p,m}$ values should be corrected for true-coincidence effects [cf. Eqs (I.3-20) and (I.3-21)].

The general treatment of correction for γ-γ coincidence summing and loss has previously been dealt with in great detail by Andreev et al. [ANDREEV72, ANDREEV73] and by Moens et al. [MOENS81, MOENS82].

The formulae given by Andreev et al. have been rewritten by McCallum et al. [McCALLUM75], who included the case of γ-511 keV(β^+) coincidence loss and applied it to the ^{22}Na 1274.5 keV line, where 90.5% of this transition is fed by β^+-decay. Debertin et al. [DEBERTIN79] have experimentally checked Andreev's solution for the relevant gamma-lines of ^{60}Co, ^{88}Y and ^{152}Eu for point-source and "beaker" (i.e. cylinder) geometries close to the detector; the agreement between experimental and calculated correction factors was usually better than 2% and never exceeded 5%. These authors also reported to have incorporated γ-X(IC) and γ-X(EC) coincidence summing, without revealing, however, any detail. Although the original formulae of Andreev et al. include angular correlation effects, McCallum et al., Debertin et al. and Moens et al. have pointed out that the contribution of these effects to the correction is much smaller than the uncertainty on this correction, thus making it not worthwile to add this extra complexity to the calculations.

Unlike Andreev's solution, the method of Moens et al. requires (among other parameters) gamma-intensities, and not beta-intensities, as input data. Its accuracy has been experimentally checked for the relevant gamma-lines of

^{60}Co, ^{110m}Ag [MOENS81, MOENS82] and ^{72}Ga [LIN81] for point-source geometries at 3 detector distances, including measurement on top of the detector; the agreement between experimental and calculated correction factors was completely comparable to Debertin's findings mentioned above. The solution given by Moens et al., presently being generalized and updated, is adopted in the present work. In the following, it is only presented as a practical guideline for users. Note that in all expressions the peak and total detection efficiencies (ε_p or ε_t) refer to the geometrical counting configuration on hand (i.e. ε_p^{geo} and ε_t^{geo}).

1.2. γ-γ coincidence summing (see Table IV.1-1)

The probability for γ-γ coincidence summing $\underline{A} = B + C$ is given by :

$$S(\underline{A}=B+C) = \frac{\gamma_B}{\gamma_A} a_C c_C \frac{\varepsilon_{p,B}\, \varepsilon_{p,C}}{\varepsilon_{p,A}} \qquad \text{(IV.1-1)}$$

with γ = absolute gamma-intensity ;

a = branching ratio ;

c = $1/(1+\alpha_t)$; α_t = total internal conversion coefficient ($=\alpha_K+\alpha_L+...$) ;

ε_p = full-energy peak efficiency.

If other series of cascading gamma-rays are present, e.g. $\underline{A} = M + N + O$, one should consider also :

$$S(\underline{A}=M+N+O) = \frac{\gamma_M}{\gamma_A} a_N c_N a_O c_O \frac{\varepsilon_{p,M}\, \varepsilon_{p,N}\, \varepsilon_{p,O}}{\varepsilon_{p,A}} \qquad \text{(IV.1-2)}$$

leading to the total probability for increase of $N_{p,\underline{A}}$:

$$S(\underline{A}) = S(\underline{A}=B+C) + S(\underline{A}=M+N+O) \qquad \text{(IV.1-3)}$$

[+S(A=...), for other occuring cascading series]

It should be remarked immediately that the sum pulses originating from B+C, etc. are subject to the same true-coincidence losses (γ-γ, γ-KX(IC), etc.) as $\underline{A}$ itself. Thus, the total probability for increase of $N_{p,\underline{A}}$ should be reduced with $L(\underline{A}) \cdot S(\underline{A})$, where $L(\underline{A})$ is the total probability for coincidence loss of $\underline{A}$ (see IV.1.3).

Eqs (IV.1-1) and (IV.1-2) show that, for analytically interesting gamma's (γ_A relatively high), multiplication of the ε_p-terms (which are maximum of the order of 0.2) renders γ-γ coincidence summing caused by triple cascades in many cases negligible, and quadruple and higher order cascades should not be taken into account at all.

1.3. γ-γ and γ-KX(IC) coincidence loss (see Table IV.1-1)

In the present work, the formulae given by Moens et al. [MOENS81] for γ-γ coincidence loss are modified so as to include γ-KX(IC) coincidence loss as well. Both effects have to be treated simultaneously, since they are originating from the same energy transitions. The reasoning to arrive at the expressions for calculating the probability for γ-γ + γ-KX(IC) coincidence loss is similar to the one for γ-γ coincidence loss described by Moens et al., and is demonstrated below for the simple case A-B/KX(B) [see Fig. IV.1-1].

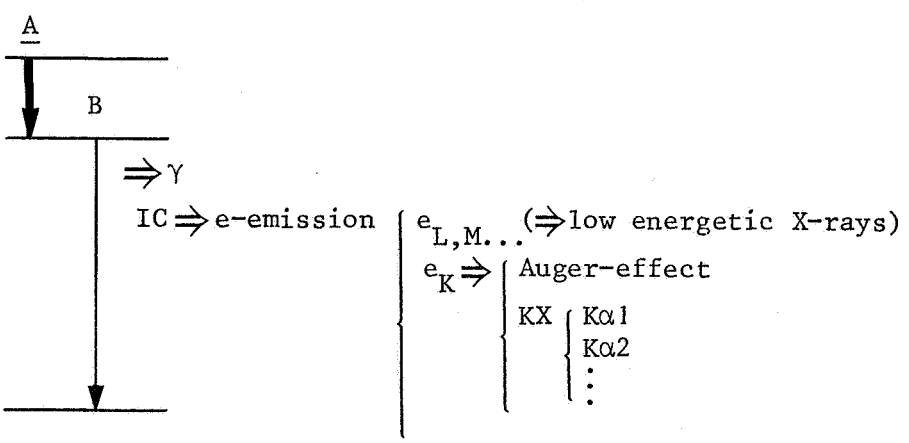


Fig. IV.1-1 : γ-γ plus γ-KX(IC) coincidence loss

The probability for pulse losses of A is the sum of the probabilities for pulse losses caused by γ-γ and γ-KX(IC) coincidence :

$$L(A) = L[A\text{-}B/KX(B)]$$

$$= L(A\text{-}B) + L[A\text{-}K\alpha1(B)] + L[A\text{-}K\alpha2(B)] + \ldots \qquad \text{(IV.1-4)}$$

The partial contributions are derived as :

$L(A\text{-}B)$ = probability that A is followed by transition B ($= a_B$)

x probability that gamma-ray B is emitted ($= c_B = \frac{1}{1+\alpha_{t,B}}$)

x probability that gamma-ray B gives a total or partial energy deposition in the detector ($= \varepsilon_{t,B}$)

$= a_B \, c_B \, \varepsilon_{t,B}$

$L[\underline{A}\text{-K}\alpha 1(B)]$ = probability that $\underline{A}$ is followed by transition B (= a_B)
x probability that a K-electron is emitted (= $c_B\ \alpha_{K,B}$)
x probability that a KX-ray is emitted (= ω_K, fluorescence yield)
x probability that the KX-ray is Kα1 (= kα1, relative emission rate)
x probability that the Kα1-ray gives a total or partial energy deposition in the detector (= $\varepsilon_{t,K\alpha 1}$)
= $a_B\ c_B\ \alpha_{K,B}\ \omega_K\ k\alpha 1\ \varepsilon_{t,K\alpha 1}$

and so on for $L[\underline{A}\text{-K}\alpha 2(B)]$, etc.
Thus, $L(\underline{A})$ is finally :

$$L(\underline{A}) = a_B\ c_B(\varepsilon_{t,B} + \alpha_{K,B}\ \omega_K \sum_i ki\ \varepsilon_{t,Ki}) \qquad \text{(IV.1-5)}$$

with i = α1, α2, etc. It is clear that, when only γ-γ or γ-KX coincidence loss is important, one should drop the right - or left - hand term of the summation between brackets, respectively.

The above reasoning can be extended easily to more complicated cascades, but in practice the contribution from cascades with more than five components (including $\underline{A}$) appears to be always negligible and should thus not be considered. Introducing the notation

$$\Sigma_Y = \varepsilon_{t,Y} + \alpha_{K,Y}\ \omega_K \sum_i ki\ \varepsilon_{t,Ki} \qquad \text{(IV.1-6)}$$

with Y = B, C, D or E, the probabilities for γ-γ plus γ-KX(IC) coincidence loss are given by Eqs (IV.1-7) - (IV.1-11) in Table IV.1-2.

It is easy to derive from Eqs (IV.1-7) - (IV.1-11) the relevant formulae for coincidence loss for cascades with four, three and two components (including $\underline{A}$) by simply dropping the irrelevant terms. Accordingly, for a four-component cascade with $\underline{A}$ as the upper line, one can put $a_E = 0$ in Eq. (IV.1-7), which leads to the same effect as putting $\gamma_B = 0$ in Eq. (IV.1-8); for a three-component cascade with $\underline{A}$ as the middle line, one can put $a_D = a_E = 0$ in Eq. (IV.1-8), or $\gamma_B = a_E = 0$ in Eq. (IV.1-9) or $\gamma_B = \gamma_C = 0$ in Eq. (IV.1-10) ; for a two-component cascade with $\underline{A}$ as the lower line, one can put $a_C = a_D = a_E = 0$ in Eq. (IV.1-8), or $\gamma_B = a_D = a_E = 0$ in Eq. (IV.1-9) or $\gamma_B = \gamma_C = a_E = 0$ in Eq. (IV.1-10) or $\gamma_B = \gamma_C = \gamma_D = 0$ in Eq. (IV.1-11).

Following the method of Moens et al [MOENS81], one should first consider all existing cascades (wherein $\underline{A}$ is included), and then calculate the total probability for loss by summation of the individual contributions. For instance,

TABLE IV.1-2 : Calculation of the probability L(A) for pulse losses of A, caused by γ-γ plus γ-KX(IC) coincidence. Measured gamma A is part of a five-component cascade; the formulae for simpler cascades can be derived by dropping the irrelevant terms (see text)

$$L\,[\,A - B/KX(B) - C/KX(C) - D/KX(D) - E/KX(E)\,]$$

$$= F_1 - F_2 + F_3 - F_4$$

$$F_1 = a_B{}^{c_B}\Sigma_B + a_B{}^{a_C}{}^{c_C}\Sigma_C + a_B{}^{a_C}{}^{a_D}{}^{c_D}\Sigma_D + a_B{}^{a_C}{}^{a_D}{}^{a_E}{}^{c_E}\Sigma_E$$

$$F_2 = a_B{}^{a_C}{}^{c_B}{}^{c_C}\Sigma_B\Sigma_C + a_B{}^{a_C}{}^{a_D}{}^{c_B}{}^{c_D}\Sigma_B\Sigma_D + a_B{}^{a_C}{}^{a_D}{}^{a_E}{}^{c_B}{}^{c_E}\Sigma_B\Sigma_E + a_B{}^{a_C}{}^{a_D}{}^{c_C}{}^{c_D}\Sigma_C\Sigma_D + a_B{}^{a_C}{}^{a_D}{}^{a_E}{}^{c_C}{}^{c_E}\Sigma_C\Sigma_E + a_B{}^{a_C}{}^{a_D}{}^{a_E}{}^{c_D}{}^{c_E}\Sigma_D\Sigma_E$$

$$F_3 = a_B{}^{a_C}{}^{a_D}{}^{c_B}{}^{c_C}{}^{c_D}\Sigma_B\Sigma_C\Sigma_D + a_B{}^{a_C}{}^{a_D}{}^{a_E}{}^{c_B}{}^{c_C}{}^{c_E}\Sigma_B\Sigma_C\Sigma_E + a_B{}^{a_C}{}^{a_D}{}^{a_E}{}^{c_B}{}^{c_D}{}^{c_E}\Sigma_B\Sigma_D\Sigma_E + a_B{}^{a_C}{}^{a_D}{}^{a_E}{}^{c_C}{}^{c_D}{}^{c_E}\Sigma_C\Sigma_D\Sigma_E$$

$$F_4 = a_B{}^{a_C}{}^{a_D}{}^{a_E}{}^{c_B}{}^{c_C}{}^{c_D}{}^{c_E}\Sigma_B\Sigma_C\Sigma_D\Sigma_E$$

(IV.1-7)

$$L\,[\,B/KX(B) - A - C/KX(C) - D/KX(D) - E/KX(E)\,]$$

$$= F_1 - F_2 + F_3 - F_4$$

$$F_1 = \frac{\gamma_B}{\gamma_A}\, a_A{}^{c_A}\Sigma_B + a_C{}^{c_C}\Sigma_C + a_C{}^{a_D}{}^{c_D}\Sigma_D + a_C{}^{a_D}{}^{a_E}{}^{c_E}\Sigma_E$$

$$F_2 = \frac{\gamma_B}{\gamma_A}\, a_A{}^{a_C}{}^{c_A}{}^{c_C}\Sigma_B\Sigma_C + \frac{\gamma_B}{\gamma_A}\, a_A{}^{a_C}{}^{a_D}{}^{c_A}{}^{c_D}\Sigma_B\Sigma_D + \frac{\gamma_B}{\gamma_A}\, a_A{}^{a_C}{}^{a_D}{}^{a_E}{}^{c_A}{}^{c_E}\Sigma_B\Sigma_E + a_C{}^{a_D}{}^{c_C}{}^{c_D}\Sigma_C\Sigma_D + a_C{}^{a_D}{}^{a_E}{}^{c_C}{}^{c_E}\Sigma_C\Sigma_E + a_C{}^{a_D}{}^{a_E}{}^{c_D}{}^{c_E}\Sigma_D\Sigma_E$$

$$F_3 = \frac{\gamma_B}{\gamma_A}\, a_A{}^{a_C}{}^{a_D}{}^{c_A}{}^{c_C}{}^{c_D}\Sigma_B\Sigma_C\Sigma_D + \frac{\gamma_B}{\gamma_A}\, a_A{}^{a_C}{}^{a_D}{}^{a_E}{}^{c_A}{}^{c_C}{}^{c_E}\Sigma_B\Sigma_C\Sigma_E + \frac{\gamma_B}{\gamma_A}\, a_A{}^{a_C}{}^{a_D}{}^{a_E}{}^{c_A}{}^{c_D}{}^{c_E}\Sigma_B\Sigma_D\Sigma_E + a_C{}^{a_D}{}^{a_E}{}^{c_C}{}^{c_D}{}^{c_E}\Sigma_C\Sigma_D\Sigma_E$$

$$F_4 = \frac{\gamma_B}{\gamma_A}\, a_A{}^{a_C}{}^{a_D}{}^{a_E}{}^{c_A}{}^{c_C}{}^{c_D}{}^{c_E}\Sigma_B\Sigma_C\Sigma_D\Sigma_E$$

(IV.1-8)

TABLE IV.1-2 : continued

$L\,[B/KX(B) - C/KX(C) - \underline{A} - D/KX(D) - E/KX(E)]$

$$= F_1 - F_2 + F_3 - F_4$$

$$F_1 = \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{A}{}^{c}{}_{A}{}^{\Sigma}{}_{B} + \frac{\gamma_C}{\gamma_A} a_A{}^{c}{}_{A}{}^{\Sigma}{}_{C} + a_D{}^{c}{}_{D}{}^{\Sigma}{}_{D} + a_D{}^{a}{}_{E}{}^{c}{}_{E}{}^{\Sigma}{}_{E}$$

$$F_2 = \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{A}{}^{c}{}_{C}{}^{c}{}_{A}{}^{\Sigma}{}_{B}{}^{\Sigma}{}_{C} + \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{A}{}^{a}{}_{D}{}^{c}{}_{A}{}^{c}{}_{D}{}^{\Sigma}{}_{B}{}^{\Sigma}{}_{D} + \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{A}{}^{a}{}_{D}{}^{a}{}_{E}{}^{c}{}_{A}{}^{c}{}_{E}{}^{\Sigma}{}_{B}{}^{\Sigma}{}_{E} + \frac{\gamma_C}{\gamma_A} a_A{}^{a}{}_{D}{}^{c}{}_{A}{}^{c}{}_{D}{}^{\Sigma}{}_{C}{}^{\Sigma}{}_{D} + \frac{\gamma_C}{\gamma_A} a_A{}^{a}{}_{D}{}^{a}{}_{E}{}^{c}{}_{A}{}^{c}{}_{E}{}^{\Sigma}{}_{C}{}^{\Sigma}{}_{E} + a_D{}^{a}{}_{E}{}^{c}{}_{D}{}^{c}{}_{E}{}^{\Sigma}{}_{D}{}^{\Sigma}{}_{E}$$

$$F_3 = \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{A}{}^{a}{}_{D}{}^{c}{}_{C}{}^{c}{}_{A}{}^{c}{}_{D}{}^{\Sigma}{}_{B}{}^{\Sigma}{}_{C}{}^{\Sigma}{}_{D} + \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{A}{}^{a}{}_{D}{}^{a}{}_{E}{}^{c}{}_{C}{}^{c}{}_{A}{}^{c}{}_{E}{}^{\Sigma}{}_{B}{}^{\Sigma}{}_{C}{}^{c}{}_{E} + \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{A}{}^{a}{}_{D}{}^{a}{}_{E}{}^{c}{}_{A}{}^{c}{}_{D}{}^{c}{}_{E}{}^{\Sigma}{}_{B}{}^{\Sigma}{}_{D}{}^{\Sigma}{}_{E} + \frac{\gamma_C}{\gamma_A} a_A{}^{a}{}_{D}{}^{a}{}_{E}{}^{c}{}_{A}{}^{c}{}_{D}{}^{c}{}_{E}{}^{\Sigma}{}_{C}{}^{\Sigma}{}_{D}{}^{\Sigma}{}_{E}$$

$$F_4 = \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{A}{}^{a}{}_{D}{}^{a}{}_{E}{}^{\Sigma}{}_{B}{}^{\Sigma}{}_{C}{}^{\Sigma}{}_{D}{}^{\Sigma}{}_{E}$$

(IV.1-9)

$L\,[B/KX(B) - C/KX(C) - D/KX(D) - \underline{A} - E/KX(E)]$

$$= F_1 - F_2 + F_3 - F_4$$

$$F_1 = \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{D}{}^{a}{}_{A}{}^{c}{}_{A}{}^{\Sigma}{}_{B} + \frac{\gamma_C}{\gamma_A} a_D{}^{a}{}_{A}{}^{c}{}_{A}{}^{\Sigma}{}_{C} + \frac{\gamma_D}{\gamma_A} a_A{}^{c}{}_{A}{}^{\Sigma}{}_{D} + a_E{}^{c}{}_{E}{}^{\Sigma}{}_{E}$$

$$F_2 = \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{D}{}^{a}{}_{A}{}^{c}{}_{C}{}^{c}{}_{A}{}^{\Sigma}{}_{B}{}^{\Sigma}{}_{C} + \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{D}{}^{a}{}_{A}{}^{c}{}_{D}{}^{c}{}_{A}{}^{\Sigma}{}_{B}{}^{\Sigma}{}_{D} + \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{D}{}^{a}{}_{A}{}^{a}{}_{E}{}^{c}{}_{A}{}^{c}{}_{E}{}^{\Sigma}{}_{B}{}^{\Sigma}{}_{E} + \frac{\gamma_C}{\gamma_A} a_D{}^{a}{}_{A}{}^{c}{}_{D}{}^{c}{}_{A}{}^{\Sigma}{}_{C}{}^{\Sigma}{}_{D} + \frac{\gamma_C}{\gamma_A} a_D{}^{a}{}_{A}{}^{a}{}_{E}{}^{c}{}_{A}{}^{c}{}_{E}{}^{\Sigma}{}_{C}{}^{\Sigma}{}_{E} + \frac{\gamma_D}{\gamma_A} a_A{}^{a}{}_{E}{}^{c}{}_{A}{}^{c}{}_{E}{}^{\Sigma}{}_{D}{}^{\Sigma}{}_{E}$$

$$F_3 = \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{D}{}^{a}{}_{A}{}^{c}{}_{C}{}^{c}{}_{D}{}^{c}{}_{A}{}^{\Sigma}{}_{B}{}^{\Sigma}{}_{C}{}^{\Sigma}{}_{D} + \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{D}{}^{a}{}_{A}{}^{a}{}_{E}{}^{c}{}_{C}{}^{c}{}_{A}{}^{c}{}_{E}{}^{\Sigma}{}_{B}{}^{\Sigma}{}_{C}{}^{\Sigma}{}_{E} + \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{D}{}^{a}{}_{A}{}^{a}{}_{E}{}^{c}{}_{D}{}^{c}{}_{A}{}^{c}{}_{E}{}^{\Sigma}{}_{B}{}^{\Sigma}{}_{D}{}^{\Sigma}{}_{E} + \frac{\gamma_C}{\gamma_A} a_D{}^{a}{}_{A}{}^{a}{}_{E}{}^{c}{}_{D}{}^{c}{}_{A}{}^{c}{}_{E}{}^{\Sigma}{}_{C}{}^{\Sigma}{}_{D}{}^{\Sigma}{}_{E}$$

$$F_4 = \frac{\gamma_B}{\gamma_A} a_C{}^{a}{}_{D}{}^{a}{}_{A}{}^{a}{}_{E}{}^{c}{}_{C}{}^{c}{}_{D}{}^{c}{}_{A}{}^{c}{}_{E}{}^{\Sigma}{}_{B}{}^{\Sigma}{}_{C}{}^{\Sigma}{}_{D}{}^{\Sigma}{}_{E}$$

(IV.1-10)

TABLE IV.1-2 : continued

$$L[B/KX(B) - C/KX(C) - D/KX(D) - E/KX(E) - \underline{A}]$$

$$= F_1 - F_2 + F_3 - F_4$$

$$F_1 = \frac{\gamma_B}{\gamma_A} a_C a_D a_E a_A c_A \Sigma_B + \frac{\gamma_C}{\gamma_A} a_D a_E a_A c_A \Sigma_C + \frac{\gamma_D}{\gamma_A} a_E a_A c_A \Sigma_D + \frac{\gamma_E}{\gamma_A} a_A c_A \Sigma_E$$

$$F_2 = \frac{\gamma_B}{\gamma_A} a_C a_D a_E a_A c_E c_A \Sigma_B \Sigma_E + \frac{\gamma_B}{\gamma_A} a_C a_D a_E a_A c_D c_A \Sigma_B \Sigma_D + \frac{\gamma_B}{\gamma_A} a_C a_D a_E a_A c_C c_A \Sigma_B \Sigma_C + \frac{\gamma_C}{\gamma_A} a_D a_E a_A c_D c_A \Sigma_C \Sigma_D + \frac{\gamma_C}{\gamma_A} a_D a_E a_A c_E c_A \Sigma_C \Sigma_E + \frac{\gamma_D}{\gamma_A} a_E a_A c_E c_A \Sigma_D \Sigma_E$$

$$F_3 = \frac{\gamma_B}{\gamma_A} a_C a_D a_E a_A c_C c_D c_A \Sigma_B \Sigma_C \Sigma_D + \frac{\gamma_B}{\gamma_A} a_C a_D a_E a_A c_C c_E c_A \Sigma_B \Sigma_C \Sigma_E + \frac{\gamma_B}{\gamma_A} a_C a_D a_E a_A c_D c_E c_A \Sigma_B \Sigma_D \Sigma_E + \frac{\gamma_C}{\gamma_A} a_D a_E a_A c_D c_E c_A \Sigma_C \Sigma_D \Sigma_E$$

$$F_4 = \frac{\gamma_B}{\gamma_A} a_C a_D a_E a_A c_C c_D c_E c_A \Sigma_B \Sigma_C \Sigma_D \Sigma_E$$

(IV.1-11)

In Eqs (IV.1-7) - (IV.1-11) :

$$\Sigma y = \varepsilon_{t,y} + \alpha_{K,y}\, \omega_K \sum_i ki\, \varepsilon_{t,Ki}$$

(y = B, C, D or E), with i = α1, α2, etc.

if the cascades A-B/KX(B)-C/KX(C)-D/KX(D) and A-M/KX(M)-N/KX(N) are present, one obtains :

$$L(A) = L[A\text{-}B/KX(B)\text{-}C/KX(C)\text{-}D/KX(D)] + L[A\text{-}M/KX(M)\text{-}N/KX(N)] \quad \text{(IV.1-12)}$$

In many cases, some smaller "subcascades" (including A) are common to the different cascading series considered, and a proper subtraction should be made so as to count only once their contribution to the coincidence loss. For instance, if the cascading series are B/KX(B)-A - C/KX(C) - D/KX(D), E/KX(E)-A - C/KX(C) - D/KX(D), B/KX(B)-A - F/KX(F) and E/KX(E)-A - F/KX(F), one should write :

$$\begin{aligned} L(A) = {} & L[B/KX(B)\text{-}A - C/KX(C) - D/KX(D)] \\ & + L[E/KX(E)\text{-}A - C/KX(C) - D/KX(D)] \\ & + L[B/KX(B)\text{-}A - F/KX(F)] \\ & + L[E/KX(E)\text{-}A - F/KX(F)] \\ & - L[A\text{-}C/KX(C)\text{-}D/KX(D)] \\ & - L[A\text{-}F/KX(F)] \\ & - L[B/KX(B) - A] \\ & - L[E/KX(E) - A] \end{aligned} \quad \text{(IV.1-13)}$$

Occasionally, this procedure leads to the necessity of adding again extra terms to compensate for the unwanted subtractions. This is for instance the case when the cascading series are B/KX(B)-A - C/KX(C), B/KX(B)-A - D/KX(D), B/KX(B)-A - E/KX(E) - F/KX(F), B/KX(B)-A - E/KX(E) - G/KX(G), H/KX(H)-A - C/KX(C), H/KX(H)-A - D/KX(D), H/KX(H)-A - E/KX(E) - F/KX(F) and H/KX(H)-A - E/KX(E) - G/KX(G), where one obtains :

$$\begin{aligned} L(A) = {} & L[B/KX(B)\text{-}A - C/KX(C)] \\ & + L[B/KX(B)\text{-}A - D/KX(D)] \\ & + L[B/KX(B)\text{-}A - E/KX(E) - F/KX(F)] \\ & + L[B/KX(B)\text{-}A - E/KX(E) - G/KX(G)] \\ & + L[H/KX(H)\text{-}A - C/KX(C)] \\ & + L[H/KX(H)\text{-}A - D/KX(D)] \\ & + L[H/KX(H)\text{-}A - E/KX(E) - F/KX(F)] \\ & + L[H/KX(H)\text{-}A - E/KX(E) - G/KX(G)] \\ & - L[A - E/KX(E) - F/KX(F)] \\ & - L[A - E/KX(E) - G/KX(G)] \\ & - L[A - C/KX(C)] \\ & - L[A - D/KX(D)] \end{aligned}$$

$$
\begin{aligned}
&- L[B/KX(B)-\underline{A} - E/KX(E)] \\
&- L[H/KX(H)-\underline{A} - E/KX(E)] \\
&- 2L[B/KX(B)-\underline{A}] \\
&- 2L[H/KX(H)-\underline{A}] \\
&+ L[\underline{A} - E/KX(E)]
\end{aligned}
\qquad \text{(IV.1-14)}
$$

1.4. γ-KX(EC) coincidence loss (see Table IV.1-1)

Since the effect can only be significant for KX-rays with an energy higher than 50-60 keV (i.e. for $Z \gtrsim 70$), it has only to be considered for the analytically interesting radionuclides ^{175}Hf and ^{185}Os.

a. The situation for the ^{175}Hf 343.6 keV gamma-line is illustrated in Fig. IV.1-2, where irrelevant transitions are omitted. Note that the indices β'1 and β'2 refer to β1 + β3 + β5 and β2 + β4(+...), respectively.

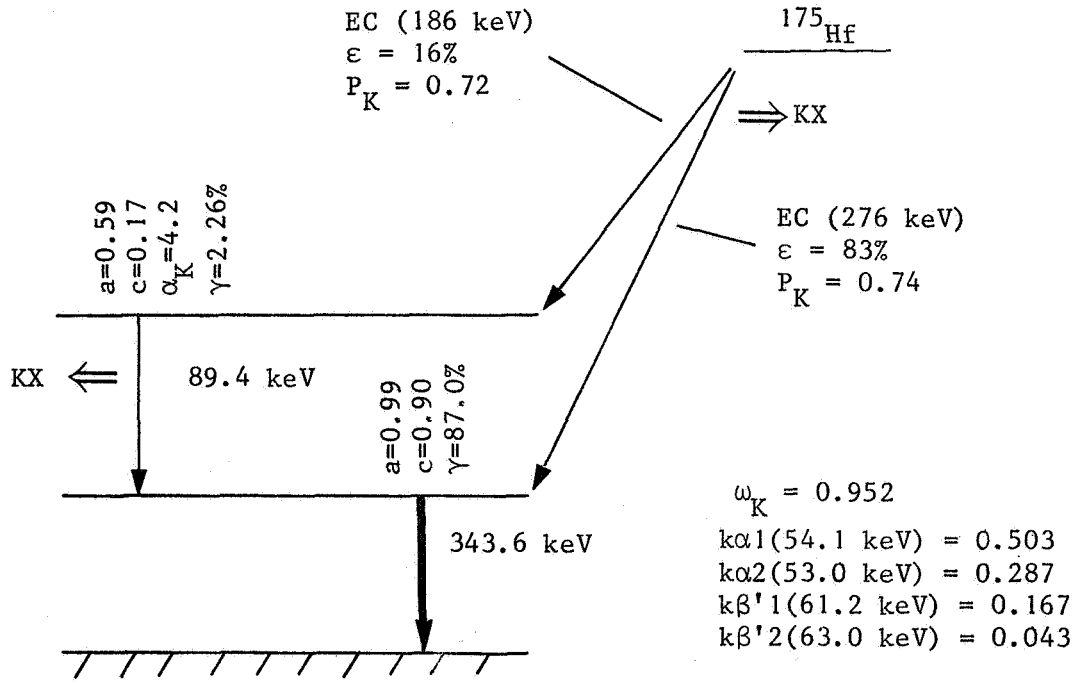


Fig. IV.1-2 : γ-KX(EC) coincidence loss for the ^{175}Hf 343.6 keV gamma-line

The contributions to coincidence loss are the following :

1. $L[KX(EC276) - \underline{343.6}]$

The partial coincidence losses are :

$L[K\alpha1(EC276) - \underline{343.6}]$ = probability that the 343.6 keV γ-line is preceeded by

EC276 $\left(= \frac{\varepsilon_{276}}{\varepsilon_{276}+a_{89.4}\varepsilon_{186}} = 0.90\right)$

x probability that EC276 is K electron capture ($= P_{K,276} = 0.74$)

x probability that a KX-ray is emitted ($= \omega_K = 0.952$)

x probability that the KX-ray is Kα1 ($= k\alpha1 = 0.503$)

x probability that the Kα1-ray gives a total or partial energy deposition in the detector ($= \varepsilon_{t,K\alpha1}$) (IV.1-15)

and similarly for $L[K\alpha2(EC276) - \underline{343.6}]$, etc.

Thus :

$$L[KX(EC276) - \underline{343.6}] = \frac{\varepsilon_{276}}{\varepsilon_{276}+a_{89.4}\varepsilon_{186}} \cdot P_{K,276}\cdot\omega_K \sum_i ki\ \varepsilon_{t,Ki} \qquad \text{(IV.1-16)}$$

with i = $\alpha1$, $\alpha2$, etc.

2. $L[KX(EC186) - 89.4/KX(89.4) - \underline{343.6}]$

Analogously as above, and taking into account the fact that there is now a cascade with three components (cf. MOENS81), one obtains :

$L[KX(EC186)-89.4/KX(89.4)-\underline{343.6}]$ =

$$\frac{a_{89.4}\varepsilon_{186}^{(*)}}{\varepsilon_{276}+a_{89.4}\varepsilon_{186}} \cdot P_{K,186}\ \omega_K \sum_i ki\ \varepsilon_{t,Ki}$$

$$+ \frac{\gamma_{89.4}}{\gamma_{343.6}}\ a_{343.6}\ c_{343.6}\ \Sigma_{89.4}$$

$$- \frac{\gamma_{89.4}}{\gamma_{343.6}}\ a_{343.6}\ c_{343.6}\ \Sigma_{89.4}\ P_{K,186}\ \omega_K \sum_i ki\ \varepsilon_{t,Ki} \qquad \text{(IV.1-17)}$$

(*) *the probability that the 343.6 keV γ-line is preceeded by EC186 is also given by* $\frac{\gamma_{89.4}}{\gamma_{343.6}}\ \frac{a_{343.6}c_{343.6}}{c_{89.4}} = 0.14$. *This is significantly different from the 0.10 value obtained from* $\frac{a_{89.4}\varepsilon_{186}}{\varepsilon_{276}+a_{89.4}\varepsilon_{186}}$, *thus revealing an inconsistency of the nuclear data.*

Finally, the total probability for coincidence loss is :

$$L(\underline{343.6}) = L[KX(EC276)-\underline{343.6}] + L[KX(EC186)-89.4/KX(89.4)-\underline{343.6}] \qquad (IV.1-18)$$

b. It is now easy to calculate immediately the coincidence loss for the ^{185}Os 646.1 keV gamma-line (see Fig. IV.1-3), for which the probability that it is preceeded by EC369 can be put equal to 1. Thus one obtains [cf. Eq. (IV.1-16)] :

$$L(\underline{646.1}) = L[KX(EC369) - \underline{646.1}] = P_{K,369}\ \omega_K \sum_i ki\ \varepsilon_{t,Ki} \qquad (IV.1-19)$$

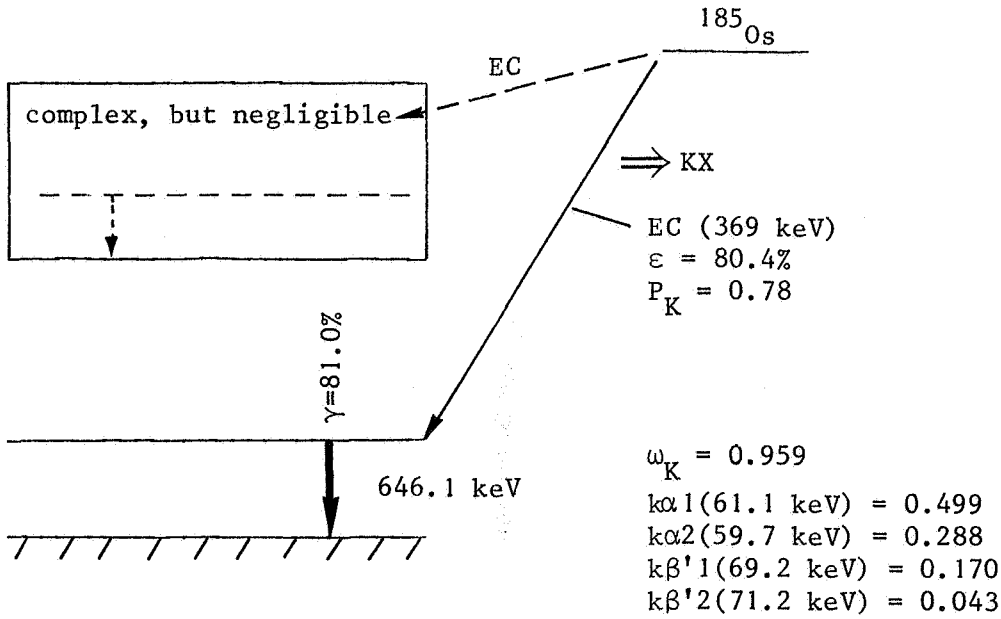


Fig. IV.1-3 : γ-KX(EC) coincidence loss for the ^{185}Os 646.1 keV gamma-line

2. CORRECTION OF MEASURED PEAK AREA

2.1. General formula

After calculating the total probabilities for coincidence summing [S(A)] and coincidence loss [L(A)], the observed number of counts ($N'_{p,A}$) in the full-energy peak of gamma-ray A can be expressed as :

$$N'_{p,A} = N_{p,A} - L(\underline{A})N_{p,A} + S(\underline{A})N_{p,A} - L(\underline{A})S(\underline{A})N_{p,A} \qquad (IV.2-1)$$

Thus, the correct number of counts ($N_{p,A}$), originating from emission of A, is given by :

$$N_{p,A} = \frac{N'_{p,A}}{COI} \qquad \text{(IV.2-2)}$$

with the coincidence correction factor COI defined as :

$$COI = [1 - L(A)][1 + S(A)] \qquad \text{(IV.2-3)}$$

2.2. Criteria for relevancy of true-coincidence effects

According to the above outlined procedure, one should - for each analytically interesting gamma-line of a given radionuclide - scrutinize the decay scheme and tabulate the relevant data (a, c, γ, α_K, etc.) for all observed cascading transitions as γ-γ (summing and loss), γ-KX(IC) and γ-KX(EC). However, in many cases the contribution to the coincidence effect is negligible. As mentioned earlier, this is in general so for cascading gamma- and X-rays with an energy below 50-60 keV, for γ-γ coincidence summing of quadruple or higher order cascades, and for γ-γ and γ-KX(IC) coincidence loss with cascades of more than 5 components (including the gamma-line considered). Other criteria to accept or reject particular contributions are given below.

1. γ-γ coincidence summing.

   For A = B+C [see Eq. (IV.1-1)], one should reject cases with $\frac{\gamma_B}{\gamma_A} a_c c_c < 0.01$, i.e. with less than 1% contribution to S(A). Analogously, for A = M+N+O [see Eq. (IV.1-2)], one should reject cases with $\frac{\gamma_M}{\gamma_A} a_N c_N a_O c_O < 0.01$. By not involving the ε_p-terms in this criterium, it is guaranteed that all contributions higher than 0.2% are taken into account.

2. γ-γ coincidence loss.

   Since generally ε_t is not exceeding a value of 0.2, the F_1-terms are dominant in Eqs (IV.1-7) - (IV.1-11), and are thus the only ones to be considered. Next, so as to examine the relevancy of γ-γ coincidence loss

only, one should drop in the F_1-terms the γ-KX(IC) contribution, by putting $\alpha_{K,Y} = 0$ in Eq. (IV.1-6). Then, the criteria for rejection are as follows :

a. in the cascade A-B-C-D-E :

if $a_B a_C a_D a_E c_E < 0.01$, cancel the E term ;

if, in addition, $a_B a_C a_D c_D < 0.01$, cancel the D-E terms ;

if, in addition, $a_B a_C c_C < 0.01$, cancel the C-D-E terms ;

if, in addition, $a_B c_B < 0.01$, cancel the B-C-D-E terms, i.e. A is practically coincidence-free.

b. in the cascade B-A-C-D-E :

if $a_C a_D a_E c_E < 0.01$, cancel the E term ;

if, in addition, $a_C a_D c_D < 0.01$, cancel the D-E terms ;

if, in addition, $a_C c_C < 0.01$, cancel the C-D-E terms ;

if $\frac{\gamma_B}{\gamma_A} a_A c_A < 0.01$, cancel the B term.

c. in the cascade B-C-A-D-E :

if $a_D a_E c_E < 0.01$, cancel the E term ;

if, in addition, $a_D c_D < 0.01$, cancel the D-E terms ;

if $\frac{\gamma_B}{\gamma_A} a_C a_A c_A < 0.01$, cancel the B term ;

if, in addition, $\frac{\gamma_C}{\gamma_A} a_A c_A < 0.01$, cancel the B-C terms.

d. in the cascade B-C-D-A-E :

if $a_E c_E < 0.01$, cancel the E term ;

if $\frac{\gamma_B}{\gamma_A} a_C a_D a_A c_A < 0.01$, cancel the B term ;

if, in addition, $\frac{\gamma_C}{\gamma_A} a_D a_A c_A < 0.01$, cancel the B-C terms ;

if, in addition, $\frac{\gamma_D}{\gamma_A} a_A c_A < 0.01$, cancel the B-C-D terms.

e. in the cascade B-C-D-E-A :

if $\frac{\gamma_B}{\gamma_A} a_C a_D a_E a_A c_A < 0.01$, cancel the B term ;

if, in addition, $\frac{\gamma_C}{\gamma_A} a_D a_E a_A c_A < 0.01$, cancel the B-C terms ;

if, in addition, $\frac{\gamma_D}{\gamma_A} a_E a_A c_A < 0.01$, cancel the B-C-D terms ;

if, in addition, $\frac{\gamma_E}{\gamma_A} a_A c_A < 0.01$, cancel the B-C-D-E terms, i.e. A is practically coincidence-free.

3. γ-KX(IC) coincidence loss

Again, only the dominant F_1-terms should be considered in Eqs (IV.1-7) - (IV.1-11), and one should drop the left hand term ($\varepsilon_{t,\gamma}$) in Eq. (IV.1-6). Then, the criteria for rejection are completely similar to the ones described above (see sub 2.) but one should additionally investigate the relevancy of the Kα1, Kα2, etc. contributions. Consider for instance the case of the ^{190m}Os 616.1 keV gamma-line (see Fig. IV.2-1). Apart from the γ-γ coincidence 616.1 - 502.6 - 361.1 - 186.7 (all relevant), one should in principle consider also the γ-KX(IC) coincidence 616.1 - KX(502.6) - KX(361.1) - KX(186.7).

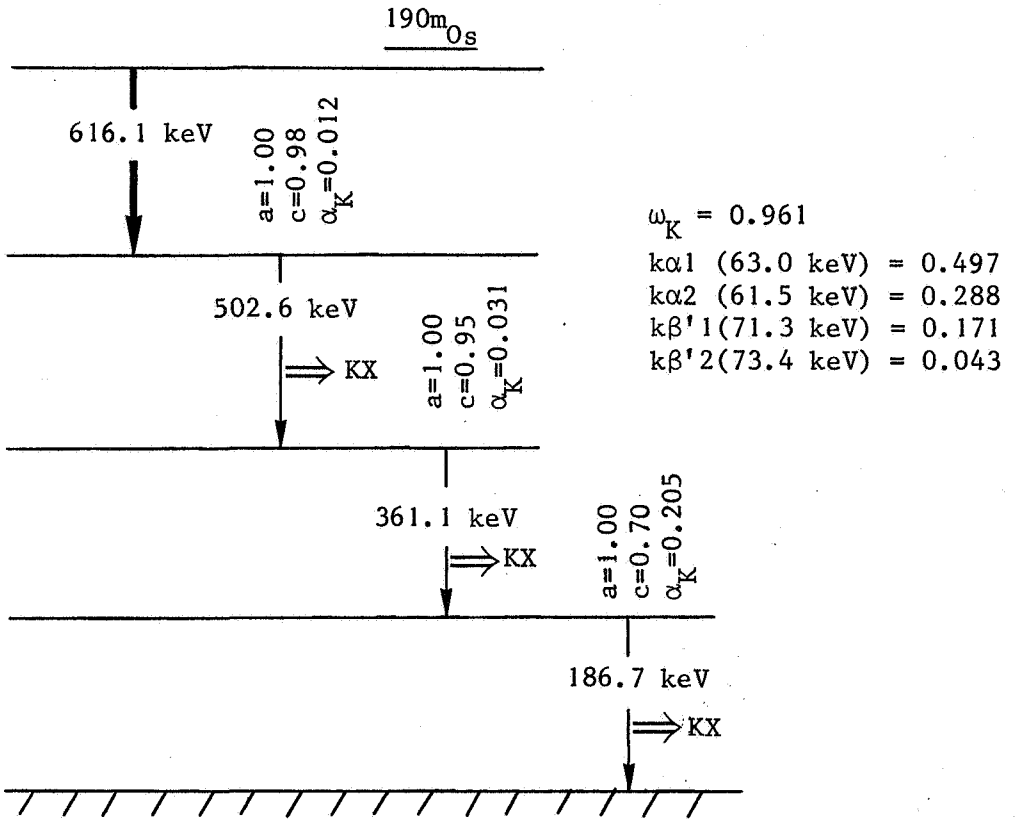


Fig. IV.2-1 : Relevancy of γ-KX coincidence loss for the ^{190m}Os 616.1 keV line

Investigation of the relevancy leads to :

KX(186.7) Kα1 : $a_{502.6}{}^{a}361.1{}^{a}186.7{}^{c}186.7{}^{\alpha}K,186.7{}^{\omega}K$ kα1=0.069; relevant ;
Kα2 : $a_{502.6}{}^{a}361.1{}^{a}186.7{}^{c}186.7{}^{\alpha}K,186.7{}^{\omega}K$ kα2=0.040; relevant ;
Kβ'1: $a_{502.6}{}^{a}361.1{}^{a}186.7{}^{c}186.7{}^{\alpha}K,186.7{}^{\omega}K$ kβ'1=0.024; relevant ;
Kβ'2: $a_{502.6}{}^{a}361.1{}^{a}186.7{}^{c}186.7{}^{\alpha}K,186.7{}^{\omega}K$ kβ'2=0.0059; not relevant.

KX(361.1) Kα1 : $a_{502.6}{}^{a}361.1{}^{c}361.1{}^{\alpha}K,361.1{}^{\omega}K$ kα1=0.014; relevant ;
Kα2 : $a_{502.6}{}^{a}361.1{}^{c}361.1{}^{\alpha}K,361.1{}^{\omega}K$ kα2=0.0082; not relevant.

KX(502.6) Kα1 : $a_{502.6}{}^{c}502.6{}^{\alpha}K,502.6{}^{\omega}K$ kα1=0.0056; not relevant.

Thus, in this case, the combined γ-γ plus γ-KX(IC) coincidences to be considered are reduced to : 616.1 - 502.6 - 361.1/Kα1(361.1) - 186.7/Kα1 → β'1(186.7).

4. γ-KX(EC) coincidence loss

For the cases considered in the present work, one obtains the following situation when analysing the relevancy (and maintaining the 1% criterium):

^{175}Hf [see Eqs (IV.1-16), (IV.1-17) and Fig. IV.1-2]

Kα1 → β'1(EC 186) - 89.4/Kα1 → β'1 (89.4) - 343.6

and

Kα1 → β'2 (EC 276) - 343.6

^{185}Os [see Eq. (IV.1-19) and Fig. IV.1-3]

Kα1 → β'2 (EC 369) - 646.1

2.3. Comment on the importance of γ-KX coincidence

Table IV.2-1 gives a survey of the systematic errors on the coincidence correction factors COI [Eq.(IV.2-3)], and thus on the corrected peak area $N_{p,A}$ [Eq. (IV.2-2)], which would be generated by not taking into account γ - KX coincidence effects. The errors were calculated for point sources measured at 1.29 cm distance to Ge-detector MK7 (see chapter II.2.1). Only the most intense gamma-lines (i.e. of direct analytical importance) of radionuclides from ^{175}Hf onwards were considered (see Table IV.2-4).

TABLE IV.2-1 : Percentile errors on the coincidence correction factors (COI) by not taking into account γ-KX coincidence. The data are calculated for point sources measured at 1.29 cm distance to Ge-detector MK7

Isotope	E_γ,keV	% Error on COI by neglecting γ-KX	Isotope	E_γ,keV	% Error on COI by neglecting γ-KX
^{175}Hf	343.6	13.9	^{183m}W	107.9	7.4
^{179m}Hf	214.1	9.2	^{187}W	479.6	19.9
^{180m}Hf	443.1	3.5	^{188m}Re	63.6	13.7
	332.3	4.7	^{185}Os	646.1	15.7
	215.2	3.3	^{190m}Os	616.1	3.2
^{181}Hf	133.0	1.3		502.6	3.2
	482.2	3.5		361.1	2.9
^{182m}Ta	185.1	16.0		186.7	0.3
	171.6	9.7	^{193}Os	460.5	7.3
	146.8	8.9	^{197m}Hg	134.0	4.7
^{182}Ta	1221.4	3.2	^{239}Np	106.1	12.2
	1121.3	6.3			

In addition to the above evidence of the importance of γ-KX coincidence, a comparison was made, for the 646.1 keV line of an ^{185}Os point-source counted at 0.78 cm ("geo") and 16.37 cm ("ref") distance to detector MK7, between the experimentally measured and calculated COI^{geo}-factor. From Fig. IV.1-3 and Table IV.2-2 it follows that $COI^{geo} = 1$ if γ-KX(EC) is neglected (no γ-γ coincidence). On the other hand, taking into account γ-KX(EC) coincidence loss, one can calculate from Eqs (IV.2-3) [with $S(\underline{A})=0$] and (IV.1-19) that $COI^{geo} = 0.803$ [introducing ε_p^{geo} (obtained according to III.2) and P/T (see IV.3.2)]. The experimentally measured COI-factor was obtained as :

$$COI_{exp}^{geo} = \left(\frac{N'_p/t_m}{DC}\right)^{geo} \Big/ \left[\left(\frac{N'_p/t_m}{DC}\right)^{ref} \cdot \frac{\bar{\Omega}^{geo}}{\bar{\Omega}^{ref}}\right] \qquad \text{(IV.2-4)}$$

where N'_p = observed number of pulses in the 646.4 keV photopeak ;
D = decay factor normalizing to a reference time.

Note that in the above reasoning it is assumed to $COI^{ref} = 1$ (calculated : 0.997). From three repeated experiments, COI_{exp}^{geo} was found to be 0.834 $\pm$ 0.042 ($\pm$ 5%), which is reasonably consistent (+ 4% deviation) with $COI_{calc}^{geo} = 0.803$.

2.4. Delayed γ-γ emission

Up to now it was assumed that in the decay of a radionuclide the cascading radiations (γ or X) are emitted without appreciable time delay.

For a few analytically interesting gamma-rays, however, one should take into account the existence of an intermediate decay scheme level of finite lifetime (expressed as a half-life T_1) when calculating the true-coincidence correction factor. This situation of "delayed γ-γ emission" is pictured in Fig. IV.2-2. It can be expected that the magnitude of the coincidence effects A = B+C, B-C and B-C will be influenced by the value of T_1. This is quite clear for ^{75}Se (see Fig. IV.2-3; only relevant lines shown), where the 0.3039 MeV level with its "long" half-life of 17 ms obviously makes that the 96.7 keV and 303.9 keV lines are coincidence-free, and that the 400.7 keV-line is not disturbed by coincidence summing of the 96.7 keV and 303.9 keV gamma's.

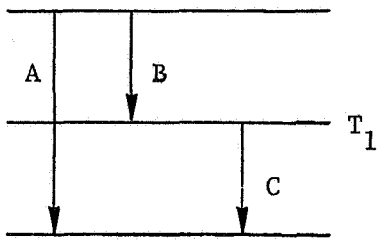


Fig. IV.2-2 : Delayed γ-γ emission (T_1=half-life of decay scheme level)

To reach pertinent conclusions for less extreme cases, the time scale of pulse processing should be considered. This is shown, with some simplifications, in Fig. IV.2-4 for a unipolar near-Gaussian shaped amplifier output pulse (as it was the case in the present work) and for the 100 MHz Wilkinson type analog-to-digital converter (ADC) as built-in in the Canberra S40 multichannel analyzer (cf. Table II.2-1).

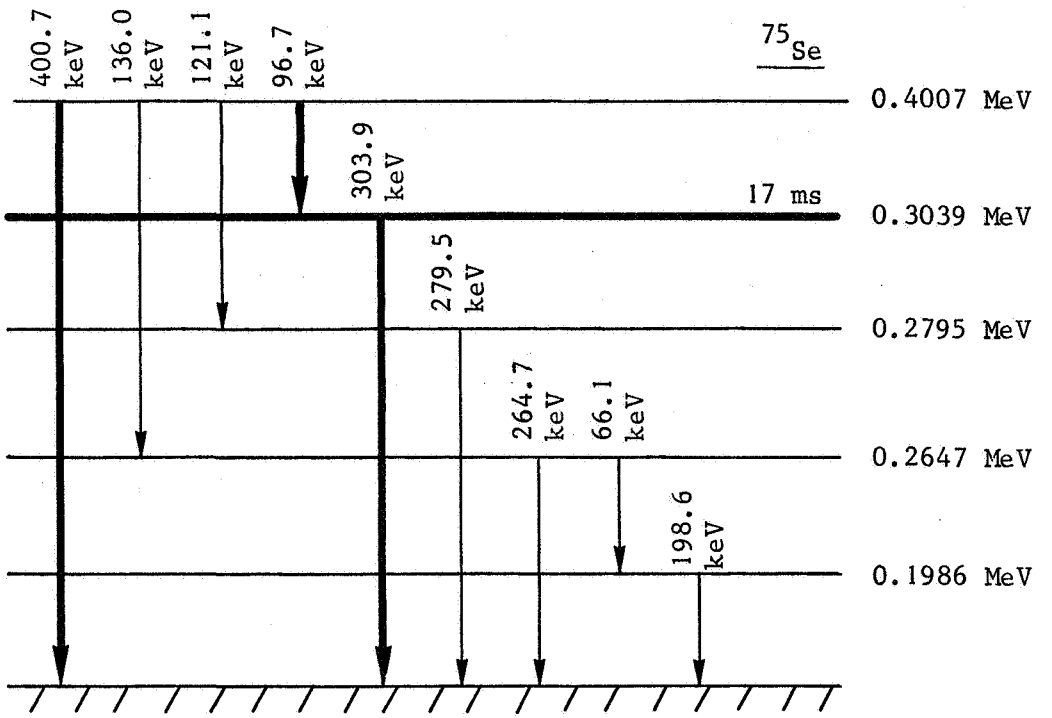


Fig. IV.2-3 : Simplified decay scheme of ^{75}Se, showing the shielding effect of the 17 ms 0.3039 MeV-level

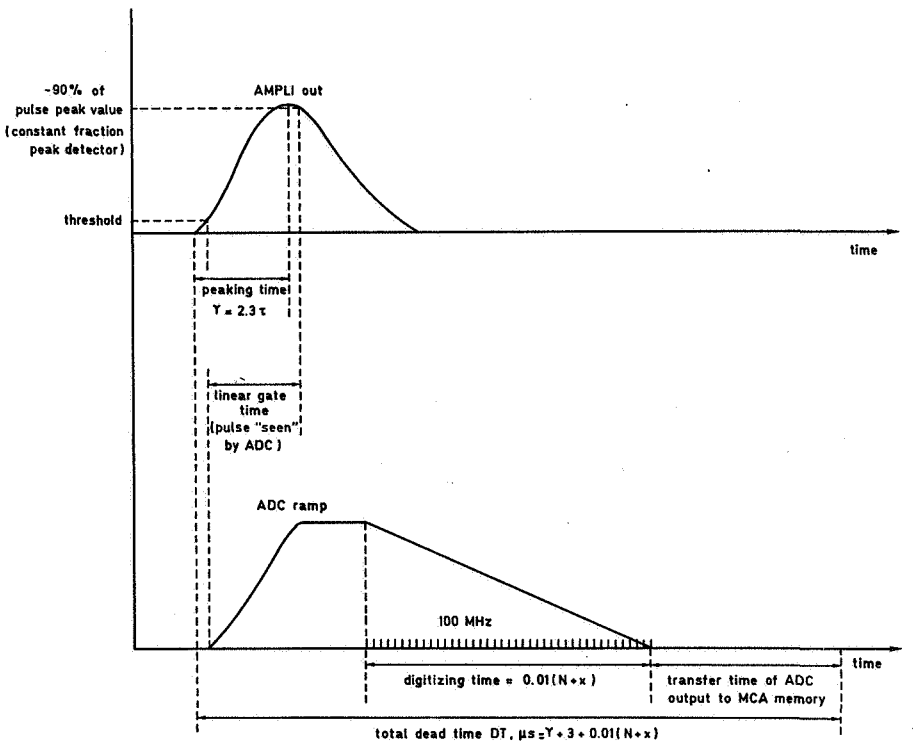


Fig. IV.2-4 : Time scale of pulse processing [τ = amplifier's pulse shaping time constant (μs); N = converted channel number; x = digital offset, in channels (= 0 in the present work); 3 μs = fixed time]

The coincidence effects to be considered are (see Figs IV.2-2 and IV.2-4):

1. Coincidence loss B-C. The correct amplitude for a full-energy pulse of B will be obtained only in case that C is emitted with a time delay larger than T (peaking time ≃ 2.3 τ), for which the probability is :

$$p\ (> T) = e^{-(T\ \ln 2)/T_1} \qquad \text{(IV.2-5)}$$

The complementary probability for emission of C within the time interval T is :

$$p(< T) = 1 - e^{-(T\ \ln 2)/T_1} \qquad \text{(IV.2-6)}$$

The coincidence correction factor for B can be calculated as :

$$COI = p(< T)\ COI_{nsh} + p(> T)\ COI_{sh} \qquad \text{(IV.2-7)}$$

with COI_{sh} = coincidence correction factor for B taking into account all relevant coincidence effects, except B-C (i.e. assuming $T \ll T_1$, leading to complete shielding of B from C) ;

COI_{nsh} = coincidence correction factor for B taking into account all relevant coincidence effects, including B-C (i.e. assuming $T \gg T_1$, leading to B not being shielded from C).

2. Coincidence loss B-C. If a pulse (not necessarily a full-energy pulse) of B is detected, no full-energy pulse of C can be obtained unless C is emitted with a time delay larger than DT (dead time), for which the probability is :

$$p(> DT) = e^{-(DT\ \ln 2)/T_1} \qquad \text{(IV.2-8)}$$

The complementary probability for emission of C within the time interval DT is :

$$p(< DT) = 1 - e^{-(DT\ \ln 2)/T_1} \qquad \text{(IV.2-9)}$$

As mentioned in Fig. IV.2-3, DT is given by :

$$DT(\mu s) = T + 3 + 0.01\ (N + x) \qquad \text{(IV.2-10)}$$

The problem is rather complex since N (associated with B) can be any channel number between $N_{\text{full-energy B}}$ and $N_{\text{threshold}}$ (≃ 65 in the present work; ADC gain = 8192). The practical consequences of not correcting accurately are discussed below.

3. Coincidence summing A = B+C. Perfect coincidence summing will be obtained only in case that the time delay between emission of B and C is very small compared to T, say < 0.01 T. The probability for C to be emitted within this time interval is :

$$p(< 0.01\ T) = 1 - e^{-(0.01\ T\ \ln 2)/T_1} \qquad \text{(IV.2-11)}$$

It is to be expected that the sum peak A will show some tailing at the low-energy wing.

The analytically relevant cases are (cf. Table IV.2-4) :

^{47}Ca : 530.4 - (T_1 = 0.27 μs) 767.0

Eq. (IV.2-7) can be applied; however even for τ = 1 μs (T ≃ 2.3 μs) one obtains p(> T) ≃ 0, i.e. no shielding.

^{47}Ca : 530.4 - (T_1 = 0.27 μs) 767.0

From Eq. (IV.2-8) it follows that, even for N = 65 (threshold) and τ = 1 μs, p(> DT) ≃ 0, i.e. no shielding.

^{77}Ge : 558.1 - 156.4 - (T_1 = 116 μs) 211.1 - 264.4

Eq. (IV.2-7) can be applied; for instance, for τ = 2 μs (T ≃ 4.6 μs), one obtains p(< T) = 0.027. Since the contribution to coincidence loss is very small (due to $a_{156.4}$ = 0.018; see IV.2.2), one can assume total shielding.

^{77}Ge : 367.4 = 156.4 + (T_1 = 116 μs) 211.1

Eq. (IV.2-11) yields, for τ = 2 μs, p(< 0.01 T) ≃ 0; thus, one can neglect coincidence summing.

^{77}Ge : B - (T_1 = 116 μs) 211.1
B - (T_1 = 116 μs) 211.1 - 264.4

with B = 156.4 keV, 714.1 keV, 1085.1 keV, etc.

The worst case is B = 1085.1 keV : for a full-energy pulse (N=2170) and τ = 2 μs, Eq. (IV.2-8) yields p(> DT) ≃ 0.84; thus, for close-in counting geometries, significant errors are to be expected when assuming complete shielding.

^{101}Mo : B - (T_1 = 760 μs) 191.9, with B = 80.9 keV, 408.7 keV etc.

Since τ is at maximum a few μs, one has p(< T) ≃ 0, and complete shielding can be assumed.

^{101}Mo : B - (T_1 = 760 μs) 191.9, with B = 80.9 keV, 408.7 keV, 1840.2 keV etc.
The worst case is B = 1840.2 keV : for a full-energy pulse (N=3680) and τ = 2 μs, Eq. (IV.2-8) yields p(> DT) ≃ 0.96. Since the contribution to coincidence loss is small [$(\gamma_{1840.2}/\gamma_{191.9})\ a_{191.9}c_{191.9}$ = 0.057; see IV.2.2], one can assume complete shielding.

^{149}Nd : 267.7 - 30.0 - (T_1 = 35 μs) 240.2
Eq. (IV.2-7) can be applied; for instance, for τ = 2 μs, one obtains p(< T) ≃ 0.087.

^{165m}Dy : 515.5 = 153.8 + (T_1 = 1.51 μs) 361.7
Eq. (IV.2-11) yields, for τ = 2 μs, p(< 0.01 T) ≃ 0.021 ; since $(\gamma_{153.8}/\gamma_{515.5})\ a_{361.7}c_{361.7}$ ≃ 0.12 (see IV.2.2), the error made by not taking into account coincidence summing is negligible.

^{165}Dy : 633.4 - (T_1 = 1.51 μs) 361.7
Eq. (IV.2-7) can be applied; for instance, for τ = 1 μs, one obtains (p < T) ≃ 0.65.

^{165}Dy : B - (T_1 = 1.51 μs) 361.7, with B = 633.4 keV etc.
For N = 65 (threshold) and τ = 1 μs, Eq. (IV.2-9) yields p(< DT) ≃ 0.93. Thus, for close-in geometries, small errors are to be expected when shielding is neglected.

^{171}Er : 210.6 - (T_1 = 2.60 μs) C, with C = 308.3 keV etc.
Eq. (IV.2-7) can be applied; for instance, for τ = 1 μs, one obtains p(< T) ≃ 0.46.

^{177}Yb : 1080.1 - (T_1 = 0.12 μs) 150.4
941.7 - 138.6 - (T_1 = 0.12 μs) 150.4
899.2 - (T_1 = 0.12 μs) 150.4
138.6 - (T_1 = 0.12 μs) 150.4
Eq. (IV.2-7) can be applied; however, even for τ = 1 μs (T ≃ 2.3 μs) one obtains p(> T) ≃ 0, and the effect of shielding can be neglected.

^{177}Yb : B - (T_1 = 0.12 μs) 150.4, with B = 138.6 keV, 899.2 keV etc.
Even for N = 65 (threshold) and τ = 1 μs, p(> DT) ≃ 0; thus, the effect of shielding can be neglected.

^{187}W : 685.7 = 479.6 + (T_1 = 0.56 μs) 72.1 + 134.2

Eq. (IV.2-11) yields, for τ = 2 μs, p(< 0.01 T) ≃ 0.055; since $(\gamma_{479.6}/\gamma_{685.7})\ a_{72.1}c_{72.1}a_{134.2}c_{134.2} \simeq 0.13$ (see IV.2.2), the error made by not taking into account coincidence summing is small.

^{187}W : 551.5 = 479.6 + (T_1 = 0.56 μs) 72.1

As above, p(< 0.01 T) ≃ 0.055; here, $(\gamma_{479.6}/\gamma_{551.5})\ a_{72.1}c_{72.1}$ ≃ 2.21, and a significant error is to be expected when not taking into account coincidence summing.

^{187}W : 479.6 - (T_1 = 0.56 μs) 72.1 - 134.2

Eq. (IV.2-7) can be applied; for instance, for τ = 1 μs, one obtains p(< T) ≃ 0.94.

^{187}W : 479.6 - (T_1 = 0.56 μs) 72.1 - 134.2

Even for N = 65 (threshold) and τ = 1 μs, p(> DT) ≃ 0; the effect of shielding can be neglected.

The above outlined considerations were experimentally checked for ^{77}Ge and ^{171}Er.

The shielding effect of the ^{77}Ge 115 μs 0.4755 MeV level (see Fig. IV.2-5), when considering the 1085.2 keV line, was demonstrated by comparing the experimentally determined and calculated COI-factors for measurements with

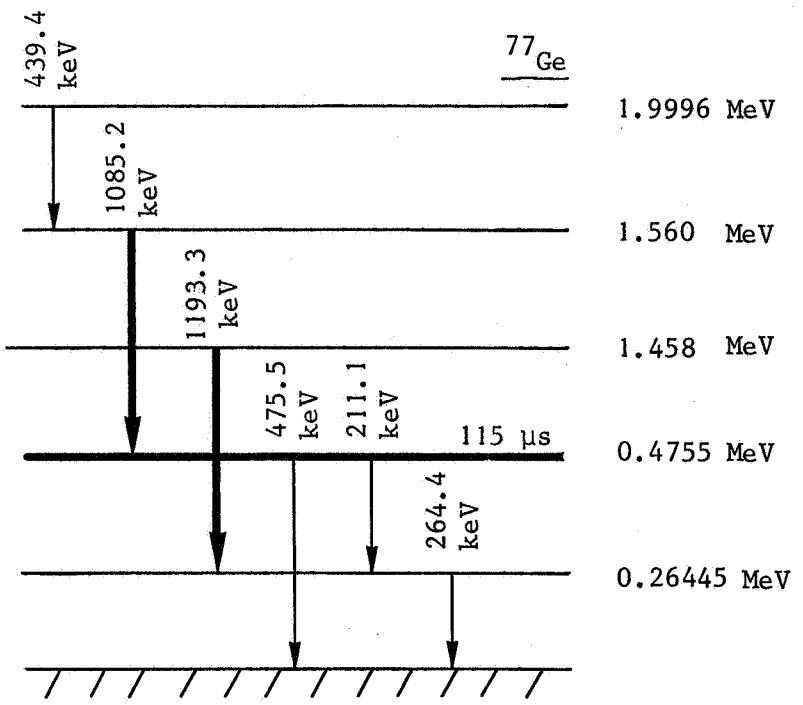


Fig. IV.2-5 : Part of the ^{77}Ge decay scheme, showing the shielding effect of the 115 μs 0.4755 MeV-level

the Ge-spectrometers MK4 and MK7 (τ put at 2 μs), exactly as described in IV.2.3 for ^{185}Os. The results are related to counting of a ^{77}Ge point-source at "ref" distances of 17.30 cm to detector MK4 or 16.37 cm to detector MK7, and "geo" distances of 2.15 cm to detector MK4 resp. 1.29 cm to detector MK7. Table IV.2-2 shows the comparison for the 1085.2 keV line, the coincidence loss of which should be lower than 1% (only 439.4 - 1085.2), in contrast with a loss of 20-30% if no shielding effect would exist (439.4 - 1085.2 - 475.5 and 439.4 - 1085.2 - 211.1 - 264.4). As a control, results are also given for the 1193.3 keV line, the coincidence loss of which (1193.3 - 264.4) is not influenced by the 115 μs 0.4755 MeV-level. In the above it is assumed that COI^{ref} = 1 [calculated : 1.000 (MK4 and MK7) for the 1085.2 keV line; 0.995 (MK4 and MK7) for the 1193.3 keV line].

TABLE IV.2-2 : Comparison of experimental and calculated coincidence correction factors (COI) for the ^{77}Ge 1085.2 keV and 1193.3 keV lines, showing - for the former - the shielding effect of the 115 μs 0.4755 MeV-level (see Fig. IV.2-5); "geo" = 2.15 cm or 1.29 cm distance to detector MK4 or detector MK7, respectively. The experiments were performed in threefold

^{77}Ge E_γ,keV	Ge-spectrometer MK4; τ=2μs			Ge-spectrometer MK7; τ=2μs		
	COI^{geo}_{exp}	COI^{geo}_{calc} with 116 μs-level causing		COI^{geo}_{exp}	COI^{geo}_{calc} with 116 μs-level causing	
		shielding	no shielding		shielding	no shielding
1085.2	1.010 ±0.014	0.997	0.793	0.990 ±0.012	0.996	0.696
1193.3	0.877 ±0.017	-	0.890	0.839 ±0.017	-	0.835

Eq. (IV.2-7) is applicable to coincidence losses of the ^{171}Er 210.6 keV line (see Fig. IV.2-6). The accuracy of COI-calculation was experimentally

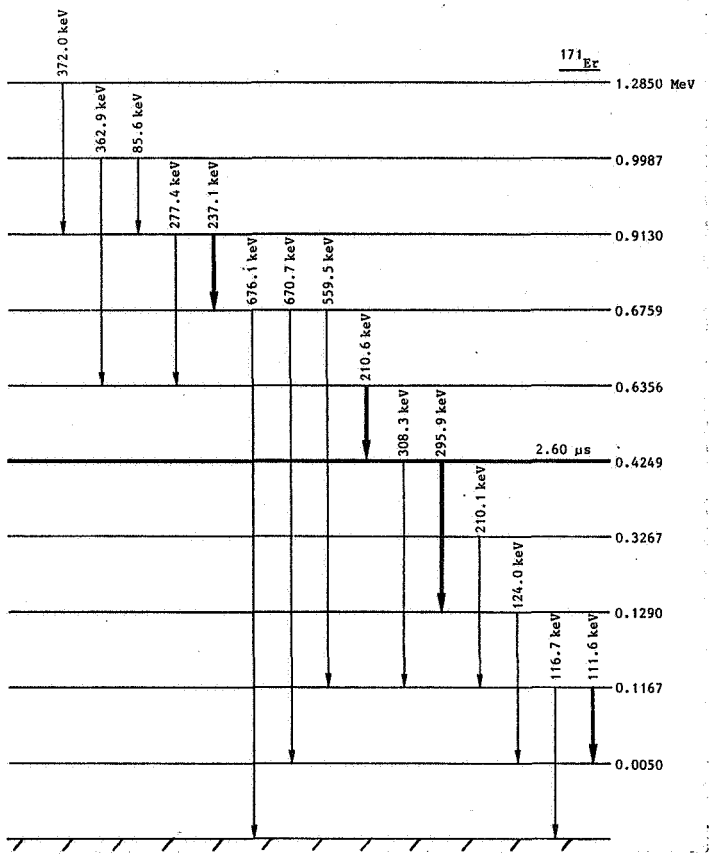


Fig. IV.2-6 : Simplified ^{171}Er decay scheme showing the shielding effect of the 2.60 µs 0.4249 MeV-level (cf. Table IV.2-4)

tested for measurements with the Ge-spectrometers MK4 and MK7 and for pulse shaping time constants τ = 1 and 2 µs. The experiments were performed in exactly the same way as described in IV.2.3 for ^{185}Os. The results are related to counting of a ^{171}Er point source at "ref" distances of 17.30 cm to detector MK4 or 16.37 cm to detector MK7, and "geo" distances of 2.15 cm to detector MK4 resp. 1.29 cm to detector MK7. The calculations were performed assuming that $T \simeq 2.3\ \tau$ (confirmed by oscilloscopic investigation). The comparison of calculated and experimentally determined COI-factors is shown in Table IV.2-2, including also a number of gamma-lines for which the COI-factor is not influenced by shielding of the 0.4249 MeV-level (according to IV.2.2, only the coincidence losses 295.9 - 124.0 and 308.3 - 111.6 are relevant for the 295.9 keV and 111.6 keV lines, respectively). In the above it is assumed that $COI^{ref} = 1$ [for all lines $COI^{ref} > 0.995$ by calculation]. Note that the studied peak at 210.6 keV energy is in fact originating from emission of 210.6 keV and 210.1 keV gamma-rays (see Fig. IV.2-6), with $\gamma_{210.6}/\gamma_{210.1} \simeq 92$; by not taking into account the contribution of the 210.1 keV line, the error on COI_{calc}, as quoted in Table IV.2-3 for the 210.6 keV line, is negligibly small (< 0.5%).

2.5. Special cases encountered in practice

In many cases it is more accurate or even unavoidable to determine the total peak area of a multiplet with close-lying energies $E_{\gamma,1}$, $E_{\gamma,2}$ etc. Then,

TABLE IV.2-3 : Comparison of experimental and calculated coincidence correction factors (COI) for the ^{171}Er 111.6 keV, 210.6 keV, 237.1 keV and 295.9 keV lines, showing for the 210.6 keV line the partial "shielding" effect of the 2.60 μs 0.4249 MeV level [see Fig. IV.2-6; see Eq. (IV.2-7)]. The results refer to measurements on detectors MK4 [amplifier CANBERRA 2020; τ = 1 and 2 μs; "geo" = 2.15 cm distance] and MK7 [amplifier CANBERRA 1413, τ = 1 and 2 μs; "geo" = 1.29 cm distance]. The experiments were carried out in threefold

^{171}Er	Ge-spectrometer MK4					
			τ = 1 μs		τ = 2 μs	
E_γ, keV	$(COI^{geo}_{calc})_{sh}$	$(COI^{geo}_{calc})_{nsh}$	COI^{geo}_{calc}	COI^{geo}_{exp}	COI^{geo}_{calc}	COI^{geo}_{exp}
111.6	-	0.906	0.906	0.927 ±0.028	0.906	0.914 ±0.027
210.6	0.900	0.777	0.844	0.822 ±0.025	0.813	0.814 ±0.024
237.1	-	0.903	0.903	0.925 ±0.028	0.903	0.861 ±0.026
295.9	-	0.970	0.970	0.964 ±0.029	0.970	0.951 ±0.029
^{171}Er	Ge-spectrometer MK7					
			τ = 1 μs		τ = 2 μs	
E_γ, keV	$(COI^{geo}_{calc})_{sh}$	$(COI^{geo}_{calc})_{nsh}$	COI^{geo}_{calc}	COI^{geo}_{exp}	COI^{geo}_{calc}	COI^{geo}_{exp}
111.6	-	0.865	0.865	0.880 ±0.026	0.865	0.875 ±0.026
210.6	0.850	0.651	0.759	0.759 ±0.023	0.709	0.687 ±0.021
237.1	-	0.858	0.858	0.820 ±0.025	0.858	0.872 ±0.026
295.9	-	0.913	0.913	0.881 ±0.026	0.913	0.903 ±0.027

an effective energy can be defined as :

$$E_{eff} = \frac{\sum_i \gamma_i E_{\gamma,i}}{\sum_i \gamma_i} \qquad \text{(IV.2-12)}$$

Accordingly, the 1%-criterium for relevancy of true-coincidence effects should be increased with a factor $\sum_i \gamma_i/\gamma_i$ and the coincidence correction factor becomes :

$$COI = \sum_i \gamma_i \; COI_i / \sum_i \gamma_i \qquad \text{(IV.2-13)}$$

As a result, coincidence correction is often not necessary for minor components of a multiplet. E.g. for the ^{101}Mo 505.8 keV effective energy, the 1%-criterium should be increased to 1.1% for the 505.9 keV component (γ = 11.8%) and to 10.7% for the 505.1 keV component (γ = 1.22%). Then, $COI_{505.8}$ can be written as (cf. Table IV.2-4) :

$$COI_{505.8} = (\gamma_{505.1} + \gamma_{505.9} \; COI_{505.9})/(\gamma_{505.1} + \gamma_{505.9})$$

Another special case is the measurement of the ^{99}Mo/^{99m}Tc 140.5 keV gamma-ray which is emitted by both the mother and the daughter isotope (with, for the latter, no true-coincidence effects). After reaching mother-daughter equilibrium ($t_d \gtrsim 60$ h), one can prove easily that :

$$COI_{140.5} = (0.969\gamma_{140.5,Tc} + \gamma_{140.5,Mo} \cdot COI_{140.5,Mo})/(0.969\gamma_{140.5,Tc} + \gamma_{140.5,Mo}),$$

where 0.969 is the ^{99m}Tc/^{99}Mo activity ratio [$= F_2 \; T_{Mo}/(T_{Mo} - T_{Tc})$; see Table VIII.3-1].

A last case concerns the measurement of ^{117m}In/^{117}In (both formed by β^- decay of $^{117(m)}$Cd), which both emit the analytically important 158.6 keV gamma-ray (with no coincidence effects for ^{117m}In). Here one can calculate the $COI_{158.6}$-factor by calling on other prominent gamma-lines in the spectrum of both In-isotopes, and the obvious choice is the ^{117m}In 315.3 keV line (with no coincidence effects) and the ^{117}In 553.0 keV line. From the measured peak areas of these lines (correcting $N'_{p,553.0}$ for true-coincidence), and with the introduction of the relevant detection efficiencies and gamma-intensities, it is then possible to calculate the contributions of ^{117m}In and ^{117}In to the 158.6 keV peak area. Thus, the $COI_{158.6}$-factor can be computed as :

$$COI_{158.6} = \left(N_{p,315.3} \cdot \frac{\varepsilon_{p,158.6}\,\gamma_{158.6,\,^{117m}In}}{\varepsilon_{p,315.3}\,\gamma_{315.3}} + \frac{N'_{p,553.0}}{COI_{553.0}} \cdot \frac{\varepsilon_{p,158.6}\,\gamma_{158.6,\,^{117}In}}{\varepsilon_{p,553.0}\,\gamma_{553.0}}\, COI_{158.6,\,^{117}In}\right)$$

$$\Big/ \left(N_{p,315.3} \cdot \frac{\varepsilon_{p,158.6}\,\gamma_{158.6,\,^{117m}In}}{\varepsilon_{p,315.3}\,\gamma_{315.3}} + \frac{N'_{p,553.0}}{COI_{553.0}} \cdot \frac{\varepsilon_{p,158.6}\,\gamma_{158.6,\,^{117}In}}{\varepsilon_{p,553.0}\,\gamma_{553.0}}\right)$$

2.6. Coincidence tables

2.6.1. User-orientated tabulation of coincidences and nuclear data

The cases of coincidence summing and loss to be considered (coded as described in IV.1.2 to IV.1.4) and the associated nuclear data of 152 analytically interesting radionuclides are collected in Table IV.2-4. A gamma-ray followed by the note "(coincidence) not relevant" is considered - in common neutron activation analysis applications - to have no analytical importance, neither directly (for concentration calculation via its peak area) nor indirectly (for correction of spectral interferences). The notation "no coincidence" means that the coincidence correction is smaller than 1% in the described measuring conditions [pseudo coaxial Ge-detector (conventional Ge(Li) or p-type HPGe), well-type excluded], even when counting a source on top of a large detector.

2.6.2. Exemplary coincidence correction factors

In applications where accuracy of the analytical results is not a prerequisite it might be of interest to have at one's disposal a list of coincidence correction factors, valid for some discrete distances from a point-source to a Ge-detector of average dimensions. This information is given in Table IV.2-5. The data refer to the following geometric configuration :

- a detector with an active volume of 101 cm^3 (actually MK4; see II.2.1) ;
- point-sources measured at source-detector distances of : 2.15 cm (Position 0), 5.28 cm (Position 1), 8.28 cm (Position 2), 11.27 cm (Position 3), 14.27 cm (Position 4) and 17.27 cm (Position 5). Note that these figures refer to the active detector body ;
- amplifier's pulse shaping time constant = 2 µs (important in case of delayed γ-γ emission; see IV.2.4).

TABLE IV.2-4 : True-coincidence cascade-schemes and compilation of associated nuclear data, for the relevant gamma-lines of analytically interesting radionuclides, and for counting on a pseudo-coaxial Ge-detector [conventional Ge(Li) or p-type HPGe, no well-type]. Up to Lu-177, only γ-γ coincidence is considered; from Hf-175, γ-KX(IC) and γ-KX(EC) coincidence is considered as well (see note before Hf-175).
Notations : "not relevant" = gamma-line without analytical importance ; "no coindicence" = coincidence correction always << 1%

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
F-20	1	1633.7			100.0	no coincidence
Na-24	1	2754.0	1.00	1.00	99.881	1-2
	2	1368.6	1.00	1.00	99.994	1-2
Mg-27	1	1014.4	0.97	(1.)	28.0	1=2+3
	2	170.7	0.03	(1.)	0.84	2-3
	3	843.8	1.00	(1.)	71.8	2-3
Al-28	1	1778.9			100.	no coincidence
S-37	1	3103.8			94.1	no coincidence
Cl-38	1	1642.4	1.00	(1.)	32.5	1-2
	2	2167.5	1.00	(1.)	44.0	1-2
K-42	1	312.7	0.98	(1.)	0.319	1-2
	2	1524.7	1.00	(1.)	17.9	1-2
Ca-47	1	1297.1	0.92	(1.)	74.9	1=3+4
	2	530.4	0.0013	(1.)	0.105	feeds 0.27 µs level (see IV.2.4); 2-5 (for τ in µs range)
	3	489.2	0.08	(1.)	6.7	3-4
	4	807.9	1.00	(1.)	6.9	3-4
	5	767.0	1.00	(1.)	0.195	fed by 0.27 µs level (see IV.2.4); 2-5
Sc-47	1	159.4			68.	no coincidence

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Ca-49	1	1408.9	1.00	(1.)	0.63	1-4
	2	987.3	0.011	(1.)	0.076	2-4
	3	1144.5	0.60	(1.)	0.11	3-7-8 ; 3-6
	4	3084.4	1.00	(1.)	92.1	no coincidence
	5	856.4	0.0014	(1.)	0.13	1-5-8
	6	2371.7	0.93	(1.)	0.49	not relevant
	7	143.2	0.07	(1.)	0.035	3-7-8
	8	2228.9	1.00	(1.)	0.19	not relevant
Sc-46m	1	142.5			56.0	no coincidence
Sc-46	1	1120.5	1.00	1.00	99.987	1-2
	2	889.3	1.00	1.00	99.9836	1-2
Ti-51	1	928.6	0.85	(1.)	6.9	1=2+3
	2	608.5	0.15	(1.)	1.18	2-3
	3	320.1	1.00	(1.)	92.9	2-3
V-52	1	647.4	0.79	(1.)	0.024	not relevant
	2	1333.6	0.99	(1.)	0.59	1-2-5 ; 2=3+4
	3	398.1	0.013	(1.)	0.008	not relevant
	4	935.5	1.00	(1.)	0.061	not relevant
	5	1434.0	1.00	(1.)	100.0	no coincidence
Cr-51	1	320.1			9.85	no coincidence
Mn-56	1	2522.8	0.05	(1.)	0.99	not relevant
	2	2113.1	0.98	(1.)	14.3	2-4
	3	1810.7	0.98	(1.)	27.2	3-4
	4	846.8	1.00	(1.)	98.9	1-4 ; 2-4 ; 3-4
Fe-59	1	335.0	0.21	(1.)	0.27	1-5 ; 1=2+4
	2	142.6	0.79	(1.)	0.98	2-3 ; 2-4-5
	3	1291.6	0.93	1.00	43.6	2-3 ; 3=4+5
	4	192.3	0.067	0.99	2.95	2-4-5
	5	1099.2	1.00	1.00	56.1	4-5

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Co-60m	1	58.6			2.02	no coincidence
Co-60	1	1173.2	1.00	1.00	99.88	1-2
	2	1332.5	1.00	1.00	99.9816	1-2
Ni-65	1	507.8	0.34	(1.)	0.29	not relevant
	2	1481.8	0.836	(1.)	23.2	2=3+4
	3	366.3	0.164	(1.)	4.69	3-4
	4	1115.5	1.00	(1.)	14.9	1-4 ; 3-4
Cu-64	1	511.0			35.74	no coincidence (except in well-type detectors)
	2	1345.9			0.49	no coincidence
Cu-66	1	833.7	1.00	1.00	0.17	not relevant
	2	1039.2	1.00	1.00	7.4	1-2
Zn-65	1	1115.5			50.70	no coincidence
Zn-69m	1	438.6			94.8	no coincidence
Ga-70	1	176.2	0.99	0.94	0.30	1-2
	2	1039.2	1.00	(1.)	0.67	1-2
Ga-72	1	2029.1	0.85	(1.)	0.124	not relevant
	2	924.1	0.17	(1.)	0.143	not relevant
	3	495.9	0.68	(1.)	0.56	not relevant
cont'd	4	2507.8	0.85	(1.)	12.8	4-34 ; 4=5+33 ; 4=6+28 ; 4=6+29+33 ; 4=6+30+31

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Ga-72	5	1878.0	0.0154	(1.)	0.231	not relevant
(cont'd)	6	1276.7	0.105	(1.)	1.559	6-28-34 ; 6-29-32 ; 6-29-33-34 ; 6-30-31-34 ; -1*(6-29)
	7	2491.0	0.0024	(1.)	7.48	7-34 ; 7=8+33 ; 7=9+31 ; 7=10+28 ; 7=10+29+33 ; 7=10+30+31 ; 7=11+27+31 ; 7=12+23 ; 7=12+24+33 ; 7=12+25+31 ; 7=13+19+31 7=13+18 ; 7=14+15
	8	1861.1	0.37	(1.)	5.23	8-32 ; 8-33-34 ; 8=10+29 ; 8=11+26 ; 8=12+24
	9	1596.7	0.30	(1.)	4.24	9-31-34 ; 9=10+30 ; 9=11+27 ; 9=12+25 ; 9=13+19
	10	1260.1	0.081	(1.)	1.148	10-28-34 ; 10-29-32 ; 10-29-33-34 ; 10-30-31-34 ; -1*(10-29)
	11	861.1	0.065	(1.)	0.912	not relevant
	12	810.2	0.143	1.00	2.01	12-22 ; 12-23-34 ; 12-24-32 ; 12-24-33-34 ; 12-25-31-34 ; -1*(12-24) ; 12=13+21
	13	381.2	0.02	(1.)	0.276	not relevant
	14	289.5	0.014	(1.)	0.201	not relevant
	15	2201.7	0.85	(1.)	26.1	15-34 ; 15=16+33 ; 15=17+29+33
	16	1571.7	0.035	(1.)	0.835	not relevant
	17	970.5	0.032	(1.)	1.105	17-28-34 ; 17-29-32 ; 17-29-33-34 ; 17-30-31-34 ; -1*(17-29)
	18	2109.5	0.44	(1.)	1.034	not relevant
	19	1215.1	0.34	(1.)	0.797	3-19-31-34 ; 13-19-31-34 ; -1*(19-31-34) ; 19=21+25 ; 19=20+27
	20	479.6	0.037	(1.)	0.086	3-20-26-33-34 ; 3-20-27-31-34 ; 13-20-26-33-34 ; 13-20-27-31-34 -1*(3-20) ; -1*(13-20) ; -1*(20-26-33-34) ; -1*(20-27-31-34)
	21	428.4	0.12	(1.)	0.184	not relevant
	22	2515.4	0.02	(1.)	0.253	22=23+34 ; 22=24+32 ; 22=24+33+34 ; 22=25+31+34
	23	1680.8	0.068	(1.)	0.868	not relevant
	24	1050.8	0.58	(1.)	6.93	21-24-32 ; 12-24-32 ; 2-24-32 ; 21-24-33-34 ; 12-24-33-34 ; 2-24-33-34 ; -2*(24-32) ; -2*(24-33-34) ; -1*(12-24) ; -1*(21-24) ; -1*(2-24)
	25	786.4	0.27	1.00	3.17	21-25-31-34 ; 12-25-31-34 ; 2-25-31-34 ; -2*(25-31-34)
	26	999.9	0.07	(1.)	0.796	not relevant
	27	735.6	0.86	(1.)	0.360	not relevant
	28	1230.9	0.14	(1.)	1.44	17-28-34 ; 10-28-34 ; 6-28-34 ; -2*(28-34) ; 28=29+33 ; 28=30+31
	29	600.9	0.67	1.00	5.59	17-29-32 ; 10-29-32 ; 6-29-32 ; 17-29-33-34 ; 10-29-33-34 ; 6-29-33-34 ; -2*(29-32) ; -2*(29-33-34) ; -1*(17-29) ;
cont'd						-1*(10-29) ; -1*(6-29)

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,%	Coincidence
Ga-72 (cont'd)	30	336.6	0.19	(1.)	0.107	not relevant
	31	894.2	1.00	1.00	9.85	17-30-31-34 ; 10-30-31-34 ; 6-30-31-34 ; 11-27-31-34 ; 12-25-31-34 ; 3-19-31-34 ; 9-31-34 ; 1-31-34 ; -2*(30-31-34) ; -5*(31-34)
	32	1464.0	0.123	(1.)	3.56	6-29-32 ; 12-24-32 ; 26-32 ; 16-32 ; 8-32 ; 32=33+34
	33	629.9	0.88	(1.)	24.4	17-29-33-34 ; 10-29-33-34 ; 6-29-33-34 ; 26-33-34 ; 16-33-34 ; 12-24-33-34 ; 8-33-34 ; -2*(29-33-34); -4*(33-34)
	34	834.0	1.00	1.00	95.65	29-33-34 ; 12-24-33-34 ; 8-33-34 ; 25-31-34 ; 9-31-34 ; 28-34 ; 18-34 ; 15-34 ; 7-34 ; 4-34 ; -2*(33-34) ; -1*(31-34)
		2501.8			20.5	E_{eff} of lines 7, 4 & 22 $COI = (COI_7.\gamma_7 + COI_4.\gamma_4 + COI_{22}.\gamma_{22})/(\gamma_7 + \gamma_4 + \gamma_{22})$
		2507.9			13.0^5	E_{eff} of lines 4 & 22 $COI = (COI_4.\gamma_4 + COI_{22}.\gamma_{22})/(\gamma_4 + \gamma_{22})$
Ge-75m	1	139.7			38.8	no coincidence
Ge-75	1	264.6			11.3	no coincidence
Ge-77	1	582.5	0.37	(1.)	0.74	not relevant
	2	1368.3	0.48	(1.)	3.18	not relevant
	3	810.4	0.34	(1.)	2.15	not relevant
	4	673.1	0.96	(1.)	0.63	not relevant
	5	1309.3	0.29	(1.)	0.46	not relevant
	6	928.9	0.14	(1.)	0.99	not relevant
	7	907.1	0.83	(1.)	0.90	not relevant
	8	1263.9	0.34	(1.)	0.80	not relevant
	9	338.7	0.31	0.99	0.63	not relevant
	10	1193.3	0.81	(1.)	2.43	not relevant
	11	749.9	1.00	(1.)	0.84	not relevant
	12	745.7	0.75	(1.)	0.91	not relevant
cont'd	13	925.5	0.036	1.00	0.74	not relevant

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,%	Coincidence
Ge-77 (cont'd)	14	558.1	0.65	1.00	15.2	1-9-14-16 ; 1-9-14-17-22 ; 1-9-14-18-21 ; 1-9-14-19 ; 4-14-16 ; 4-14-17-22 ; 4-14-18-21 ; 4-14-19 ; 3-14-16 ; 3-14-17-22 ; 3-14-18-21 ; 3-14-19 ; -3*(1-9-14) ; -3*(4-14) ; -3*(3-14) ; -2*(14-16) ; -2*(14-17-22) ; -2*(14-18-21) ; -2*(14-19) [see IV.2.4]
	15	461.4	1.00	(1.)	1.20	not relevant
	16	631.8	0.18	1.00	6.59	not relevant
	17	416.3	0.50	1.00	20.6	2-17-22 ; 6-17-22 ; 7-17-22 ; 11-17-22 ; 12-17-22 ; 15-17-22 ; 3-14-17-22 ; -6*(17-22)
	18	367.4	0.29	1.00	13.3	2-18-21 ; 6-18-21 ; 7-18-21 ; 11-18-21 ; 12-18-21 ; 15-18-21 ; 3-14-18-21 ; -6*(18-21) [see IV.2.4]
	19	156.4	0.018	0.87	0.76	feeds 116 µs level (see IV.2.4) ; not relevant
	20	211.1	0.96	0.93	29.2	fed by 116 µs level (see IV.2.4) ; 20-21 (not accurate)
	21	264.4	1.00	0.99	51.0	10-21 ; 13-21 ; 2-18-21 ; 20-21 (not accurate; see IV.2.4) ; 8-21 ; 14-18-21 ; -1*(18-21)
	22	215.5	1.00	0.99	27.1	2-17-22 ; 6-17-22 ; 7-17-22 ; 11-17-22 ; 12-17-22 ; 15-17-22 ; 3-14-17-22 ; -6*(17-22)
As-76	1	1453.6	0.20	(1.)	0.11	1-20 ; 1-21-23 ; 1=2+18 ; 1=3+15
	2	980.9	0.076	(1.)	0.041	not relevant
	3	882.1	0.10	(1.)	0.058	not relevant
	4	2096.3	0.53	(1.)	0.55	not relevant
	5	1439.1	0.27	(1.)	0.28	5-20 ; 5-21-23 ; 5=6+15
	6	867.6	0.13	(1.)	0.13	6-12 ; 6-13-23 ; 6-14-22-23 ; 6-15-20 ; 6-15-21-23 ; 6-16-19-23 ; -1*(6-15)
	7	727.0	0.67	(1.)	0.018	not relevant
	8	1212.9	0.86	(1.)	1.44	8-20 ; 8-21-23 ; 8=9+18
	9	740.1	0.070	(1.)	0.12	9-17-23 ; 9-18-20 ; 9-18-21-23 ; -1*(9-18)
	10	575.3	0.97	(1.)	0.067	not relevant
	11	695.2	0.33	(1.)	0.009	not relevant
	12	1787.7	0.14	(1.)	0.29	3-12 ; 6-12 ; 10-12 ; 12=13+23 ; 12=14+22+23 ; 12=15+20 ; 12=15+21+23 ; 12=16+19+23
cont'd	13	1228.5	0.60	(1.)	1.21	3-13-23 ; 6-13-23 ; 7-13-23 ; 10-13-23 ; -3*(13-23) ; 13=14+22 ; 13=15+21 ; 13=16+19

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,%	Coincidence
As-76 (cont'd)	14	665.3	0.18	(1.)	0.36	3-14-22-23 ; 6-14-22-23 ; 7-14-22-23 ; 10-14-22-23 ; -3*(14-22-23)
	15	571.5	0.068	(1.)	0.14	3-15-21-23 ; 3-15-20 ; 6-15-21-23 ; 6-15-20 ; 7-15-21-23 ; 7-15-20 ; 10-15-21-23 ; 10-15-20 ; -1*(3-15) ; -1*(7-15) ; -1*(10-15) ; -3*(15-21-23) ; -3*(15-20) ; -1*(6-15)
	16	456.9	0.018	(1.)	0.036	not relevant
	17	1129.9	0.67	(1.)	0.13	2-17-23 ; 9-17-23 ; -1*(17-23)
	18	472.8	0.26	(1.)	0.050	not relevant
	19	771.7	1.00	(1.)	0.12	10-16-19-23 ; 6-16-19-23 ; 11-19-23 ; -1*(19-23) ; -1*(16-19-23)
	20	1216.1	0.36	(1.)	3.42	1-20 ; 5-20 ; 8-20 ; 15-20 ; 20=21+23
	21	657.1	0.64	(1.)	6.17	1-21-23 ; 5-21-23 ; 8-21-23 ; 15-21-23 ; -3*(21-23)
	22	563.2	1.00	(1.)	1.20	6-14-22-23
	23	559.1	1.00	(1.)	45.0	4-23 ; 13-23 ; 22-23 ; 8-21-23
		559.2			46.2	E_{eff} of lines 22 & 23 $COI = (COI_{22}\cdot\gamma_{22} + COI_{23}\cdot\gamma_{23})/(\gamma_{22} + \gamma_{23})$
		1215.1			4.86	E_{eff} of lines 8 & 20 $COI = (COI_{8}\cdot\gamma_{8} + COI_{20}\cdot\gamma_{20})/(\gamma_{8} + \gamma_{20})$
Se-75 (see IV.2.4)	1	400.7	0.13	1.00	11.44	1=2+7 ; 1=3+6 ; 1=2+8+9
	2	136.0	0.65	0.97	58.5	2-7 ; 2-8-9
	3	121.1	0.19	0.96	17.17	3-6
	4	96.7	0.038	0.50	3.42	no coincidence
	5	303.9	0.98	0.95	1.321	no coincidence
	6	279.5	1.00	0.99	24.94	3-6
	7	264.7	0.98	0.99	58.6	2-7 ; 7=8+9
	8	66.1	0.017	0.77	1.13	not relevant
	9	198.6	1.00	0.98	1.466	2-8-9

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,%	Coincidence
Se-77m	1	162.1			52.4	no coincidence
Br-80	1	703.8	1.00	(1.)	0.19	1-3
	2	639.4	0.78	(1.)	0.26	2-3
	3	616.3	1.00	(1.)	6.7	1-3 ; 2-3
	4	812.2	1.00	(1.)	0.040	not relevant
	5	665.8	1.00	(1.)	1.08	4-5
Br-82	1	1007.5	0.94	(1.)	1.27	1-14-17 ; 1=2+10
	2	401.1	0.06	(1.)	0.10	not relevant
	3	827.8	0.24	1.00	24.1	3-14-17 ; 3=4+13 ; 3=5+10
	4	554.3	0.723	0.99	70.6	4-11-17 ; 4-12-15 ; 4-12-16-17 ; 4-13-14-17 ; -1*(4-12)
	5	221.5	0.023	0.95	2.27	5-9-15 ; 5-9-16-17 ; 5-10-14-17 ; -1*(5-9)
	6	92.2	0.0077	0.43	0.72	6-7-16-17 ; 6-7-15 ; -1*(6-7)
	7	1081.3	0.76	(1.)	0.63	6-7-16-17 ; 6-7-15 ; -1*(6-7)
	8	1650.3	0.334	(1.)	0.75	2-8-17 ; 5-8-17 ; -1*(8-17) ; 8=9+16 ; 8=10+14
	9	952.0	0.16	(1.)	0.38	5-9-15 ; 5-9-16-17 ; 2-9-15 ; 2-9-16-17 ; -1*(5-9) ; -1*(2-9) ; -1*(9-15) ; -1*(9-16-17)
	10	606.3	0.51	(1.)	1.25	5-10-14-17 ; 2-10-14-17 ; -1*(10-14-17)
	11	1317.5	0.38	1.00	27.0	4-11-17 ; 11=12+16 ; 11=13+14
	12	619.1	0.61	1.00	43.3	4-12-15 ; 4-12-16-17 ; -1*(4-12)
	13	273.5	0.012	0.98	0.81	4-13-14-17
	14	1044.0	1.00	1.00	27.5	1-14-17 ; 3-14-17 ; 4-13-14-17 ; 5-10-14-17 ; -3*(14-17)
	15	1474.9	0.367	1.00	16.4	6-7-15 ; 4-12-15 ; 15=16+17
	16	698.4	0.63	1.00	28.4	4-12-16-17 ; 5-9-16-17 ; 6-7-16-17 ; -2*(16-17)
	17	776.5	1.00	1.00	83.4	1-14-17 ; 3-14-17 ; 4-11-17 ; 4-12-16-17 ; 5-10-14-17 ; -2*(14-17)
Rb-86m	1	556.1			98.2	no coincidence
Rb-86	1	1076.7			8.78	no coincidence

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Rb-88	1	2118.9	0.64	(1.)	0.45	not relevant
	2	1366.7	0.15	(1.)	0.100	2-7
	3	338.9	0.09	(1.)	0.060	not relevant
	4	3009.4	0.67	(1.)	0.26	not relevant
	5	2677.9	0.90	(1.)	2.05	3-5-11 ; 5=6+10
	6	1779.8	0.10	(1.)	0.22	3-6-10-11
	7	3486.5	1.00	(1.)	0.14	not relevant
	8	1382.5	0.75	(1.)	0.78	8-11 ; 8=9+10
	9	484.5	0.03	(1.)	0.030	not relevant
	10	898.0	0.99	1.00	14.7	6-10-11 ; 1-10-11 ; -1*(10-11)
	11	1836.0	1.00	1.00	22.4	4-11 ; 5-11 ; 1-10-11 ; 6-10-11 ; -1*(10-11)
Sr-85m	1	231.7			84.72	no coincidence
Sr-85	1	514.0			99.270	no coincidence
Sr-87m	1	388.4			82.3	no coincidence
Y-90m	1	682.0	0.003	(1.)	0.32	1=2+3
	2	479.5	1.00	0.91	90.99	2-3
	3	202.5	1.00	0.97	96.6	2-3
Zr-95	1	724.2			44.1[5]	no coincidence
	2	756.7			54.5	no coincidence
Nb-95	1	765.8			99.79	no coincidence
Zr-97	1	971.5	0.61	(1.)	0.29	not relevant
	2	699.3	0.21	(1.)	0.10	not relevant
	3	1362.5	0.24	(1.)	1.33	3=4+17
	4	855.0	0.060	(1.)	0.34	not relevant
	5	829.7	0.043	(1.)	0.23	not relevant
cont'd	6	355.4	0.43	0.99	2.38	6-12 ; 6-13-18

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Zr-97	7	254.2	0.23	0.96	1.29	7-8 ; 7-9-18
(cont'd)	8	1851.8	0.24	(1.)	0.45	not relevant
	9	703.7	0.56	(1.)	1.04	7-9-18
	10	1021.2			1.04	no coincidence
	11	513.5	0.32	(1.)	0.57	not relevant
	12	1750.5	0.44	(1.)	1.18	6-12 ; 12=13+18
	13	602.4	0.51	(1.)	1.37	6-13-18
	14	400.4	0.55	(1.)	0.39	not relevant
	15	272.4	0.40	(1.)	0.28	not relevant
	16	1275.9	1.00	(1.)	0.95	2-15-16 ; 5-16 ; 1-16
	17	507.7	1.00	0.99	5.31	11-17 ; 4-17
	18	1148.0	1.00	1.00	2.65	14-18 ; 6-13-18 ; 7-9-18
Nb-97m	1	743.3			97.9	no coincidence
Nb-97	1	657.9			98.4	no coincidence
Nb-94m	1	702.0	1.00	1.00	0.0031	1-2
	2	871.0	1.00	1.00	0.50	no coincidence
Mo-99	1	961.1	0.88	1.00	0.10	not relevant
	2	621.3	0.22	1.00	0.025	not relevant
	3	822.8	0.98	1.00	0.13	not relevant
	4	778.0	0.26	1.00	4.36	no coincidence
	5	739.5	0.74	1.00	12.14	5-8 ; 5-9-10
	6	411.5	0.001	1.00	0.016	not relevant
	7	366.4	1.00	0.99	1.16	6-7 ; 2-7
	8	181.1	0.88	0.87	6.08	1-8 ; 3-8 ; 5-8 ; 8=9+10
	9	40.6	0.12	0.20	0.85	not relevant
	10	140.5	1.00	0.90	5.18	5-9-10
Tc-99m	1	140.5			87.2	no coincidence
		140.5				from ^{99}Mo + ^{99m}Tc; at equilibrium ($t_d \gtrsim 60$ h) : COI = $(0.969\gamma_{140,Tc} + COI_{140,Mo}\cdot\gamma_{140,Mo})/(0.969\gamma_{140,Tc} + \gamma_{140,Mo})$

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Mo-101 (see IV.2.4)	1	1339.4	0.39	(1.)	0.17	not relevant
	2	611.6	0.43	(1.)	0.14	not relevant
	3	1941.8	0.032	(1.)	0.055	not relevant
	4	1530.3	0.16	(1.)	0.27	not relevant
	5	1325.7	0.15	(1.)	0.26	not relevant
	6	510.1	0.57	(1.)	0.98	not relevant
	7	1414.2	0.80	(1.)	0.50	not relevant
	8	1526.6	0.15	(1.)	0.11	not relevant
	9	1548.7	0.43	(1.)	0.15	not relevant
	10	1030.1	0.20	(1.)	0.071	not relevant
	11	1523.0	0.14	(1.)	0.29	not relevant
	12	1418.6	0.42	(1.)	0.88	not relevant
	13	1768.2	0.054	(1.)	0.15	not relevant
	14	1532.5	0.29	(1.)	5.96	6-14-87 ; 6-14-88 ; -1*(6-14) ; 14=18+72
	15	1431.6	0.017	(1.)	0.36	not relevant
	16	1377.7	0.012	(1.)	0.24	not relevant
	17	1336.3	0.0084	(1.)	0.18	not relevant
	18	1161.0	0.19	(1.)	3.97	6-18-69 ; 6-18-70 ; 6-18-71 ; 6-18-72-87 ; 6-18-73 ; -4*(6-18)
	19	1020.0	0.022	(1.)	0.47	not relevant
	20	728.3	0.004	(1.)	0.092	not relevant
	21	448.7	0.033	(1.)	0.69	not relevant
	22	1712.8	0.22	(1.)	0.20	not relevant
	23	1394.8	0.67	(1.)	0.61	not relevant
	24	1673.9	0.11	(1.)	1.69	not relevant
	25	1355.9	0.11	(1.)	1.67	not relevant
	26	1346.1	0.070	(1.)	1.03	not relevant
	27	1251.1	0.31	(1.)	4.61	27-74 ; 27-75 ; 27-76-87 ; 27-76-88 ; -1*(27-76)
	28	934.2	0.23	(1.)	3.40	28-64 ; 28-65 ; 28-66-92 ; 28-67-87 ; 28-68-83 ; 28=30+54
	29	642.8	0.084	(1.)	1.24	not relevant
	30	367.9	0.007	(1.)	0.11	not relevant
	31	318.0	0.016	(1.)	0.24	not relevant
	32	1382.7	0.42	(1.)	1.15	not relevant
	33	1186.6	0.37	(1.)	1.03	not relevant
cont'd	34	869.7	0.12	(1.)	0.34	34-65 ; 34-67-87

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Mo-101 (cont'd)	35	1520.4	0.40	(1.)	0.24	not relevant
	36	1308.1	0.15	(1.)	0.094	not relevant
	37	1293.3	0.34	(1.)	0.21	not relevant
	38	1517.8	0.067	(1.)	0.22	not relevant
	39	1200.0	0.53	(1.)	1.75	not relevant
	40	778.3	0.29	(1.)	0.96	not relevant
	41	1260.2	0.078	(1.)	0.15	not relevant
	42	1169.0	0.12	(1.)	0.23	not relevant
	43	1064.2	0.11	(1.)	0.21	not relevant
	44	888.7	0.12	(1.)	0.23	not relevant
	45	1249.4	0.26	(1.)	0.26	31-45-90 ; 31-45-91 ; -1*(31-45)
	46	933.3	0.74	(1.)	0.75	31-46-75 ; 31-46-76-87 ; -1*(31-46)
	47	1011.1	0.26	(1.)	2.26	47-83 ; 47=48+68
	48	590.1	0.65	(1.)	5.64	48-64 ; 48-65 ; 48-67-87
	49	514.1	0.093	(1.)	0.81	not relevant
	50	903.6	0.098	(1.)	0.20	not relevant
	51	1310.7	0.10	(1.)	0.058	not relevant
	52	883.5	0.41	(1.)	0.70	not relevant
	53	707.8	0.037	(1.)	0.064	not relevant
	54	566.6	0.43	(1.)	0.73	not relevant
	55	1304.0	0.34	(1.)	2.78	1-55 ; 20-55 ; 29-55 ; 55=56+88 ; 55=57+83 ; 55=58+75 ; 55=58+76+88
	56	804.4	0.12	(1.)	1.00	not relevant
	57	713.0	0.41	(1.)	3.38	29-57-83 ; 29-57-84 ; 20-57-83 ; 20-57-84 ; 1-57-83 ; 1-57-84 ; -2*(57-83) ; -2*(57-84) ; -1*(29-57) ; -1*(20-57) ; -1*(1-57)
	58	608.4	0.13	(1.)	1.07	not relevant
	59	943.5	0.62	(1.)	0.16	not relevant
	60	571.7	0.41	(1.)	0.19	not relevant
	61	515.4	0.87	(1.)	0.51	not relevant
	62	815.3	0.25	(1.)	0.18	not relevant
	63	603.0	0.14	(1.)	0.10	not relevant
	64	1018.6	0.040	(1.)	0.64	not relevant
	65	1012.5	0.80	(1.)	12.8	54-65 ; 48-65 ; 40-65 ; 34-65 ; 28-65 ; 19-65 ; 7-65 ; 4-65 ; 65=67+88 ; 65=68+83
cont'd						

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,Σ	Coincidence
Mo-101 (cont'd)	66	739.5	0.019	(1.)	0.30	not relevant
	67	512.8	0.11	(1.)	1.75	not relevant
	68	421.7	0.035	(1.)	0.56	not relevant
	69	887.0	0.040	(1.)	0.23	not relevant
	70	877.4	0.59	(1.)	3.40	53-70 ; 44-70 ; 6-18-70 ; 70=72+87 ; 70=73+85
	71	871.1	0.31	(1.)	1.80	44-71 ; 6-18-71 ; 71=72+87
	72	371.6	0.031	(1.)	0.18	not relevant
	73	353.0	0.025	(1.)	0.14	not relevant
	74	701.8	0.036	(1.)	0.38	not relevant
	75	695.6	0.69	(1.)	7.20	29-58-75 ; 52-75 ; 50-75 ; 31-46-75 ; 43-75 ; 33-75 ; 27-75 ; 17-75 ; 12-75 ; 8-75 ; 75=76+88
	76	195.9	0.27	(1.)	2.86	29-58-76-87 ; 29-58-76-88 ; 52-76-87 ; 52-76-88 ; 50-76-87 ; 50-76-88 ; 31-46-76-87 ; 31-46-76-88 ; 43-76-87 ; 43-76-88 ; 33-76-87 ; 33-76-88 ; 27-76-87 ; 27-76-88 ; 17-76-87 ; 17-76-88 ; 12-76-87 ; 12-76-88 ; 8-76-87 ; 8-76-88 ; -1*(29-58-76) ; -1*(52-76) ; -1*(50-76) ; -1*(31-46-76) ; -1*(43-76) ; -1*(33-76) ; -1*(27-76) ; -1*(17-76) ; -1*(12-76) ; -1*(8-76) ; -9*(76-87) ; -9*(76-88)
	77	381.2	0.49	(1.)	0.30	not relevant
	78	333.7	1.00	(1.)	0.78	not relevant
	79	606.8	0.10	(1.)	0.21	not relevant
	80	408.7	0.78	(1.)	1.60	10-60-80 ; 26-80 ; 15-80 ; 3-80 ; 80=81+92 ; 80=82+89+92
	81	327.7	0.10	(1.)	0.21	not relevant
	82	115.8	0.016	(1.)	0.032	not relevant
	83	590.9	0.95	(1.)	16.4	68-83 ; 61-83 ; 29-57-83 ; 47-83 ; 42-83 ; 39-83 ; 25-83 ; 23-83 ; 11-83
	84	398.9	0.052	(1.)	0.90	not relevant
	85	524.2	0.30	(1.)	0.17	not relevant
	86	505.1	1.00	(1.)	1.22	no coincidence (for effective energy only)
	87	505.9	0.89	(1.)	11.8	33-76-87 ; 27-76-87 ; 12-76-87 ; 72-87 ; 28-67-87 ; 56-87 ; 37-87 ; 32-87 ; 6-14-87 ; -2*(76-87)
	88	499.7	0.11	(1.)	1.47	58-76-88 ; 52-76-88 ; 46-76-88 ; 33-76-88 ; 27-76-88 ; 72-88 ; 12-76-88 ; 48-67-88 ; 28-67-88 ; 29-56-88 ; 37-88 ; 32-88 ;
cont'd						6-14-88 ; -5*(76-88) ; -1*(67-88)

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,Σ	Coincidence
Mo-101 (cont'd)	89	212.0	0.88	(1.)	0.51	not relevant
	90	379.3	0.41	(1.)	0.32	not relevant
	91	187.4	0.59	(1.)	0.47	not relevant
	92	80.9	1.00	0.66	3.83	49-63-89-92 ; 36-89-92 ; 26-81-92 ; 78-92 ; 16-77-92 ; 24-92 ; 9-77-92 ; 48-66-92 ; 28-66-92 ; 49-62-92 ; 5-59-92 ; 21-51-92 ; 22-92 ; 13-92 ; 38-92 ; 35-92 ; -1*(89-92) ; -1*(77-92) ; -1*(66-92)
	93	191.9	1.00	0.78	18.8	fed by 760 µs level (see IV.2.4) ; no coincidence
		192.4			21.7	E_{eff} of lines 93 & 76 $COI = (\gamma_{93} + COI_{76}\cdot\gamma_{76})/(\gamma_{93} + \gamma_{76})$
		505.8			13.1	E_{eff} of lines 86 & 87 $COI = (\gamma_{86} + COI_{87}\cdot\gamma_{87})/(\gamma_{86} + \gamma_{87})$
		590.7			22.0	E_{eff} of lines 48 & 83 $COI = (COI_{48}\cdot\gamma_{48} + COI_{83}\cdot\gamma_{83})/(\gamma_{48} + \gamma_{83})$
		870.9			2.14	E_{eff} of lines 34 & 71 $COI = (COI_{34}\cdot\gamma_{34} + COI_{71}\cdot\gamma_{71})/(\gamma_{34} + \gamma_{71})$
		934.0			4.15	E_{eff} of lines 46 & 28 $COI = (COI_{46}\cdot\gamma_{46} + COI_{28}\cdot\gamma_{28})/(\gamma_{46} + \gamma_{28})$
		1012.3			15.0	E_{eff} of lines 47 & 65 $COI = (COI_{47}\cdot\gamma_{47} + COI_{65}\cdot\gamma_{65})/(\gamma_{47} + \gamma_{65})$
		1251.0			4.87	E_{eff} of lines 45 & 27 $COI = (COI_{45}\cdot\gamma_{45} + COI_{27}\cdot\gamma_{27})/(\gamma_{45} + \gamma_{27})$
Tc-101	1	811.4	0.072	(1.)	0.060	not relevant
	2	627.0	0.46	(1.)	0.39	not relevant
cont'd	3	393.3	0.12	(1.)	0.097	not relevant

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ,%	Coincidence
Tc-101 (cont'd)	4	617.3	0.17	(1.)	0.051	not relevant
	5	715.6	0.36	(1.)	0.69	not relevant
	6	531.4	0.53	(1.)	1.02	6-10 ; 6-11-14
	7	545.1	0.91	(1.)	5.98	3-7 ; 7=8+12 ; 7=9+11+14
	8	238.3	0.048	(1.)	0.31	not relevant
	9	233.7	0.042	(1.)	0.27	not relevant
	10	311.3	0.12	0.99	0.24	not relevant
	11	184.1	0.88	0.94	1.69	9-11-14 ; 6-11-14 ; 4-11-14 ; 2-11-14 ; -3*(11-14)
	12	306.8	0.99	0.98	88.0	no coincidence
	13	179.7	0.008	0.86	0.64	not relevant
	14	127.2	1.00	0.85	2.86	13-14 ; 9-11-14 ; 6-11-14 ; 4-11-14 ; 2-11-14 ; 5-14 ; 1-14 ; -3*(11-14)
Ru-97	1	569.3	0.82	1.00	0.89	1-5
	2	460.6	0.11	0.99	0.12	not relevant
	3	324.5	0.99	0.98	10.2	2-3 ; 3=4+5
	4	108.8	0.010	(1.)	0.11	not relevant
	5	215.7	1.00	0.96	86.2	1-5
Ru-103	1	610.3	0.87	1.00	5.73	1=2+4
	2	557.0	0.13	1.00	0.85	2-4
	3	497.1			90.9	no coincidence
	4	53.3	1.00	0.32	0.37	not relevant
Ru-105	1	1017.5	0.91	(1.)	0.32	not relevant
	2	907.6	0.32	(1.)	0.53	not relevant
	3	878.1	0.29	(1.)	0.47	not relevant
	4	738.3	0.047	(1.)	0.076	not relevant
	5	407.6	0.055	(1.)	0.090	not relevant
	6	875.9	0.71	1.00	2.50	6-34 ; 6=8+24
	7	845.9	0.18	(1.)	0.63	not relevant
	8	559.2	0.031	(1.)	0.11	not relevant
	9	822.0	0.33	(1.)	0.21	not relevant
	10	969.4	0.52	1.00	2.10	5-10 ; 10=12+34 ; 10=13+32 ; 10=14+30+38 ; 10=14+31+32 ; 10=15+26 ; 10=16+24+34
cont'd						

Radio-nuclide	Line Code	E_γ, keV	a	c	γ,%	Coincidence
Ru-105 (cont'd)	11	513.7	0.049	(1.)	0.20	not relevant
	12	500.1	0.14	(1.)	0.55	not relevant
	13	470.1	0.045	0.99	0.18	no coincidence (for effective energy only)
	14	330.8	0.17	0.99	0.67	not relevant
	15	245.2	0.006	0.97	0.025	not relevant
	16	183.6	0.028	0.87	0.099	not relevant
	17	343.3	1.00	(1.)	0.028	not relevant
	18	676.4	0.82	1.00	15.6	18=19+37 ; 18=20+35
	19	413.5	0.12	1.00	2.25	19-37
	20	350.2	0.053	1.00	1.02	20-35 ; 20-36-37
	21	306.7	0.004	0.98	0.080	not relevant
	22	656.2	0.12	1.00	2.06	22=23+37
	23	393.4	0.22	1.00	3.77	23-37
	24	316.4	0.66	0.98	11.1	24-34
	25	286.3	0.002	0.97	0.028	not relevant
	26	724.3	0.98	1.00	47.3	26=27+38
	27	575.1	0.018	1.00	0.85	not relevant
	28	225.1	0.003	0.96	0.12	not relevant
	29	638.7	0.27	(1.)	0.22	not relevant
	30	489.5	0.67	0.99	0.55	not relevant
	31	139.3	0.065	0.88	0.047	not relevant
	32	499.3	0.88	(1.)	2.05	3-32 ; 7-32 ; 21-32 ; 9-32 ; 14-31-32 ; 13-32 ; 28-32 ; 25-32 ; 17-32 ; 32=33+38
	33	350.0	0.12	1.00	1.02	not relevant
	34	469.4	1.00	0.99	17.5	1-34 ; 2-34 ; 6-34 ; 12-34 ; 24-34
	35	326.1	0.88	0.99	1.06	11-35 ; 20-35 ; 35=36+37
	36	62.4	0.12	0.43	0.066	not relevant
	37	262.8	1.00	0.97	6.57	19-37 ; 23-37 ; 20-36-37
	38	149.1	1.00	0.88	1.76	27-38 ; 4-30-38 ; 14-30-38 ; 13-33-38 ; 9-33-38 ; 7-33-38 ; 3-33-38 ; -1*(30-38) ; -3*(33-38)
		469.4			17.7	E_{eff} of lines 13 & 34
cont'd						$COI = (\gamma_{13} + COI_{34} \cdot \gamma_{34})/(\gamma_{13} + \gamma_{34})$

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Ru-105 (cont'd) Rh-105m	1	129.7			20.0	no coincidence
Rh-105	1	319.2			19.2	no coincidence
	2	306.1			5.13	no coincidence
Rh-104m	1	77.5	(1.)	0.022	2.07	not relevant
	2	51.4	1.00	0.51	48.2	1-2
Rh-104	1	1237.1	0.92	(1.)	0.07	not relevant
	2	555.8	1.00	(1.)	2.0	1-2
Pd-109m	1	188.9			55.7	no coincidence
Pd-109	1	781.4	0.61	1.00	0.0112	1=2+20 ; 1=5+12 ; 1=6+9
	2	736.7	0.092	1.00	0.0017	not relevant
	3	558.1	0.13	1.00	0.0024	not relevant
	4	454.3	0.030	(1.)	0.0005	not relevant
	5	145.1	0.061	0.87	0.0011	not relevant
	6	134.2	0.071	0.83	0.0013	not relevant
	7	551.4	0.39	(1.)	0.0006	not relevant
	8	447.6	0.53	0.99	0.0008	not relevant
	9	647.3	0.73	1.00	0.0244	6-9 ; 9=10+20
	10	602.5	0.24	1.00	0.00798	6-10-20
	11	423.9	0.029	0.99	0.0010	not relevant
	12	636.3	0.46	1.00	0.00998	5-12
	13	413.0	0.30	0.99	0.00659	5-13-19 ; 13=14+18
	14	309.1	0.23	0.99	0.00488	14-17 ; 14-18-19
	15	390.6	0.22	0.99	0.0009	not relevant
	16	286.3	0.033	(1.)	0.0001	not relevant
	17	415.2	0.89	0.99	0.0107	16-17 ; 5-14-17 ; 8-17 ; 4-17 ; 17=18+19
cont'd	18	103.9	0.11	0.72	0.0009	not relevant

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Pd-109 (cont'd)	19	311.4	1.00	0.98	0.0320	14-18-19 ; 15-19 ; 5-13-19 ; 11-19 ; 7-19 ; 3-19
	20	44.7	1.00	0.14	0.0011	not relevant
		311.1			0.0368	E_{eff} of lines 14 & 19 $COI = (COI_{14}\cdot\gamma_{14} + COI_{19}\cdot\gamma_{19})/(\gamma_{14} + \gamma_{19})$
		414.4			0.0173	E_{eff} of lines 13 & 17 $COI = (COI_{13}\cdot\gamma_{13} + COI_{17}\cdot\gamma_{17})/(\gamma_{13} + \gamma_{17})$
Ag-109m	1	88.0			3.61	no coincidence
Pd-111m	1	1063.4	0.78	(1.)	0.13	not relevant
	2	1045.2	0.33	(1.)	0.095	not relevant
	3	1282.5	0.67	1.00	0.99	not relevant
	4	1200.1	0.27	(1.)	0.30	not relevant
	5	882.1	0.17	(1.)	0.20	not relevant
	6	1115.9	0.20	(1.)	1.04	not relevant
	7	797.8	0.18	(1.)	0.97	not relevant
	8	357.9	0.08	(1.)	0.40	not relevant
	9	272.0	0.03	(1.)	0.16	not relevant
	10	1001.2	0.18	(1.)	0.095	not relevant
	11	525.6	0.58	(1.)	1.23	not relevant
	12	439.3	0.48	(1.)	0.23	not relevant
	13	632.8	0.98	1.00	3.38	8-12-13-16 ; 8-12-13-17-18 ; 9-11-13-16 ; 9-11-13-17-18 ; 7-13-16 ; 7-13-17-18 ; 5-13-16 ; 5-13-17-18 ; 2-13-16 ; 2-13-17-18 ; 1-13-16 ; 1-13-17-18 ; -1*(8-12-13) ; -1*(7-13) ; -1*(9-11-13) ; -1*(5-13) ; -1*(2-13) ; -1*(1-13) ; -5*(13-16) ; -5*(13-17-18)
	14	118.7	0.05	(1.)	0.095	not relevant
	15	575.0	0.97	1.00	3.02	14-15-19 ; 10-15-19 ; 6-15-19 ; 4-15-19 ; 3-15-19 ; -4*(15-19)
	16	391.3	0.93	0.99	5.13	8-12-13-16 ; 9-11-13-16 ; 7-13-16 ; 5-13-16 ; 2-13-16 ; 1-13-16 ; -5*(13-16) ; 16=17+18
cont'd						

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ,%	Coincidence
Pd-111m (cont'd)	17	101.8	0.07	0.71	0.27	not relevant
	18	289.8	1.00	0.98	0.99	not relevant
	19	70.4	1.00	0.46	7.87	not relevant
	20	172.1			33.0	no coincidence
Ag-111	1	342.1	0.97	0.98	6.68	1=2+3
	2	96.7	0.03	0.65	0.2	not relevant
	3	245.4	1.00	0.94	1.24	not relevant
Ag-108	1	1007.2	0.63	(1.)	0.014	not relevant
	2	618.9	1.00	(1.)	0.262	2-3
	3	433.9	1.00	(1.)	0.50	1-3 ; 2-3
	4	633.0			1.76	no coincidence
Ag-110m	1	1384.3	0.37	1.00	24.34	1-14-17 ; 1=2+13 ; 1=3+10 ; 1=4+6
	2	763.9	0.33	1.00	22.29	2-11-17 ; 2-12-15 ; 2-12-16-17 ; 2-13-14-17 ; -1*(2-12)
	3	706.7	0.24	1.00	16.4	3-8-17 ; 3-9-15 ; 3-9-16-17 ; 3-10-14-17 ; -1*(3-9)
	4	446.8	0.055	0.99	3.72	4-6-14-17
	5	626.1	0.56	(1.)	0.23	not relevant
	6	937.5	1.00	1.00	34.37	4-6-14-17
	7	708.1	0.87	(1.)	0.3	5-7-14-17
	8	1562.3	0.072	1.00	1.027	3-8-17 ; 8=9+16 ; 8=10+14
	9	744.3	0.28	1.00	4.73	3-9-15 ; 3-9-16-17 ; -1*(3-9)
	10	677.6	0.64	1.00	10.3	3-10-14-17
	11	1505.0	0.59	1.00	13.05	2-11-17 ; 11=12+16 ; 11=13+14
	12	687.0	0.29	1.00	6.43	2-12-15 ; 2-12-16-17 ; -1*(2-12)
	13	620.4	0.12	1.00	2.802	2-13-14-17
	14	884.7	1.00	1.00	72.7	1-14-17 ; 2-13-14-17 ; 3-10-14-17 ; 4-6-14-17 ; -3*(14-17)
	15	1475.8	0.36	1.00	3.990	2-12-15 ; 3-9-15 ; 15=16+17
cont'd	16	818.0	0.64	1.00	7.33	2-12-16-17 ; 3-9-16-17 ; -1*(15-17)

Radio-nuclide	Line Code	E ,keV	a	c	,%	Coincidence
Ag-110m (cont'd)	17	657.7	1.00	1.00	94.51	1-14-17 ; 2-13-14-17 ; 3-10-14-17 ; 4-6-14-17 ; 2-11-17 ; 3-8-17 ; 2-12-16-17 ; 3-9-16-17 ; -1*(16-17) ; -3*(14-17)
	18	676.6			0.14	not placed in decay scheme; no coincidence assumed
		677.6			10.48	E_{eff} of lines 18 & 10 $COI = (\gamma_{18} + COI_{10}.\gamma_{10})/(\gamma_{18} + \gamma_{10})$
		706.7			16.66	E_{eff} of lines 3 & 7 $COI = (COI_3.\gamma_3 + COI_7\gamma_7)/(\gamma_3 + \gamma_7)$
Ag-110	1	657.7			4.49	no coincidence
Cd-111m	1	150.8	1.00	0.30	30.3	1-2
	2	245.4	1.00	0.94	94.0	1-2
Cd-115m	1	1290.5	0.98	(1.)	0.77	1=2+3
	2	158.0	0.022	0.85	0.02	not relevant
	3	1132.5	1.00	(1.)	0.07	not relevant
	4	484.3	0.99	0.99	0.26	4-5
	5	933.6	1.00	1.00	1.7	4-5
Cd-115	1	527.9			27.5	no coincidence
	2	492.4	0.92	1.00	8.03	2=3+4
	3	231.4	0.08	0.98	0.740	not relevant
	4	260.9	1.00	0.97	1.94	3-4
In-115m	1	336.2			45.8	no coincidence

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Cd-117(m)						
In-117m	1	315.3			19.5	no coincidence
	2	158.6			15.9	no coincidence
In-117	3	553.0	1.00	(1.)	99.0	3-4
	4	158.6	1.00	0.86	86.0	3-4
		158.6				sum of lines 2 and 4 $COI = (N_{p,1} \cdot \frac{\epsilon_{p,2} \cdot \gamma_2}{\epsilon_{p,1} \cdot \gamma_1} + \frac{N'_{p,3}}{COI_3} \cdot \frac{\epsilon_{p,4} \cdot \gamma_4}{\epsilon_{p,3} \cdot \gamma_3} \cdot COI_4) /$ $(N_{p,1} \cdot \frac{\epsilon_{p,2} \cdot \gamma_2}{\epsilon_{p,1} \cdot \gamma_1} + \frac{N'_{p,3}}{COI_3} \cdot \frac{\epsilon_{p,4} \cdot \gamma_4}{\epsilon_{p,3} \cdot \gamma_3})$
In-114m	1	190.3			15.4	no coincidence
	2	725.2	1.00	(1.)	4.33	2-3
	3	558.4	1.00	(1.)	4.39	2-3
In-116m	1	1753.8	0.91	1.00	2.46	1-14 ; 1=4+5 ; 1=3+8 ; 1=2+9
	2	781.0	0.040	(1.)	0.11	not relevant
	3	655.7	0.040	(1.)	0.11	not relevant
	4	245.0	0.014	(1.)	0.037	not relevant
	5	1507.5	0.98	1.00	9.96	5-14
	6	416.9	0.87	0.99	29.20	6-10 ; 6-11-14 ; 6-12-13-14
	7	137.9	0.12	0.79	3.29	7-8-14
	8	1097.2	1.00	1.00	56.21	7-8-14
	9	972.6	1.00	(1.)	0.45	not relevant
	10	2112.2	0.56	1.00	15.53	6-10 ; 10=11+14 ; 10=12+13+14
	11	818.7	0.41	1.00	11.48	6-11-14 ; 11=12+13
	12	355.4	0.030	0.98	0.83	not relevant
	13	463.1	1.00	(1.)	0.83	not relevant
	14	1293.5	1.00	1.00	84.40	1-14 ; 5-14 ; 8-14 ; 6-11-14

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Sn-113(m)						
In-113m	1	391.7			64.9	no coincidence
Sn-117m	1	156.0	1.00	0.021	2.11	1-2
	2	158.6	1.00	0.86	86.4	1-2
		158.5			88.51	E_{eff} of lines 1 & 2 $COI = (COI_1 \cdot \gamma_1 + COI_2 \cdot \gamma_2)/(\gamma_1 + \gamma_2)$
Sn-123m	1	160.3			85.6	no coincidence
Sn-125m	1	331.9			99.57	no coincidence
Sn-125	1	1220.9	0.93	(1.)	0.25	not relevant
	2	270.6	0.69	(1.)	0.099	not relevant
	3	1173.3	0.30	(1.)	0.17	not relevant
	4	1151.2	0.19	(1.)	0.11	not relevant
	5	350.9	0.43	(1.)	0.25	not relevant
	6	934.6	0.096	(1.)	0.19	not relevant
	7	652.6	0.018	(1.)	0.038	not relevant
	8	915.5	0.93	(1.)	3.85	2-8-18
	9	893.4	0.06	(1.)	0.27	not relevant
	10	822.5	0.62	(1.)	3.99	5-10-18
	11	800.3	0.15	(1.)	0.99	not relevant
	12	469.8	0.21	(1.)	1.38	5-12-14 ; 5-12-15-19 ; -1*(5-12)
	13	1259.4	0.47	(1.)	0.029	not relevant
	14	1419.7	0.29	(1.)	0.454	not relevant
	15	1087.1	0.71	(1.)	1.11	5-12-15-19
	16	1017.4	0.77	(1.)	0.30	not relevant
	17	1089.2	1.00	(1.)	4.28	4-17 ; 9-17 ; 11-17
	18	1067.1	1.00	(1.)	9.04	5-10-18 ; 1-18 ; 3-18 ; 6-18 ; 8-18
	19	332.1	1.00	0.97	1.31	13-19 ; 12-15-19 ; 7-16-19
		1088.9			5.39	E_{eff} of lines 15 & 17 $COI = (COI_{15} \cdot \gamma_{15} + COI_{17} \cdot \gamma_{17})/(\gamma_{15} + \gamma_{17})$
cont'd						

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,%	Coincidence
Sb-125	1	635.9	0.85	1.00	11.23	1=2+8
	2	208.1	0.014	0.89	0.24	not relevant
(Sn-125	3	606.6			5.02	no coincidence
cont'd)	4	321.0	0.08	0.99	0.412	not relevant
	5	600.6	0.99	1.00	17.61	no coincidence
	6	204.1	0.15	0.91	0.320	not relevant
	7	463.4			10.42	no coincidence
	8	427.9	0.74	0.99	29.6	no coincidence
	9	176.3	1.00	0.87	6.75	4-9 ; 6-9
Sb-122	1	692.8	0.83	(1.)	3.7	1-2
	2	564.1	1.00	1.00	70.55	1-2
Sb-124m1	1	1101.1	1.00	(1.)	0.5	not relevant
	2	498.4	1.00	(1.)	24.5	2-3-4
	3	645.8	1.00	1.00	25.0	1-3-4 ; 2-3-4 ; -1*(3-4)
	4	602.7	1.00	1.00	25.0	1-3-4 ; 2-3-4 ; -1*(3-4)
Sb-124	1	1526.4	0.73	(1.)	0.40	1-23-24 ; 1=2+20
	2	816.9	0.15	(1.)	0.078	not relevant
	3	1376.1	0.80	1.00	0.49	not relevant
	4	662.5	0.026	(1.)	0.015	not relevant
	5	2090.9	0.63	1.00	5.48	5-24 ; 5=6+23 ; 5=7+22 ; 5=8+20+23 ; 5=9+12
	6	1445.3	0.024	(1.)	0.35	not relevant
	7	1368.2	0.27	1.00	2.61	7-21 ; 7-22-24
	8	735.7	0.015	1.00	0.13	not relevant
	9	400.0	0.060	0.99	0.127	not relevant
	10	525.3	0.47	1.00	0.117	not relevant
	11	444.1	0.53	0.99	0.20	not relevant
	12	1691.0	0.93	1.00	47.6	12-24 ; 12=13+23 ; 12=14+22
	13	1045.1	0.035	1.00	1.82	13-23-24 ; 13=15+20
	14	968.2	0.035	1.00	1.88	14-21 ; 14-22-24
	15	335.8	0.0015	0.99	0.08	not relevant
cont'd	16	976.4	0.52	(1.)	0.088	not relevant

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,%	Coincidence
Sb-124	17	1436.6	0.24	(1.)	1.20	11-17-24 ; 17=19+22 ; 17=18+23
(cont'd)	18	970.7	0.18	1.00	0.74	not relevant
	19	713.8	0.57	1.00	2.28	11-19-21 ; 11-19-22-24 ; -1*(11-19)
	20	709.3	0.57	1.00	1.37	2-20-23-24 ; 8-20-23-24 ; 10-20-23-24 ; 15-20-23-24 ; -3*(20-23-24)
	21	1325.5	0.11	1.00	1.55	3-21 ; 7-21 ; 14-21 ; 19-21 ; 21=22+24
	22	722.8	0.89	1.00	10.80	3-22-24 ; 7-22-24 ; 14-22-24 ; 19-22-24 ; -3*(22-24)
	23	645.9	1.00	1.00	7.42	1-23-24 ; 6-23-24 ; 13-23-24 ; 16-23-24 ; 18-23-24 ; 20-23-24 ; -5*(23-24)
	24	602.7	1.00	1.00	97.89	5-24 ; 12-24 ; 17-24 ; 22-24 ; 13-23-24 ; 20-23-24 ; -1*(23-24)
Te-127	1	417.9	0.85	0.98	0.993	1=2+5 ; 1=3+4
	2	360.3	0.12	0.98	0.135	not relevant
	3	215.1	0.035	0.92	0.039	not relevant
	4	202.8	0.93	0.90	0.058	not relevant
	5	57.6	1.00	0.21	0.030	not relevant
Te-129	1	459.6			7.14	no coincidence
Te-131	1	997.2	0.325	(1.)	3.34	not relevant
	2	544.9	0.042	(1.)	0.43	not relevant
	3	948.5	0.86	(1.)	2.26	not relevant
	4	452.3	0.811	0.99	18.2	2-4-5
	5	149.7	1.00	0.79	68.9	1-5 ; 3-5 ; 4-5
I-131	1	364.5	0.93	0.98	81.6	1=2+3
	2	284.3	0.069	0.95	6.20	not relevant
	3	80.2	1.00	0.39	2.63	not relevant
I-128	1	526.6	0.80	0.99	1.59	1-2
	2	442.9	1.00	0.99	16.9	1-2
Cs-134m	1	127.5			12.7	no coincidence

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Cs-134	1	1365.2	0.11	1.00	3.04	1-10
	2	801.9	0.32	1.00	8.73	2-8 ; 2-9-10
	3	569.3	0.57	0.99	15.43	3-7-10
	4	1038.6	0.40	1.00	1.00	4-10 ; 4=5+9 ; 4=6+7
	5	475.4	0.59	0.99	1.465	5-8 ; 5-9-10
	6	242.9	0.008	(1.)	0.021	not relevant
	7	795.8	1.00	1.00	85.44	3-7-10
	8	1168.0	0.18	1.00	1.805	5-8 ; 2-8 ; 8=9+10
	9	563.2	0.82	0.99	8.38	2-9-10 ; 5-9-10 ; -1*(9-10)
	10	604.7	1.00	0.99	97.56	1-10 ; 4-10 ; 3-7-10 ; 2-9-10 ; 5-9-10 ; -1*(9-10)
Ba-131m	1	79.1	1.00	0.076	1.19	1-2
	2	108.5	1.00	0.53	55.2	1-2
Ba-131	1	1047.6	0.46	1.00	1.170	1=2+30 ; 1=3+29 ; 1=4+27 ; 1=5+25 ; 1=6+21 ; 1=7+18 ; 1=8+14+29 ; 1=9+10 ; 1=9+11+29 ; 1=9+12+25
	2	969.2	0.014	(1.)	0.037	not relevant
	3	923.8	0.25	1.00	0.730	not relevant
	4	914.7	0.016	1.00	0.042	not relevant
	5	831.6	0.08	1.00	0.231	not relevant
	6	674.4	0.05	0.99	0.133	not relevant
	7	461.2	0.04	0.98	0.103	not relevant
	8	427.7	0.036	0.99	0.098	not relevant
	9	351.2	0.06	0.99	0.102	not relevant
	10	696.5	0.18	0.99	0.148	not relevant
	11	572.7	0.24	0.99	0.155	not relevant
	12	480.4	0.58	0.99	0.323	not relevant
	13	620.1	0.027	1.00	1.36	13=14+29 ; 13=15+27 ; 13=16+25 ; 13=17+21 ; 13=17+22+29 ; 13=17+23+27
	14	496.3	0.89	0.99	46.8	14-29
	15	486.5	0.038	0.99	2.07	15-27 ; 15-28-30 ; 15=17+23
	16	404.0	0.027	0.99	1.306	16-25 ; 16-26-29
	17	247.0	0.014	0.93	0.641	not relevant
cont'd	18	585.0	0.88	0.99	1.221	7-18 ; 18=19+29 ; 18=20+27

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Ba-131	19	461.2	0.08	0.98	0.103	not relevant
(cont'd)	20	451.4	0.04	0.99	0.045	not relevant
	21	373.2	0.68	0.98	14.0	17-21 ; 21=22+29 ; 21=23+27 ; 21=24+25
	22	249.4	0.16	0.94	2.82	17-22-29
	23	239.6	0.14	0.94	2.40	17-23-27
	24	157.1	0.0013	(1.)	0.190	not relevant
	25	216.1	0.95	0.91	19.7	12-25 ; 16-25 ; 24-25 ; 25=26+29
	26	92.3	0.052	0.59	0.64	not relevant
	27	133.6	0.94	0.69	2.16	4-27 ; 15-27 ; 20-27 ; 17-23-27 ; 27=28+30
	28	54.8	0.06	0.09	0.437	not relevant
	29	123.8	1.00	0.55	29.0	3-29 ; 14-29 ; 22-29 ; 26-29
	30	78.8	1.00	0.37	0.730	not relevant
Ba-133m	1	276.1			18.0	no coincidence
Ba-135m	1	268.2			16.0	no coincidence
Ba-137m	1	661.6			89.9	no coincidence
Ba-139	1	1420.5	0.87	(1.)	0.261	1=2+3
	2	1254.7	0.13	(1.)	0.033	not relevant
	3	165.9	1.00	0.81	23.76	no coincidence
La-140	1	925.2	0.64	1.00	7.09	1-12 ; 1=2+10 ; 1=3+7 ; 1=3+8+11
	2	173.6	0.012	0.98	0.12	not relevant
	3	109.4	0.019	0.53	0.19	not relevant
	4	919.6	0.48	1.00	2.88	4-12 ; 4=5+11
	5	432.5	0.52	0.98	2.94	5-11-12
	6	867.8	1.00	1.00	5.63	6-12
	7	815.8	0.55	1.00	23.5	7-12 ; 7=8+11
	8	328.8	0.45	0.96	20.5	8-11-12
	9	266.6	0.54	0.94	0.49	not relevant
	10	751.8	0.83	1.00	4.40	2-10-12
	11	487.0	1.00	0.99	45.5	9-11-12 ; 5-11-12 ; 8-11-12 ; -2*(11-12)
	12	1596.5	1.00	0.99	95.49	1-12 ; 4-12 ; 6-12 ; 7-12 ; 10-12 ; 5-11-12 ; 8-11-12 ; -1*(11-12)

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Ce-137	1	447.2			2.24	no coincidence
	2	436.6			0.334	no coincidence
Ce-139	1	165.9			80.35	no coincidence
Ce-141	1	145.4			48.2	no coincidence
Ce-143	1	880.4	0.73	(1.)	1.01	1-12 ; 1=2+11
	2	587.3	0.19	(1.)	0.26	not relevant
	3	447.2	0.05	(1.)	0.079	not relevant
	4	722.0	0.41	(1.)	5.32	4=5+12 ; 4=6+7
	5	664.5	0.42	(1.)	5.60	5-12 ; 5=6+8 ; 5=6+9+11
	6	231.6	0.16	0.91	2.04	6-7 ; 6-8-12 ; 6-9-11
	7	490.4	0.90	(1.)	2.13	3-7 ; 6-7 ; 7=8+12
	8	433.0	0.06	(1.)	0.16	not relevant
	9	139.7	0.04	(1.)	0.056	not relevant
	10	350.6	0.07	0.98	3.27	10=11+12
	11	293.3	0.93	0.95	42.8	11-12
	12	57.4	1.00	0.15	12.3	not relevant
Pr-142	1	1575.6			3.7	no coincidence
Nd-147	1	685.9	0.37	0.99	0.78	1=2+12 ; 1=3+10 ; 1=3+11+12 ; 1=4+8 ; 1=4+9+12
	2	594.8	0.12	0.99	0.248	not relevant
	3	275.4	0.42	0.91	0.77	3-10 ; 3-11-12
	4	196.6	0.09	0.81	0.182	not relevant
	5	531.0	0.89	0.98	12.7	5=6+12
	6	439.9	0.08	0.98	1.17	6-12 ; 6=7+11
	7	120.5	0.029	0.52	0.373	not relevant
	8	489.3	0.14	0.98	0.140	not relevant
	9	398.2	0.86	0.97	0.83	4-9-12
	10	410.5	0.07	0.98	0.125	not relevant
	11	319.4	0.93	0.94	1.91	3-11-12 ; 7-11-12 ; -1*(11-12)
	12	91.1	1.00	0.32	28.1	3-11-12 ; 7-11-12 ; 9-12 ; 6-12 ; -1*(11-12)

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Nd-149	1	357.8	0.14	(1.)	0.16	1-25 ; 1-26-38
	2	654.8	0.42	1.00	7.95	2=3+40 ; 2=4+36 ; 2=5+31 ; 2=6+30 ; 2=7+28 ; 2=9+21 ; 2=9+23+36
	3	540.5	0.35	1.00	6.58	3-40 ; 3=7+29 ; 3=9+22
	4	443.6	0.060	0.99	1.15	4-36 ; 4-37-40 ; 4=9+23 ; 4=5+33
	5	384.7	0.014	0.96	0.27	not relevant
	6	366.7	0.029	0.99	0.54	not relevant
	7	294.8	0.030	0.99	0.57	not relevant
	8	258.1	0.020	0.98	0.38	not relevant
	9	229.6	0.026	0.97	0.48	not relevant
	10	96.9	0.0023	0.77	0.034	no coincidence (for effective energy only)
	11	197.8	0.21	(1.)	0.049	11-29-40
	12	423.6	0.34	0.99	7.43	12-40 ; 12=13+39 ; 12=14+37 ; 12=15+32 ; 12=16+29
	13	349.2	0.063	0.98	1.38	13-38 ; 13-39-40 ; 13=17+19+27
	14	326.6	0.21	0.99	4.56	14-36 ; 14-37-40 ; 14=15+33
	15	267.7	0.30	0.92	6.03	line 34 feeds 35 µs level (see IV.2.4) COIsh : 15-31 ; 15-32-40 ; 15-33-36 COInsh : 15-31 ; 15-32-40 ; 15-33-36 ; 15-34-35
	16	177.8	0.0075	0.95	0.16	not relevant
	17	75.7	0.053	0.18	0.23	not relevant
	18	192.0	0.28	0.83	0.57	not relevant
	19	74.7	0.65	0.63	0.98	not relevant
	20	65.4	0.023	0.54	0.031	not relevant
	21	425.2	0.18	0.98	0.27	21=22+40 ; 21=23+36
	22	311.0	0.34	0.95	0.51	not relevant
	23	214.0	0.30	0.84	0.40	not relevant
	24	155.1	0.023	0.92	0.034	no coincidence (for effective energy only)
	25	282.5	0.18	0.92	0.62	not relevant
	26	208.1	0.74	0.83	2.55	20-26-38 ; 20-26-39-40 ; 8-26-38 ; 8-26-39-40 ; -1*(20-26) ; -1*(8-26) ; -1*(26-38) ; -1*(26-39-40)
	27	198.9	0.87	0.81	1.39	17-19-27-38 ; 17-19-27-39-40 ; -1*(17-19-27)
	28	360.1	0.15	0.96	0.15	not relevant
	29	245.7	0.85	0.89	0.80	not relevant
	30	288.2	1.00	0.93	0.69	not relevant
	31	270.2	0.42	0.98	10.7	5-31 ; 15-31 ; 18-31 ; 31=32+40 ; 31=33+36
	32	155.9	0.25	0.93	5.93	5-32-40 ; 18-32-40 ; 15-32-40 ; -2*(32-40)
cont'd	33	58.9	0.10	0.47	1.30	not relevant

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Nd-149 (cont'd)	34	30.0	0.23	0.0029	0.017	feeds 35 μs level ; not relevant
	35	240.2	1.00	0.60	3.94	no coincidence
	36	211.3	0.88	0.85	25.9	4-36 ; 14-36 ; 23-36 ; 33-36 ; 36=37+40
	37	97.0	0.11	0.37	1.45	4-37-40 ; 14-37-40 ; 23-37-40 ; 33-37-40 ; -3*(37-40)
	38	188.6	0.26	0.78	1.79	1-26-38 ; 8-26-38 ; 13-38 ; 17-19-27-38 ; -1*(26-38) ; 38=39+40
	39	74.3	0.74	0.17	1.11	not relevant
	40	114.3	1.00	0.48	19.0	3-40 ; 12-40 ; 22-40 ; 25-40 ; 7-29-40 ; 15-32-40 ; 37-40 ; 39-40
		97.0			1.48	E_{eff} of lines 10 & 37 $COI = (\gamma_{10} + COI_{37}\cdot\gamma_{37})/(\gamma_{10} + \gamma_{37})$
		155.9			5.96	E_{eff} of lines 24 & 32 $COI = (\gamma_{24} + COI_{32}\cdot\gamma_{32})/(\gamma_{24} + \gamma_{32})$
		198.9			1.44	E_{eff} of lines 11 & 27 $COI = (COI_{11}\cdot\gamma_{11} + COI_{27}\cdot\gamma_{27})/(\gamma_{11} + \gamma_{27})$
		349.1			1.54	E_{eff} of lines 1 & 13 $COI = (COI_{1}\cdot\gamma_{1} + COI_{13}\cdot\gamma_{13})/(\gamma_{1} + \gamma_{13})$
		423.6			7.71	E_{eff} of lines 12 & 21 $COI = (COI_{12}\cdot\gamma_{12} + COI_{21}\cdot\gamma_{21})/(\gamma_{12} + \gamma_{21})$
Pm-149	1	285.9			3.1	no coincidence
Nd-151	1	1716.4	0.08	(1.)	0.14	not relevant
	2	1314.5	0.23	(1.)	0.37	not relevant
	3	1617.5	0.23	(1.)	0.38	not relevant
	4	1333.3	0.12	(1.)	0.20	not relevant
	5	1032.3	0.07	(1.)	0.12	not relevant
	6	562.6	0.29	(1.)	0.24	not relevant
cont'd	7	1475.1	0.07	(1.)	0.11	not relevant

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Nd-151 (cont'd)	8	1072.7	0.11	(1.)	0.18	not relevant
	9	809.6	0.15	(1.)	0.24	not relevant
	10	1270.9	0.17	(1.)	0.17	not relevant
	11	904.7	0.29	(1.)	0.28	not relevant
	12	1107.1	0.45	(1.)	0.47	not relevant
	13	1180.6	0.72	(1.)	15.3	13-47 ; 13=14+46
	14	1122.1	0.22	(1.)	4.62	14-44 ; 14-45-48 ; 14-46-47
	15	1041.7	0.023	(1.)	0.49	not relevant
	16	1016.4	0.62	(1.)	2.92	not relevant
	17	958.3	0.12	(1.)	0.57	not relevant
	18	943.3	0.33	(1.)	0.40	not relevant
	19	542.0	0.48	(1.)	0.58	not relevant
	20	820.0	0.08	(1.)	0.12	not relevant
	21	487.0	0.16	(1.)	0.24	not relevant
	22	797.5	0.56	1.00	5.55	22-47 ; 22=23+46 ; 22=24+43 ; 22=26+37
	23	739.4	0.16	(1.)	1.53	not relevant
	24	658.5	0.09	(1.)	0.84	not relevant
	25	589.7	0.03	(1.)	0.31	not relevant
	26	373.7	0.014	(1.)	0.14	not relevant
	27	618.8	0.23	(1.)	0.32	not relevant
	28	736.4	0.60	1.00	7.19	28-47 ; 28=29+46 ; 28=30+43 ; 28=31+37
	29	677.9	0.22	(1.)	2.63	29-44 ; 29-45-48 ; 29-46-47
	30	596.8	0.07	(1.)	0.80	not relevant
	31	312.4	0.024	(1.)	0.29	not relevant
	32	585.5	0.19	0.98	1.58	not relevant
	33	300.6	0.24	0.99	1.97	9-33-37-47 ; 5-33-37-47 ; -1*(33-37-47)
	34	263.5	0.10	(1.)	0.80	not relevant
	35	460.6	0.31	(1.)	1.11	not relevant
	36	402.2	0.56	0.97	1.96	34-36-44 ; 34-36-45-48 ; 34-36-46-47 ; 6-19-36-44 ; 8-36-44 ; 6-19-36-45-48 ; 6-19-36-46-47 ; 8-36-45-48 ; 8-36-46-47 ; 2-36-44 ; 2-36-45-48 ; 2-36-46-47 ; -2*(6-19-36) ; -2*(8-36) ; -2*(34-36) ; -2*(2-36) ; -3*(36-44) ; -3*(36-45-48) ; -3*(36-46-47)
cont'd	37	423.5	0.97	0.97	6.61	33-37-47 ; 31-37-47 ; 26-37-47 ; 11-37-47 ; 4-37-47 ; -4*(37-47)

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Nd-151 (cont'd)	38	332.8	0.55	(1.)	0.77	not relevant
	39	149.4	0.10	0.93	0.32	not relevant
	40	69.2	0.38	0.58	1.25	not relevant
	41	255.6	0.59	0.91	16.9	40-41 ; 32-41 ; 30-41 ; 27-41 ; 24-41 ; 15-41 ; 12-41 ; 3-41 ; 41=42+48 ; 41=43+47
	42	171.0	0.14	0.77	4.12	40-42-48 ; 32-42-48 ; 30-42-48 ; 27-42-48 ; 24-42-48 ; 15-42-48 ; 12-42-48 ; 3-42-48 ; -7*(42-48)
	43	138.8	0.27	0.92	7.76	40-43-47 ; 32-43-47 ; 30-43-47 ; 27-43-47 ; 24-43-47 ; 15-43-47 ; 12-43-47 ; 3-43-47 ; -7*(43-47)
	44	175.0	0.74	0.95	7.59	39-44 ; 21-38-44 ; 34-36-44 ; 19-36-44 ; 8-36-44 ; 2-36-44 ; 29-44 ; 23-44 ; 20-44 ; 18-44 ; 17-44 ; 14-44 ; 10-44 ; 7-44 ; 1-44 ; -3*(36-44) ; 44=45+48 ; 44=46+47
	45	89.9	0.17	0.80	1.77	not relevant
	46	58.5	0.09	0.50	0.92	not relevant
	47	116.7	1.00	0.85	46.8	46-47 ; 43-47 ; 33-37-47 ; 35-47 ; 28-47 ; 22-47 ; 16-47 ; 13-47
	48	85.3	1.00	0.28	2.72	not relevant
Pm-151	1	796.0	0.34	(1.)	0.055	not relevant
	2	848.7	0.29	(1.)	0.300	not relevant
	3	785.0	0.22	(1.)	0.229	not relevant
	4	678.2	0.12	(1.)	0.043	not relevant
	5	772.8	0.40	(1.)	0.96	not relevant
	6	709.1	0.06	(1.)	0.149	not relevant
	7	668.7	0.17	(1.)	0.36	not relevant
	8	717.7	0.66	1.00	4.1	8-43 ; 8-44
	9	654.2	0.039	(1.)	0.250	not relevant
	10	669.2	0.26	(1.)	0.29	not relevant
	11	564.9	0.32	(1.)	0.36	not relevant
	12	636.2	0.45	(1.)	1.47	not relevant
	13	572.5	0.017	(1.)	0.052	not relevant
	14	321.9	0.22	(1.)	0.099	not relevant
	15	445.7	0.58	0.99	4.1	15=17+47 ; 15=20+34
cont'd	16	440.8	0.22	1.00	1.53	16=19+37

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Pm-151 (Nd-151 cont'd)	17	379.9	0.14	(1.)	0.97	not relevant
	18	341.0	0.01	(1.)	0.071	no coincidence (for effective energy only)
	19	277.6	0.007	0.90	0.21	not relevant
	20	236.6	0.023	(1.)	0.163	not relevant
	21	346.1	0.10	(1.)	0.038	no coincidence (for effective energy only)
	22	206.7	0.09	(1.)	0.037	not relevant
	23	290.8	0.44	0.98	0.88	not relevant
	24	186.6	0.09	(1.)	0.169	not relevant
	25	344.9	0.053	0.99	2.18	25=27+45 ; 25=28+43 ; 25=29+38 ; 25=29+40+47 ; 25=30+36
	26	340.1	0.57	0.99	22.9	26=27+46 ; 26=28+44 ; 26=29+39 ; 26=30+37
	27	275.2	0.17	0.98	7.2	27-45 ; 27-46 ; 27=29+41
	28	240.1	0.09	0.97	3.89	28-43 ; 28-44 ; 28=29+42
	29	177.2	0.09	0.74	3.87	29-38 ; 29-39 ; 29-40-47 ; 29-41
	30	176.5	0.022	0.94	0.87	30-36 ; 30-37
	31	156.2	0.046	0.64	0.151	not relevant
	32	147.5	0.87	(1.)	0.149	not relevant
	33	202.0	0.51	(1.)	0.94	not relevant
	34	209.0	0.67	0.83	1.79	4-34 ; 7-34 ; 11-34 ; 20-34 ; 22-34 ; 24-34 ; 34=35+45
	35	139.3	0.19	0.61	0.51	not relevant
	36	168.4	0.34	0.67	0.92	30-36 ; 19-36 ; 14-36 ; 13-36 ; 9-36 ; 6-36 ; 3-36 ; 1-36
	37	163.6	0.62	0.73	1.63	30-37 ; 19-37 ; 14-37 ; 13-37 ; 9-37 ; 6-37 ; 3-37 ; 1-37
	38	167.8	0.73	0.94	8.8	29-38 ; 31-38 ; 32-38 ; 38=40+47
	39	162.9	0.08	0.91	0.89	29-39 ; 31-39 ; 32-39
	40	101.9	0.12	0.81	1.31	not relevant
	41	98.0	0.033	0.77	0.34	not relevant
	42	62.9	0.02	0.59	0.218	not relevant
	43	104.8	0.58	0.36	3.55	2-43 ; 5-43 ; 8-43 ; 10-43 ; 12-43 ; 23-43 ; 28-43 ; 33-43 ; 42-43
cont'd	44	100.0	0.42	0.33	2.56	not relevant

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Pm-151	45	69.7	0.20	0.19	0.48	not relevant
(Nd-151	46	64.9	0.80	0.16	1.97	not relevant
cont'd)	47	65.8	0.99	0.17	1.17	not relevant
		163.3			2.52	E_{eff} of lines 37 & 39 $COI = (\gamma_{37}.COI_{37} + \gamma_{39}.COI_{39})/(\gamma_{37} + \gamma_{39})$
		167.9			9.7	E_{eff} of lines 36 & 38 $COI = (\gamma_{36}.COI_{36} + \gamma_{38}.COI_{38})/(\gamma_{36} + \gamma_{38})$
		177.1			4.74	E_{eff} of lines 29 & 30 $COI = (\gamma_{29}.COI_{29} + \gamma_{30}.COI_{30})/(\gamma_{29} + \gamma_{30})$
		340.1			23.0	E_{eff} of lines 18 & 26 $COI = (\gamma_{18} + \gamma_{26}.COI_{26})/(\gamma_{18} + \gamma_{26})$
		344.9			2.22	E_{eff} of lines 21 & 25 $COI = (\gamma_{21} + \gamma_{25}.COI_{25})/(\gamma_{21} + \gamma_{25})$
Sm-153	1	69.7	0.97	0.16	5.25	1-2
	2	103.2	0.99	0.34	28.30	1-2
Sm-155	1	522.5	0.53	(1.)	0.15	not relevant
	2	61.8	0.68	0.11	0.22	not relevant
	3	246.0	0.62	0.87	3.70	1-3 ; 2-3 ; 3=4+5
	4	141.2	0.37	0.90	2.00	1-4-5 ; 2-4-5 ; -1*(4-5)
	5	104.3	0.99	0.80	74.0	4-5
Eu-152m	1	1411.7	0.90	(1.)	0.045	not relevant
	2	1314.7	0.59	(1.)	0.95	2=3+7 ; 2=4+6+7
	3	970.4	0.37	(1.)	0.60	not relevant
	4	699.3	0.044	(1.)	0.072	not relevant
cont'd	5	703.5	0.80	(1.)	0.068	not relevant

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Eu-152m	6	271.1	1.00	0.92	0.076	not relevant
(cont'd)	7	344.3	1.00	0.96	2.44	1-7 ; 3-7 ; 5-7 ; 4-6-7
	8	995.9	0.40	(1.)	0.070	not relevant
	9	1389.0	0.97	(1.)	0.77	9-14
	10	961.1	0.95	(1.)	0.20	not relevant
	11	963.4	0.44	(1.)	11.9	11=12+14
	12	841.6	0.56	(1.)	14.5	12-14
	13	562.9	1.00	0.99	0.22	8-13-14
	14	121.8	1.00	0.46	7.16	9-14 ; 10-14 ; 12-14 ; 13-14
Eu-152	1	1299.1	0.89	(1.)	1.640	1-12 ; 1=2+10 ; 1=3+9
	2	712.8	0.053	(1.)	0.096	not relevant
	3	534.2	0.024	(1.)	0.043	not relevant
	4	1089.7	0.71	(1.)	1.756	4-12 ; 4=5+11 ; 4=6+10
	5	678.6	0.20	0.99	0.479	not relevant
	6	503.4	0.064	0.98	0.15	not relevant
	7	778.9	0.94	1.00	13.06	7-12 ; 7=8+11
	8	367.8	0.063	0.99	0.868	not relevant
	9	764.9	0.48	0.99	0.175	not relevant
	10	586.3	0.79	0.98	0.461	not relevant
	11	411.1	1.00	0.98	2.277	8-11-12 ; 5-11-12 ; -1*(11-12)
	12	344.3	1.00	0.96	26.76	1-12 ; 4-12 ; 7-12 ; 10-12 ; 5-11-12 ; 8-11-12 ; -1*(11-12)
	13	564.0	0.53	(1.)	0.511	13-24 ; 13-25-33 ; 13-26
	14	1212.9	0.68	1.00	1.440	14-32-33
	15	1408.0	0.84	1.00	21.03	15-33 ; 15=16+27 ; 15=17+25 ; 15=18+22
	16	488.7	0.017	0.99	0.427	not relevant
	17	444.0	0.11	0.99	2.79	17-24 ; 17-25-33 ; 17-26
	18	295.9	0.018	0.97	0.448	not relevant
	19	1005.3	0.74	1.00	0.647	not relevant
	20	926.3	0.42	(1.)	0.290	not relevant
	21	482.3	0.046	0.94	0.027	21-29 ; 21-30-33 ; 21-31-32-33
	22	1112.1	0.76	1.00	13.60	18-22-33 ; 22=23+32
	23	867.4	0.24	1.00	4.275	18-23-32-33
cont'd	24	1085.9	0.40	1.00	10.12	13-24 ; 17-24 ; 24=26+32+33 ; 24=25+33

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ,%	Coincidence
Eu-152 (cont'd)	25	964.0	0.59	1.00	14.5	13-25-33 ; 17-25-33 ; 25=26+32
	26	719.0	0.011	0.99	0.27	not relevant
	27	919.4	0.72	(1.)	0.437	not relevant
	28	656.5	0.62	0.95	0.14	not relevant
	29	810.5	0.20	(1.)	0.328	not relevant
	30	688.7	0.57	0.96	0.883	not relevant
	31	444.0	0.21	0.98	0.32	31-32-33
	32	244.7	1.00	0.90	7.59	14-32-33 ; 19-32-33 ; 20-32-33 ; 18-23-32-33 ; 28-32-33 ; 26-32-33 ; 31-32-33 ; -6*(32-33)
	33	121.8	1.00	0.46	28.81	23-32-33 ; 14-32-33 ; 30-33 ; 22-33 ; 17-25-33 ; 15-33 ; -1*(32-33)
		444.0			3.11	E_{eff} of lines 17 & 31 $COI = (COI_{17}.\gamma_{17} + COI_{31}.\gamma_{31})/(\gamma_{17} + \gamma_{31})$
Eu-154	1	1596.5	0.066	1.00	1.820	1-31 ; 1=2+27 ; 1=2+28+30 ; 1=3+25 ; 1=3+26+30 ; 1=4+21 ; 1=4+22+30 ; 1=5+20 ; 1=6+18 ; 1=7+15 ; 1=8+12+29 ; 1=8+13+27
	2	904.1	0.029	1.00	0.915	not relevant
	3	723.3	0.71	1.00	20.28	3-24 ; 3-25-31 ; 3-26-30
	4	591.8	0.17	1.00	5.00	4-21-31 ; 4-22-30-31
	5	478.3	0.008	0.98	0.22	not relevant
	6	467.9	0.002	0.98	0.056	not relevant
	7	322.0	0.003	0.93	0.067	not relevant
	8	188.2	0.009	0.95	0.23	not relevant
	9	845.4	0.71	(1.)	0.589	not relevant
	10	1246.6	0.57	1.00	0.870	not relevant
	11	1188.6	0.70	(1.)	0.082	not relevant
	12	850.6	0.43	(1.)	0.23	not relevant
	13	715.8	0.33	0.99	0.17	not relevant
	14	1047.4	0.66	(1.)	0.142	not relevant
	15	1274.4	0.97	1.00	34.9	15-31 ; 15=16+27
	16	582.0	0.023	1.00	0.912	not relevant
cont'd	17	892.8	0.66	1.00	0.523	not relevant

Radio-nuclide	Line Code	E_γ, keV	a	c	γ,%	Coincidence
Eu-154 (cont'd)	18	1128.4	0.77	1.00	0.27	not relevant
	19	880.6	0.23	1.00	0.082	not relevant
	20	1118.5	0.44	1.00	0.10	not relevant
	21	1004.8	0.80	1.00	18.17	4-21-31 ; 21=22+30
	22	756.9	0.20	1.00	4.60	4-22-30-31
	23	676.6	0.60	0.95	0.14	not relevant
	24	996.4	0.47	1.00	10.50	3-24 ; 24=25+31 ; 24=26+30+31
	25	873.3	0.52	1.00	12.27	3-25-31 ; 25=26+30
	26	625.2	0.014	0.99	0.31	not relevant
	27	692.4	0.64	0.96	1.810	16-27-31 ; 8-13-27-31 ; 9-27-31 ; 2-27-31 ; -3*(27-31) ; 27=28+30
	28	444.4	0.18	0.98	0.569	not relevant
	29	557.6	0.98	0.99	0.26	not relevant
	30	248.0	1.00	0.90	6.95	10-30-31 ; 11-30-31 ; 14-30-31 ; 17-30-31 ; 19-30-31 ; 23-30-31 ; 3-26-30-31 ; 4-22-30-31 ; 16-28-30-31 ; 9-28-30-31 ; 2-28-30-31 ; -8*(30-31) ; -2*(28-30-31)
	31	123.1	1.00	0.45	41.0	1-31 ; 15-31 ; 4-21-31 ; 3-25-31 ; 27-31 ; 4-22-30-31
Gd-153	1	69.7	0.93	0.15	2.57	not relevant
	2	103.2	1.00	0.38	22.2	1-2
	3	97.4			31.3	no coincidence
Gd-159	1	363.6	0.98	0.99	8.0	no coincidence
	2	348.2	0.82	(1.)	0.17	2=3+4
	3	290.3	0.11	0.91	0.03	not relevant
	4	58.0	1.00	0.083	1.8	not relevant
Gd-161	1	529.5	0.22	(1.)	1.26	1-19 ; 1=2+15 ; 1=3+13 ; 1=4+10 ; 1=5+7
	2	270.9	0.16	0.98	0.67	not relevant
	3	191.4	0.12	0.95	0.63	not relevant
	4	168.5	0.021	0.68	0.081	not relevant
	5	105.6	0.39	0.33	0.73	not relevant
	6	480.1	0.40	(1.)	2.68	5-6 ; 6=8+14
	7	423.9	0.027	(1.)	0.18	not relevant
cont'd	8	165.2	0.42	0.93	2.58	5-8-14 ; 5-8-15 ; 5-8-16 ; -2*(5-8)

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,%	Coincidence
Gd-161	9	85.8	0.033	0.69	0.15	not relevant
(cont'd)	10	360.9	0.71	0.99	60.1	10-19 ; 10=11+18
	11	283.6	0.072	0.98	5.95	11-17 ; 11-18-19 ; 11=12+16
	12	102.3	0.21	0.78	13.9	12-14 ; 12-15 ; 12-16
	13	338.0	0.75	0.93	1.68	3-13-19 ; 9-13-19 ; -1*(13-19)
	14	314.9	0.92	0.93	22.7	2-14 ; 12-14 ; 5-8-14
	15	258.6	0.042	0.88	0.98	not relevant
	16	181.2	0.038	0.73	0.74	not relevant
	17	133.7	0.040	0.52	0.16	not relevant
	18	77.4	0.96	0.15	1.06	not relevant
	19	56.2	1.00	0.08	3.77	not relevant
Tb-160	1	1251.3	0.40	(1.)	0.10	not relevant
	2	1312.2	0.66	1.00	2.838	2-22 ; 2=3+21
	3	1115.1	0.33	1.00	1.548	3-21-22
	4	1102.6	0.56	(1.)	0.579	not relevant
	5	337.3	0.35	0.99	0.343	not relevant
	6	1271.9	0.76	1.00	7.505	6-22 ; 6=7+19 ; 6=8+16 ; 6=8+17+21
	7	392.5	0.14	0.99	1.361	7-18 ; 7-19-22 ; 7-20 ; 7=9+13
	8	309.6	0.09	0.99	0.873	not relevant
	9	93.9	0.0055	0.39	0.054	not relevant
	10	1199.9	0.70	1.00	2.379	10-22 ; 10=11+21
	11	1002.9	0.30	1.00	1.084	not relevant
	12	1177.9	0.32	1.00	14.97	12-22 ; 12=13+19 ; 12=13+20+21 ; 12=14+16 ; 12=14+17+21
	13	298.6	0.59	0.99	26.64	13-18 ; 13-19-22 ; 13-20
	14	215.6	0.086	0.97	4.06	14-16-22 ; 14-17-21-22
	15	872.1	0.66	(1.)	0.21	not relevant
	16	962.3	0.81	1.00	9.72	8-16-22 ; 14-16-22 ; 16=17+21 ; -1*(16-22)
	17	765.3	0.19	1.00	2.18	14-17-21-22 ; 8-17-21-22 ; 5-17-21-22 ; -2*(17-21-22)
	18	966.2	0.45	1.00	25.06	7-18 ; 13-18 ; 18=19+22
	19	879.4	0.54	1.00	30.35	7-19-22 ; 13-19-22 ; 19=20+21 ; -1*(19-22)
cont'd	20	682.3	0.011	0.99	0.60	not relevant

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,%	Coincidence
Tb-160	21	197.0	1.00	0.81	5.18	1-21-22 ; 3-21-22 ; 4-21-22 ; 11-21-22 ; 13-20-21-22 ; 14-17-21-22 ; 8-17-21-22 ; 5-17-21-22 ; 15-21-22 ; -2*(17-21-22) ; -6*(21-22)
(cont'd)	22	86.8	1.00	0.18	13.3	2-22 ; 6-22 ; 10-22 ; 12-22 ; 11-21-22 ; 3-21-22 ; 13-19-22 ; 14-16-22 ; 14-17-21-22 ; -2*(21-22)
		965.1			34.78	E_{eff} of lines 16 & 18 $COI = (COI_{16}.\gamma_{16} + COI_{18}.\gamma_{18})/(\gamma_{16} + \gamma_{18})$
Dy-165m	1	108.2			3.01	no coincidence
	2	515.5	1.00	0.99	1.527	no coincidence (see IV.2.4)
Dy-165	1	660.1	0.17	0.98	0.027	not relevant
	2	694.1	0.27	(1.)	0.012	not relevant
	3	633.4	0.36	0.98	0.568	feeds 1.51 µs level (see IV.2.4) COIsh : 3=6+10 ; 3=5+11 coinsh : 3-13 ; 3=6+10 ; 3=5+11
	4	575.6	0.049	0.98	0.079	not relevant
	5	565.7	0.083	(1.)	0.132	not relevant
	6	545.8	0.102	0.97	0.162	not relevant
	7	279.7	0.31	0.88	0.498	7-8 ; 7-9-14
	8	715.3	0.85	(1.)	0.534	7-8 ; 8=9+14
	9	620.6	0.15	(1.)	0.097	not relevant
	10	87.7	0.77	0.20	0.014	not relevant
	11	67.7	1.00	0.11	0.014	not relevant
cont'd	12	57.9	1.00	0.07	0.014	not relevant

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Dy-165 (cont'd)	13	361.7	1.00	0.78	0.84	fed by 1.51 µs level (see IV.2.4) 2-13 ; 3-13 ; 1-12-13 ; 4-12-13 ; 5-11-13 ; 6-10-13 ; -1*(12-13) ; not accurate
	14	94.7	1.00	0.24	3.58	no coincidence
Ho-166	1	1662.4	0.39	1.00	0.121	1=2+6
	2	1581.9	0.61	1.00	0.183	2-6
	3	1379.4	0.98	1.00	0.93	3-6 ; 3=4+5
	4	674.0	0.021	1.00	0.020	not relevant
	5	705.3	0.51	1.00	0.015	not relevant
	6	80.6	1.00	0.15	6.2	3-6
Er-167m	1	207.8			41.7	no coincidence
Er-171	1	372.0	0.83	0.93	0.26	not relevant
	2	362.9	0.041	0.92	0.020	not relevant
	3	85.6	0.68	0.17	0.060	not relevant
	4	277.4	0.24	0.85	0.58	not relevant
	5	237.1	0.14	0.78	0.302	3-5-6 ; 3-5-7 ; 3-5-8-15 ; 1-5-6 ; 1-5-7 ; 1-5-8-15 ; -2*(3-5) -2*(1-5) ; -1*(5-6) ; -1*(5-7) ; -1*(5-8-15)
	6	676.1	0.49	0.98	0.29	not relevant
	7	670.7	0.43	0.98	0.25	not relevant
	8	559.5	0.081	0.97	0.047	not relevant
	9	210.6	0.93	0.95	0.642	feeds 2.60 µs level (see IV.2.4) COIsh : 3-4-9 ; 1-4-9 ; 2-9 ; -1*(4-9) COInsh : 3-4-9-10-14 ; 3-4-9-10-15 ; 3-4-9-11-13 ; 2-9-10-14 ; 1-4-9-10-14 ; 1-4-9-10-15 ; 1-4-9-11-13 ; 2-9-10-15 2-9-11-13 ; -1*(3-4-9) ; -1*(4-9-11-13) ; -1*(1-4-9) ; -1*(3-4-9-10) ; -1*(1-4-9-10) ; -1*(9-11-13) ; -1*(2-9-10) ; -1*(2-9) ; -1*(4-9-10-14) ; -1*(9-10-14) ; -1*(4-9-10-15) ; -1*(9-10-15) ; +2*(9-10) ; +2*(4-9)
cont'd						

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Er-171 (cont'd)	10	308.3	0.69	0.98	64.4	10-14 ; 10-15
	11	295.9	0.31	0.98	28.9	11-13
	12	210.1	0.18	0.82	0.007	no coincidence (for effective energy only)
	13	124.0	0.73	0.42	9.1	11-13
	14	116.7	0.085	0.36	2.30	10-14
	15	111.6	0.92	0.30	20.5	10-15
		210.6			0.649	E_{eff} of lines 9 & 12 $COI = (COI_9 \cdot \gamma_9 + \gamma_{12})/(\gamma_9 + \gamma_{12})$
Tm-170	1	84.3			3.26	no coincidence
Yb-169	1	93.6	1.00	0.21	2.66	1-2 ; 1-3-4 ; 1-3-5-8 ; 1-3-5-9 ; 1-3-6-7 ; -1*(1-3-5) ; -2*(1-3)
	2	261.1	0.021	0.97	1.90	1-2-8 ; 1-2-9 ; -1*(1-2) ; 2=3+5
	3	63.1	0.98	0.47	43.7	1-3-4 ; 1-3-5-8 ; 1-3-5-9 ; 1-3-6-7 ; -3*(1-3) ; -1*(3-5)
	4	307.7	0.12	0.94	10.8	1-3-4 ; 4=5+9 ; 4=6+7
	5	198.0	0.52	0.69	34.9	1-3-5-8 ; 1-3-5-9 ; -1*(1-3-5)
	6	177.2	0.36	0.63	21.5	1-3-6-7
	7	130.5	0.68	0.46	11.1	1-3-6-7
	8	118.2	0.078	0.38	1.88	1-3-5-8 ; 2-8
	9	109.8	0.92	0.29	17.4	1-3-5-9 ; 2-9
Yb-175	1	396.3	0.66	0.95	6.5	1=2+6 ; 1=3+4
	2	282.5	0.31	0.97	3.0	2-6 ; 2=3+5
	3	144.9	0.034	0.88	0.34	3-5-6 ; 3-4
	4	251.4	0.43	0.92	0.082	not relevant
	5	137.7	0.57	0.47	0.104	3-5-6
	6	113.8	1.00	0.30	1.88	2-6 ; 3-5-6

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Yb-177	1	1241.4	0.86	(1.)	3.36	1=2+15
	2	1119.6	0.14	(1.)	0.545	2-15
	3	1109.0	0.024	(1.)	0.18	not relevant
	4	1080.1	0.76	(1.)	5.5	feeds 0.12 μs level (see IV.2.4)
						4=5+12 ; 4-14 (for τ in μs range)
	5	941.7	0.14	(1.)	1.01	line 12 feeds 0.12 μs level (see IV.2.4)
						5=6+11 ; 5-12-14 (for τ in μs range)
	6	779.3	0.017	(1.)	0.12	not relevant
	7	1149.7	0.50	(1.)	0.643	7=8+15
	8	1028.0	0.50	(1.)	0.633	8-15
	9	899.2	0.87	(1.)	0.644	feeds 0.12 μs level (see IV.2.4)
						9=10+12 ; 9-14 (for τ in μs range)
	10	760.4	0.07	(1.)	0.055	not relevant
	11	162.5	1.00	(1.)	0.060	not relevant
	12	138.6	1.00	0.42	1.33	feeds 0.12 μs level (see IV.2.4)
						5-12-14 ; 10-12-14 ; 6-11-12-14 ; -2*(12-14)
						(for τ in μs range)
	13	147.2	0.52	0.51	0.18	not relevant
	14	150.4	1.00	0.66	20.0	fed by 0.12 μs level (see IV.2.4)
						5-12-14 ; 9-14 ; 4-14
	15	121.6	1.00	0.34	3.41	2-15 ; 3-15 ; 8-15 ; 13-15
Lu-176m	1	88.4			8.90	no coincidence
Lu-177	1	208.4	0.96	0.95	11.0	1-2
	2	112.9	1.00	0.48	6.60	1-2

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Note : From Hf-175, γ-KX(IC) and γ-KX(EC) are considered in addition to γ-γ coincidence, unless otherwise stated; the meaning of the notation is as follows (exemplary) : A-B : only γ-γ coincidence has to be taken into account (γ-KX coincidence negligible) A-B/Kα1 → β'1(B) : γ-γ as well as γ-Kα1, γ-Kα2 and γ-Kβ'1 coincidence has to be taken into account (γ-Kβ'2, etc. coincidence is negligible). A-Kα1,α2(B) : γ-Kα1 and γ-Kα2 coincidence has to be taken into account (γ-Kβ'1, etc. coincidence is negligible).						
Hf-175	1	432.8	0.37	0.95	1.48	1=2+5 ; 1=3+4 ; (γ-KX not considered)
	2	318.9	0.04	0.87	0.17	not relevant
	3	89.4	0.59	0.17	2.26	3-4 ; (γ-KX not considered)
				α_K=4.2		
	4	343.6	0.99	0.90	87.0	Kα1 → β'2(EC276)-4 ; Kα1 → β'1(EC186)-3/Kα1 → β'1(3)-4
	5	113.8	1.00	0.34	0.31	not relevant
						EC276 = 276 keV EC transition ; ε = 83% ; P_K = 0.74
						EC186 = 186 keV EC transition ; ε = 16% ; P_K = 0.72
						ω_K = 0.952
						kα1(54.1 kev) = 0.503
						kα2(53.0 keV) = 0.287
						kβ'1(61.2 keV) = 0.167
						kβ'2(63.0 keV) = 0.043
Hf-179m	1	160.7	1.00	0.028	2.79	not relevant
				α_K=19.		
	2	214.1	1.00	0.95	95.2	1/Kα1 → β'2(1)-2
						ω_K = 0.954
						kα1(55.8 kev) = 0.502
						kα2(54.6 keV) = 0.287
						kβ'1(63.2 keV) = 0.168
						kβ'2(65.0 keV) = 0.043

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,%	Coincidence
Hf-180m	1	500.7	0.21	0.95	12.8	1-4-5-6 ; 1=2+3 ; (γ-KX not considered)
	2	57.5	0.79	0.65	48.4	not relevant
	3	443.1	1.00	0.98	85.0	2-3-4/Kα1(4)-5/Kα1 → β'1(5)-6/Kα1 → β'1(6)
	4	332.3	1.00	0.95	94.4	1-4-5/Kα1 → β'1(5)-6/Kα1 → β'1(6) ;
				α_K=0.037		2-3-4-5/Kα1 → β'1(5)-6/Kα1 → β'1(6) ;
						-1*[4-5/Kα1 → β'1(5)-6/Kα1 → β'1(6)]
	5	215.2	1.00	0.83	81.7	1-4/Kα1(4)-5-6/Kα1 → β'1(6) ;
				α_K=0.122		2-3-4/Kα1(4)-5-6/Kα1 → β'1(6) ;
						-1*[4/Kα1(4)-5-6/Kα1 → β'1(6)]
	6	93.3	1.00	0.17	17.0	1-4-5-6 ; 2-3-4-5-6 ; -1*(4-5-6) ; (γ-KX not considered)
				α_K=1.10		
						ω_K = 0.954
						kα1(55.8 kev) = 0.502
						kα2(54.6 keV) = 0.287
						kβ'1(63.2 keV) = 0.168
Hf-181	1	136.9	1.00	0.36	0.76	1-3 ; 1-4-5 ; (γ-KX not considered)
	2	133.0	1.00	0.44	41.7	2-3 ; 2-4-5/Kα1 → β'1(5)
				α_K=0.497		
	3	482.2	0.83	0.97	82.8	2/Kα1 → β'1(2)-3 ; 3=4+5
	4	345.9	0.16	0.95	17.2	2-4-5 ; (γ-KX not considered)
	5	136.2	1.00	0.36	5.2	2-4-5 ; (γ-KX not considered)
				α_K=1.388		
						ω_K = 0.956
						kα1(57.5 kev) = 0.501
						kα2(56.3 keV) = 0.288
						kβ'1(65.2 keV) = 0.169
		133.4			47.7	E_{eff} of lines 1, 2 & 5
						$COI = (COI_1.\gamma_1 + COI_2.\gamma_2 + COI_5.\gamma_5)/(\gamma_1 + \gamma_2 + \gamma_5)$
		136.3			5.96	E_{eff} of lines 1 & 5
						$COI = (COI_1.\gamma_1 + COI_5.\gamma_5)/(\gamma_1 + \gamma_5)$

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,%	Coincidence
Ta-182m	1	185.1	0.99	0.27	23.4	1-2 ; 1-3/Kα1 → β'2(3)-4/Kα1 → β'2(4)
				α_K=0.62		
	2	318.4	0.12	0.93	6.55	not relevant
	3	171.6	0.88	0.50	46.8	1/Kα1 → β'1(1)-3-4/Kα1 → β'2(4)
				α_K=0.84		
	4	146.8	1.00	0.41	35.6	1/Kα1 → β'1(1)-3/Kα1 → β'2(3)-4
				α_K=1.22		
						ω_K = 0.956
						kα1(57.5 kev) = 0.501
						kα2(56.3 keV) = 0.288
						kβ'1(65.2 keV) = 0.169
						kβ'2(67.0 keV) = 0.042
Ta-182	1	264.1	0.21	0.90	3.64	1-20 ; 1-21-30 ; 1-23 ; 1=3+16 ; 1=4+6 ; (γ-KX not considered)
	2	222.1	0.43	0.95	7.50	2-18-30 ; 2-19-29-30 ; 2=4+7 ; (γ-KX not considered)
	3	179.4	0.18	0.60	3.09	3-11 ; 3-12-30 ; 3-13-29 ; 3-14-27 ; 3-14-28-30 ; 3-15-24 ;
						3-16-21-30 ; 3-16-23-27 ; 3-16-23-28-30 ; 3-17-18 ; -1*(3-14)
						-1*(3-16) ; -1*(3-16-23) ; 3=4+8 ; (γ-KX not considered)
	4	65.7	0.16	0.25	2.80	not relevant
	5	1158.1	0.05	0.99	0.35	not relevant
	6	198.4	0.23	0.77	1.44	4-6-20 ; 4-6-21-30 ; 4-6-23-27 ; 4-6-23-28-30 ; -2*(4-6) ;
						-1*(4-6-23) ; 6=8+16 ; (γ-KX not considered)
	7	156.4	0.41	0.91	2.63	4-7-18-30 ; 4-7-19-29-30 ; 7=8+17 ; (γ-KX not considered)
	8	113.7	0.29	0.25	1.87	4-8-11 ; 4-8-12-30 ; 4-8-13-29 ; 4-8-14-27 ; 4-8-14-28-30 ;
				α_K=2.3		4-8-15-24 ; 4-8-16-21-30 ; 4-8-16-23-27 ; 4-8-16-23-28 ;
						4-8-17-18 ; -1*(4-8-16-23) ; -1*(4-8-16) ; -1*(4-8-14) ;
						-6*(4-8) ; (γ-KX not considered)
	9	1342.7	0.40	1.00	0.26	not relevant
	10	1113.4	0.60	0.99	0.39	not relevant
	11	1373.8	0.02	1.00	0.23	not relevant
	12	1273.7	0.057	1.00	0.66	not relevant
cont'd	13	1044.4	0.021	0.99	0.24	not relevant

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,%	Coincidence
Ta-182 (cont'd)	14	152.4	0.62	0.90	6.95	3-14-27 ; 3-14-28-30 ; 4-8-14-27 ; 4-8-14-28-30 ; -1*(3-14) ; -1*(4-8-14) ; -1*(14-27) ; -1*(14-28-30) ; 14=16+23 ; (γ-KX not considered)
	15	116.4	0.038	0.85	0.445	not relevant
	16	84.7	0.23	0.13 α_K=5.0	2.63	not relevant
	17	42.7	0.021	0.71	0.266	not relevant
	18	1231.0	0.85	1.00	11.58	2-18-30 ; 4-7-18-30 ; -1*(18-30) ; 18=19+29 ; (γ-KX not considered)
	19	1001.6	0.15	1.00	2.09	2-19-29-30 ; 4-7-19-29-30 ; 17-19-29-30 ; -2*(19-29-30) ; (γ-KX not considered)
	20	1289.0	0.0235	0.99	1.36	1-20 ; 4-6-20 ; 16-20 ; 20=21+30 ; 20=22+29+30 ; 20=23+27 ; 20=23+28+30 ; (γ-KX not considered)
	21	1189.0	0.274	1.00	16.44	1-21-30 ; 6-21-30 ; 16-21-30 ; -2*(21-30) ; 21=22+29 ; 21=23+28 ; (γ-KX not considered)
	22	959.7	0.0059	0.99	0.36	not relevant
	23	67.8	0.69	0.83	57.1	not relevant
	24	1257.4	0.54	1.00	1.50	4-8-15-24 ; 3-15-24 ; -1*(15-24) ; 24=25+30 ; 24=26+29+30 ; (γ-KX not considered)
	25	1157.3	0.23	0.99	0.64	3-15-25-30 ; 4-8-15-25-30 ; -1*(15-25-30) ; 25=26+29 ; (γ-KX not considered)
	26	928.0	0.22	1.00	0.63	not relevant
	27	1221.4	0.44	1.00	27.17	1-23-27 ; 6-23-27 ; 16/Kα1 → β'1(16)-23-27 ; 3-14-27 ; 8/Kα1,α2(8)-14-27 ; -2*(23-27) ; -1*(14-27) ; 27=28+30
	28	1121.3	0.56	1.00	35.30	3-14-28-30/Kα1 → β'1(30) ; 8/Kα1,α2(8)-14-28-30/Kα1 → β'1(30) ; 1-23-28-30/Kα1 → β'1(30) ; 6-23-28-30/Kα1 → β'1(30) ; 16/Kα1 → β'1(16)-23-28-30/Kα1 → β'1(30) ; -1*[28-30/Kα1 → β'1(30)] ; -1*[14-28-30/Kα1 → β'1(30)] ; -2*[23-28-30/Kα1 → β'1(30)]
	29	229.3	1.00	0.85	3.64	4-5-29-30 ; 10-29-30 ; 3-13-29-30 ; 2-19-29-30 ; 7-19-29-30 ; 22-29-30 ; 15-26-29-30 ; -1*(19-29-30) ; -5*(29-30) ; (γ-KX not considered)
cont'd						

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,%	Coincidence
Ta-182 (cont'd)	30	100.1	1.00	0.23 α_K=0.76	14.23	12-30 ; 2-18-30 ; 4-7-18-30 ; 1-21-30 ; 16-21-30 ; 25-30 ; 16-23-28-30 ; 1-23-28-30 ; 8-14-28-30 ; 3-14-28-30 ; 26-29-30 ; 2-19-29-30 ; -1*(14-28-30) ; -1*(21-30) ; -1*(23-28-30) ; -1*(28-30) ; -1*(18-30) ; -1*(29-30) ; (γ-KX not considered) ω = 0.957 kα1(59.3 kev) = 0.500 kα2(58.0 keV) = 0.288 kβ'1(67.2 keV) = 0.169
W-183m	1	102.5	0.43	(0.04) α_K=14.	2.35	not relevant
	2	107.9	0.79	0.22	18.2	1/Kα1 → β'1(1)-2-3/Kα1 → β'1(3) ; 1/Kα1 → β'1(1)-2-4-5 ; -1*[1/Kα1 → β'1(1)-2]
	3	99.1	0.55	0.21 α_K=(1.)	8.6	not relevant
	4	52.6	0.45	0.10	6.7	not relevant
	5	46.5	1.00	0.11	5.9	not relevant ω = 0.957 kα1(59.3 kev) = 0.500 kα2(58.0 keV) = 0.288 kβ'1(67.2 keV) = 0.169
W-187	1	745.2	0.67	0.98	0.318	not relevant
	2	246.2	0.25	0.74	0.127	not relevant
	3	239.0	0.18	0.75	0.10	not relevant
	4	772.9	1.00	0.98	4.40	no coincidence ; (γ -KX not considered)
cont'd	5	685.7	0.50	1.00	29.2	5=6+13 (see IV.2.4)

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
W-187 (cont'd)	6	551.5	0.093	0.99	5.44	6-13 (not accurate ; see IV.2.4)
	7	479.6	0.41	0.98	23.4	feeds 0.56 μs level (see IV.2.4) COIsh : no coincidence COInsh : 7-12/Kα1 → β'2(12)-13/Kα1 → β'2(13)
	8	625.5	0.41	0.99	1.16	3-8 ; 8=9+11 ; (γ-KX not considered)
	9	113.8	0.13	0.21	0.074	not relevant
	10	618.3	0.96	0.97	6.7	2-10 ; (γ-KX not considered)
	11	511.8	1.00	0.98	0.69	not relevant
	12	72.1	0.97	0.53 α_K=0.72	11.9	not relevant
	13	134.2	1.00	0.31 α_K=1.86	9.5	line 12 is fed by 0.56 μs level (see IV.2.4) 1-13 ; 6-13 ; 7-12-13 ; (γ-KX not considered) ω = 0.959 kα1(61.1 kev) = 0.499 kα2(59.7 keV) = 0.288 kβ'1(69.2 keV) = 0.170 kβ'2(71.2 keV) = 0.043
Re-186	1	122.3			0.70	no coincidence ; (γ-KX not considered)
	2	137.2			9.5	no coincidence

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Re-188m	1	106.0	0.98	0.18 α_K=3.5	10.8	1-3
	2	92.5	0.91	0.13 α_K=5.4	5.15	2-3
	3	63.6	1.00	0.22	21.6	1/Kα1 → β'2(1)-3 ; 2/Kα1 → β'2(2)-3 ω_K = 0.959 kα1(61.1 kev) = 0.499 kα2(59.7 keV) = 0.288 kβ'1(69.2 keV) = 0.170 kβ'2(71.2 keV) = 0.043
Re-188	1	1308.0	0.63	0.99	0.067	not relevant
	2	1150.9	0.16	0.99	0.017	not relevant
	3	1017.6	0.38	0.99	0.015	not relevant
	4	1132.3	0.47	1.00	0.088	not relevant
	5	829.5	0.79	1.00	0.411	5-11 ; 5-12-13 ; (γ-KX not considered)
	6	672.5	0.21	1.00	0.111	not relevant
	7	825.9	0.66	0.99	0.051	not relevant
	8	931.3	0.88	0.99	0.565	8-13 ; 8=9+12 ; (γ-KX not considered)
	9	453.3	0.12	0.97	0.071	not relevant
	10	635.0	0.98	0.99	0.15	2-10-13 ; 3-10-13 ; 6-10-13 ; -2*(10-13) ; (γ-KX not considered)
	11	633.1	0.54	0.99	1.26	9-11 ; 7-11 ; 5-11 ; 4-11 ; 1-11 ; 11=12+13 ; (γ-KX not considered)
	12	478.0	0.46	0.98	1.04	9-12-13 ; 7-12-13 ; 5-12-13 ; 4-12-13 ; 1-12-13 ; -4*(12-13) ; (γ-KX not considered)
	13	155.0	1.00	0.55	15.0	8-13 ; 12-13
		633.3			1.41	E_{eff} of lines 10 & 11 $COI = (COI_{10}\cdot\gamma_{10} + COI_{11}\cdot\gamma_{11})/(\gamma_{10} + \gamma_{11})$

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,%	Coincidence
Os-185	1	880.5	0.72	0.99	5.00	1=2+7 ; 1=3+5 ; (γ-KX not considered)
	2	234.2	0.089	0.67	0.42	not relevant
	3	162.9	0.19	0.43	0.56	not relevant
	4	874.8	1.00	0.99	6.61	no coincidence ; (γ-KX not considered)
	5	717.4	0.65	0.99	4.12	3-5 ; 5=6+8 ; (γ-KX not considered)
	6	592.1	0.21	0.99	1.33	3-6-8 ; (γ-KX not considered)
	7	646.1	1.00	0.99	81.0	Kα1 → β'2(EC369)-7
	8	125.4	1.00	0.27	0.35	not relevant
						EC369 = 369 keV EC transition ; ε = 80.4% ; P_K = 0.78
						ω_K = 0.959
						kα1(61.1 kev) = 0.499
						kα2(59.7 keV) = 0.288
						kβ'1(69.2 keV) = 0.170
						kβ'2(71.2 keV) = 0.043
Os-190m	1	616.1	1.00	0.99	98.5	1-2-3/Kα1(3)-4/Kα1 → β'1(4)
	2	502.6	1.00	0.98	97.8	1-2-3/Kα1(3)-4/Kα1 → β'1(4)
	3	361.1	1.00	0.95	95.2	1-2-3-4/Kα1 → β'1(4)
				α_K=0.031		
	4	186.7	1.00	0.70	69.9	1-2-3/Kα1(3)-4
				α_K=0.205		
						ω_K = 0.961
						kα1(63.0 kev) = 0.497
						kα2(61.5 keV) = 0.288
						kβ'1(71.3 keV) = 0.171
Os-191	1	129.4			25.9	no coincidence

Radio-nuclide	Line Code	E_γ,keV	a	c	γ,%	Coincidence
Os-193	1	560.0	0.0079	(1.)	0.0028	no coincidence (for effective energy only) ; (γ-KX not considered)
	2	441.0	0.28	0.91	0.092	not relevant
	3	142.1	0.71	0.30	0.075	3-10-27 ; (γ-KX not considered)
	4	532.0	0.16	0.96	0.083	not relevant
	5	350.2	0.015	0.84	0.0071	not relevant
	6	251.6	0.59	0.68	0.217	6-18 ; 6-19-31 ; 6-20-30 ; 6-21-29-31 ; (γ-KX not considered)
	7	154.7	0.15	0.36	0.030	not relevant
	8	556.0	0.031	(1.)	0.0032	no coincidence (for effective energy only) ; (γ-KX not considered)
	9	525.0	0.072	0.99	0.016	not relevant
	10	298.8	0.89	0.91	0.186	3-10-27 ; (γ-KX not considered)
	11	559.3	0.69	0.95	0.486	11=12+30 ; (γ-KX not considered)
	12	420.3	0.25	0.90	0.17	not relevant
	13	557.4	0.56	0.95	1.304	7-13 ; 13=14+31 ; 13=15+30 ; 13=17+18 ; (γ-KX not considered)
	14	484.3	0.074	0.93	0.17	not relevant
	15	418.4	0.023	0.96	0.055	not relevant
	16	377.3	0.033	0.86	0.071	not relevant
	17	96.8	0.31	0.13	0.099	not relevant
				α_K=5.55		
	18	460.5	0.47	0.93	3.95	17/Kα1,α2(17)-18 ; 6-18 ; 18=19+31 ; 18=20+30 ; 18=21+28
	19	387.5	0.16	0.88	1.26	17-19-31 ; 6-19-31 ; -1*(19-31) ; 19=21+29 ; (γ-KX not considered)
	20	321.6	0.17	0.81	1.28	17-20-30 ; 6-20-30 ; -1*(20-30) ; (γ-KX not considered)
	21	280.4	0.18	0.74	1.24	17-21-28 ; 17-21-29-31 ; 6-21-28 ; 6-21-29-31 ; -1*(17-21) ; -1*(6-21) ; -1*(21-28) ; -1*(21-29-31) ; (γ-KX not considered)
	22	98.7	0.014	0.13	0.017	not relevant
	23	361.8	0.38	0.85	0.296	22-23 ; 23=24+31 ; 23=25+28 ; (γ-KX not considered)
	24	288.8	0.17	0.90	0.14	not relevant
	25	181.8	0.45	0.47	0.193	22-25-28 ; 22-25-29-31 ; -1*(22-25) ; (γ-KX not considered)
	26	218.8	0.58	0.61	0.0087	26-30 ; (γ-KX not considered)
	27	219.1	1.00	0.79	0.276	3-10-27 ; 2-27 ; (γ-KX not considered)
	28	180.0	0.085	0.51	0.182	21-28 ; 25-28 ; 16-28 ; 4-28 ; 28=29+31 ; (γ-KX not considered)
cont'd						

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Os-193 (cont'd)	29	107.0	0.92	0.16	0.64	not relevant
	30	138.9	1.00	0.30	4.266	12-30 ; 20-30
	31	73.0	1.00	0.13	3.24	not relevant
						ω_K = 0.962 kα1(64.9 kev) = 0.497 kα2(63.3 keV) = 0.288
		139.0			4.34	E_{eff} of lines 3 & 30 $COI = (COI_3 \cdot \gamma_3 + COI_{30} \cdot \gamma_{30})/(\gamma_3 + \gamma_{30})$
		180.9			0.375	E_{eff} of lines 25 & 28 $COI = (COI_{25} \cdot \gamma_{25} + COI_{28} \cdot \gamma_{28})/(\gamma_{25} + \gamma_{28})$
		219.1			0.285	E_{eff} of lines 26 & 27 $COI = (COI_{26} \cdot \gamma_{26} + COI_{27} \cdot \gamma_{27})/(\gamma_{26} + \gamma_{27})$
		557.9			1.80	E_{eff} of lines 1, 8, 11, & 13 $COI = (\gamma_1 + \gamma_8 + COI_{11} \cdot \gamma_{11} + COI_{13} \cdot \gamma_{13})/(\gamma_1 + \gamma_8 + \gamma_{11} + \gamma_{13})$
Ir-192	1	588.6	0.82	0.98	4.57	not relevant
	2	416.5	0.13	0.96	0.664	not relevant
	3	604.4	0.20	0.98	8.20	not relevant
	4	308.5	0.79	0.91	29.68	4-6 ; 4-7-8 ; (γ-KX not considered)
	5	468.1	1.00	0.97	48.1	2-5-8 ; (γ-KX not considered)
	6	612.5	0.14	0.98	5.34	not relevant
	7	296.0	0.86	0.90	29.02	4-7-8 ; 1-7-8 ; -1*(7-8) ; (γ-KX not considered)
	8	316.5	1.00	0.92	82.85	4-7-8 ; 1-7-8 ; 3-8 ; 5-8 ; -1*(7-8)

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Ir-194	1	1468.9	0.56	(1.)	0.191	not relevant
	2	1175.6	0.17	(1.)	0.060	not relevant
	3	1000.1	0.29	(1.)	0.046	not relevant
	4	1183.5	0.55	(1.)	0.30	not relevant
	5	889.9	0.092	(1.)	0.050	not relevant
	6	589.2	0.25	(1.)	0.140	not relevant
	7	1150.8	0.95	(1.)	0.60	7-13 ; (γ-KX not considered)
	8	938.7	0.34	(1.)	0.60	8-13 ; 8=9+12 ; (γ-KX not considered)
	9	645.1	0.66	(1.)	1.17	9-11 ; 9-12-13 ; (γ-KX not considered)
	10	300.7	0.84	(1.)	0.35	not relevant
	11	622.0	0.116	(1.)	0.34	not relevant
	12	293.5	0.88	0.94	2.6	2-12-13 ; 3-12-13 ; 5-12-13 ; 9-12-13 ; 6-10-12-13 ; -4*(12-13)
	13	328.4	1.00	(1.)	13.1	1-13 ; 4-13 ; 7-13 ; 8-13 ; 9-12-13 ; 10-12-13 ; -1*(12-13)
Pt-197m	1	346.5	1.00	0.11	11.2	1-2
	2	53.1	1.00	0.011	1.08	not relevant
Pt-199						
Au-199	1	208.2	0.97	0.53	8.4	1=2+3
	2	49.8	0.028	0.053	0.328	not relevant
	3	158.4	1.00	0.56	36.8	no coincidence
Au-198	1	675.9	0.87	0.97	1.06	1-2 ; (γ-KX not considered)
	2	411.8	1.00	0.96	95.56	no coincidence
Hg-197m	1	165.0		α_K=77	0.274	not relevant
	2	134.0	1.00	0.37	34.0	Kα1 → β'2(1)-2
						ω_K = 0.966 kα1(70.8 kev) = 0.493 kα2(68.9 keV) = 0.290 kβ'1(80.2 keV) = 0.170 kβ'2(82.5 keV) = 0.047

TABLE IV.2-4 : continued

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Hg-203	1	279.2			81.46	no coincidence
Th-233						
Pa-233	1	415.8	0.45	0.87	1.82	1=3+9 ; 1=4+7 ; (γ-KX not considered)
	2	375.4	0.17	0.85	0.676	2=3+10 ; 2=4+8 ; (γ-KX not considered)
	3	103.9	0.17	0.17	0.68	not relevant
	4	75.3	0.22	0.071	1.31	not relevant
	5	398.6	0.41	0.89	1.48	5=6+9 ; (γ-KX not considered)
	6	86.6	0.59	0.14	2.05	not relevant
	7	340.5	0.40	0.57	4.44	4-7
	8	300.1	0.59	0.51	6.64	4-8
	9	312.0	0.98	0.55	38.6	6-9
	10	271.6	0.024	0.69	0.96	not relevant
U-239						
Np-239	1	226.4			0.34	no coincidence (for effective energy only)
	2	334.3			2.05	2=4+7
	3	315.9			1.61	3=4+8
	4	106.1	0.85	0.79	22.9	4-6/Kα1 → β3(6) ; 4-7/Kα1 → β3(7) ; 4-8/Kα1,α2(8) ; (interference from 106.5 keV negligible)
	5	285.5	0.011	0.80	0.781	4-5 ; 5=7+9
	6	277.6	0.39	0.40	14.2	4-6
				α_K=1.22		
	7	228.2	0.44	0.27	10.8	4-7
				α_K=1.95		
	8	209.8	0.16	0.22	3.27	4-8
cont'd				α_K=2.4		

Radio-nuclide	Line Code	E_γ, keV	a	c	γ, %	Coincidence
Np-239 (U-239 cont'd)	9	57.3	0.65	0.0044	0.10	not relevant ω_K = 0.977 kα1(103.8 kev) = 0.479 kα2(99.6 keV) = 0.299 kβ1(117.3 keV) = 0.106 kβ'2(120.6 keV) = 0.060 kβ3(116.3 keV) = 0.056
		228.1			11.1	E_{eff} of lines 1 & 7 $COI = (\gamma_1 + COI_7 \cdot \gamma_7)/(\gamma_1 + \gamma_7)$

TABLE IV.2-5 : Exemplary COI-values ($N_p = N'_p/COI$) for point sources measured at 6 discrete distances to the active body of a 101 cm^3 Ge-detector, with an amplifier's pulse shaping time constant τ = 2 µs (only relevant in case of delayed γ-γ coincidence ; see IV.2.4).

[position 0 : 2.15 cm; position 1 : 5.28 cm; position 2 : 8.28 cm; position 3 : 11.27 cm; position 4 : 14.27 cm; position 5 : 17.27 cm].

NOTE : THE DATA CANNOT BE USED FOR ACCURATE CORRECTIONS !

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI) Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Na-24	1368.6	0.9316	0.9770	0.9884	0.9927	0.9953	0.9967
	2754.0	0.9209	0.9739	0.9868	0.9918	0.9945	0.9961
Mg-27	170.7	0.9144	0.9722	0.9859	0.9913	0.9942	0.9958
	843.8	0.9986	0.9996	0.9998	0.9999	0.9999	0.9999
	1014.4	1.0023	1.0007	1.0003	1.0002	1.0001	1.0001
Al-28	1778.9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
S-37	3103.8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Cl-38	1642.4	0.9276	0.9758	0.9877	0.9924	0.9950	0.9965
	2167.5	0.9429	0.9810	0.9904	0.9940	0.9960	0.9972
K-42	312.7	0.9212	0.9739	0.9868	0.9918	0.9946	0.9962
	1524.7	0.9980	0.9994	0.9997	0.9998	0.9999	0.9999
Ca-47	489.2	0.9138	0.9720	0.9859	0.9912	0.9941	0.9957
	530.4	0.9130	0.9718	0.9858	0.9912	0.9941	0.9957
	767.0	0.9497	0.9839	0.9919	0.9950	0.9966	0.9975
	807.9	0.9071	0.9704	0.9851	0.9908	0.9938	0.9954
	1297.1	1.0033	1.0010	1.0005	1.0003	1.0002	1.0001
Sc-47	159.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI) Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Ca-49	143.2	0.9115	0.9702	0.9849	0.9905	0.9938	0.9957
	856.1	0.9276	0.9758	0.9877	0.9924	0.9950	0.9965
	987.3	0.9333	0.9775	0.9886	0.9929	0.9954	0.9968
	1144.5	0.9246	0.9737	0.9867	0.9918	0.9946	0.9962
	1408.9	0.9333	0.9775	0.9886	0.9929	0.9954	0.9968
	3084.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Sc-46	889.3	0.9184	0.9732	0.9864	0.9916	0.9944	0.9960
	1120.5	0.9152	0.9724	0.9860	0.9913	0.9942	0.9958
Ti-51	320.1	0.9989	0.9996	0.9998	0.9999	0.9999	0.9999
	608.5	0.8868	0.9652	0.9825	0.9892	0.9927	0.9944
	928.6	1.0095	1.0030	1.0014	1.0008	1.0005	1.0004
V-52	1333.6	0.9187	0.9731	0.9864	0.9915	0.9944	0.9960
	1434.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Cr-51	320.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Mn-56	846.8	0.9680	0.9893	0.9946	0.9966	0.9978	0.9985
	1810.7	0.9145	0.9722	0.9859	0.9913	0.9942	0.9958
	2113.1	0.9145	0.9722	0.9859	0.9913	0.9942	0.9958
Fe-59	142.6	0.9131	0.9714	0.9855	0.9910	0.9940	0.9957
	192.3	0.9165	0.9722	0.9860	0.9913	0.9942	0.9958
	334.8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1099.2	0.9945	0.9983	0.9992	0.9995	0.9996	0.9997
	1291.6	1.0026	1.0005	1.0002	1.0001	1.0001	1.0000
Co-60	1173.2	0.9205	0.9738	0.9867	0.9918	0.9945	0.9961
	1332.5	0.9191	0.9734	0.9865	0.9916	0.9944	0.9960
Ni-65	366.3	0.9183	0.9732	0.9864	0.9916	0.9944	0.9960
	1115.5	0.9656	0.9892	0.9945	0.9966	0.9977	0.9983
	1481.8	1.0083	1.0026	1.0013	1.0008	1.0005	1.0003

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI) Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Cu-64	511.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1345.9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Cu-66	1039.2	0.9980	0.9994	0.9997	0.9998	0.9999	0.9999
Zn-65	1115.5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Zn-69m	438.6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Ga-72	479.6	0.7517	0.9142	0.9559	0.9726	0.9815	0.9865
	600.9	0.8124	0.9364	0.9675	0.9798	0.9864	0.9901
	629.9	0.9871	0.9945	0.9971	0.9982	0.9988	0.9991
	786.5	0.6653	0.8859	0.9416	0.9637	0.9756	0.9823
	810.9	0.8880	0.9631	0.9813	0.9884	0.9922	0.9944
	834.0	0.9133	0.9711	0.9853	0.9909	0.9939	0.9957
	894.2	0.8313	0.9429	0.9708	0.9819	0.9879	0.9912
	970.5	0.7744	0.9230	0.9606	0.9755	0.9835	0.9879
	1050.8	0.8293	0.9427	0.9708	0.9819	0.9878	0.9911
	1215.1	0.8126	0.9367	0.9676	0.9799	0.9864	0.9901
	1230.9	0.9951	0.9998	0.9995	0.9992	0.9993	0.9994
	1260.1	0.7142	0.9036	0.9508	0.9694	0.9794	0.9849
	1276.8	0.7744	0.9230	0.9606	0.9755	0.9835	0.9879
	1291.3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
cont'd	1464.0	1.1339	1.0446	1.0217	1.0126	1.0082	1.0058

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI) Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Ga-72	1596.7	0.8466	0.9489	0.9739	0.9838	0.9891	0.9921
(cont'd)	1861.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	2201.7	0.9149	0.9724	0.9860	0.9913	0.9942	0.9958
	2491.0	0.9411	0.9812	0.9904	0.9940	0.9959	0.9970
	2501.8	0.9275	0.9765	0.9881	0.9926	0.9950	0.9964
	2507.9	0.9197	0.9738	0.9867	0.9918	0.9945	0.9960
Ge-77	211.1	0.8899	0.9659	0.9829	0.9895	0.9929	0.9945
	215.5	0.8888	0.9637	0.9816	0.9886	0.9923	0.9943
	264.4	0.8939	0.9668	0.9833	0.9898	0.9930	0.9947
	367.4	1.3577	1.1088	1.0542	1.0331	1.0226	1.0175
	416.3	0.8400	0.9488	0.9742	0.9841	0.9892	0.9918
	558.1	0.8122	0.9384	0.9688	0.9808	0.9869	0.9901
	1085.2	0.9973	0.9991	0.9996	0.9997	0.9998	0.9999
	1087.0	0.7985	0.9353	0.9674	0.9800	0.9863	0.9895
	1193.3	0.8899	0.9659	0.9829	0.9895	0.9929	0.9945
As-76	554.5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	559.1	0.7700	0.9251	0.9621	0.9765	0.9842	0.9884
	559.2	0.7729	0.9260	0.9625	0.9768	0.9844	0.9886
	563.2	0.8824	0.9617	0.9806	0.9880	0.9919	0.9940
	571.3	0.8504	0.9502	0.9747	0.9843	0.9894	0.9923
	657.1	1.0527	1.0162	1.0081	1.0050	1.0034	1.0026
	665.3	0.8149	0.9384	0.9686	0.9806	0.9869	0.9903
	740.1	0.8279	0.9438	0.9715	0.9824	0.9881	0.9913
	771.8	0.8733	0.9587	0.9790	0.9870	0.9912	0.9935
	867.6	0.8262	0.9415	0.9702	0.9815	0.9875	0.9909
	1129.9	0.8512	0.9510	0.9750	0.9845	0.9895	0.9923
	1212.9	0.8610	0.9540	0.9766	0.9855	0.9902	0.9929
	1215.1	0.9922	0.9970	0.9982	0.9987	0.9990	0.9992
	1216.1	1.0475	1.0151	1.0073	1.0042	1.0027	1.0019
	1228.5	0.9103	0.9713	0.9854	0.9909	0.9939	0.9954
	1439.1	0.8611	0.9541	0.9766	0.9855	0.9902	0.9929
	1453.6	0.8642	0.9551	0.9772	0.9858	0.9905	0.9930
	1787.6	1.0821	1.0265	1.0128	1.0074	1.0048	1.0034

TABLE IV.2-5 : continued

Radio-nuclide	E_γ, keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Se-75	96.7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	121.1	0.8904	0.9659	0.9829	0.9895	0.9929	0.9946
	136.0	0.8899	0.9658	0.9829	0.9895	0.9928	0.9945
	198.6	0.9357	0.9627	0.9827	0.9899	0.9934	0.9954
	264.7	0.9321	0.9634	0.9825	0.9897	0.9932	0.9951
	279.5	0.9514	0.9739	0.9878	0.9929	0.9954	0.9968
	303.9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	400.7	1.6800	1.2045	1.0948	1.0540	1.0347	1.0241
Br-80	616.3	0.9941	0.9981	0.9990	0.9994	0.9996	0.9997
	639.2	0.9108	0.9713	0.9855	0.9911	0.9940	0.9956
	665.8	0.9968	0.9990	0.9995	0.9997	0.9998	0.9998
	704.0	0.9108	0.9713	0.9855	0.9911	0.9940	0.9956
Br-82	92.2	0.8440	0.9465	0.9726	0.9830	0.9886	0.9917
	221.5	0.8459	0.9471	0.9729	0.9831	0.9886	0.9917
	273.5	0.7586	0.9170	0.9574	0.9735	0.9822	0.9870
	554.3	0.8075	0.9347	0.9666	0.9792	0.9861	0.9899
	606.3	0.7463	0.9138	0.9560	0.9727	0.9815	0.9863
	619.1	0.7864	0.9273	0.9628	0.9769	0.9844	0.9886
	698.4	0.7588	0.9173	0.9576	0.9737	0.9822	0.9869
	776.5	0.8117	0.9364	0.9675	0.9798	0.9864	0.9901
	827.8	0.8405	0.9466	0.9728	0.9831	0.9886	0.9918
	835.2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	952.1	0.7683	0.9222	0.9604	0.9755	0.9834	0.9876
	1007.6	0.8393	0.9462	0.9726	0.9830	0.9886	0.9917
	1044.0	0.8280	0.9424	0.9707	0.9818	0.9878	0.9911
	1061.4	0.8233	0.9286	0.9650	0.9788	0.9860	0.9901
	1317.5	0.8585	0.9538	0.9764	0.9853	0.9900	0.9926
	1474.9	0.8742	0.9595	0.9793	0.9870	0.9912	0.9934
	1650.3	0.8496	0.9530	0.9762	0.9852	0.9898	0.9922

Radio-nuclide	E_γ, keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Rb-86	1076.6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Rb-88	898.0	0.9216	0.9738	0.9867	0.9918	0.9946	0.9962
	1366.3	0.9351	0.9780	0.9889	0.9931	0.9955	0.9970
	1382.4	0.8171	0.9371	0.9679	0.9800	0.9867	0.9907
	1779.8	0.8455	0.9477	0.9733	0.9834	0.9889	0.9921
	1836.0	0.9353	0.9788	0.9893	0.9933	0.9956	0.9968
	2677.9	0.9241	0.9747	0.9872	0.9920	0.9947	0.9963
Sr-85m	151.2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	231.7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Sr-85	514.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Sr-87m	388.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Y-90m	202.5	0.9990	0.9997	0.9998	0.9999	0.9999	1.0000
	479.5	0.8883	0.9659	0.9830	0.9897	0.9929	0.9945
	682.0	1.2354	1.0726	1.0346	1.0201	1.0130	1.0091
Zr-95	235.7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	724.2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	742.2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	756.7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Nb-95	765.8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Zr-97	254.2	0.8910	0.9635	0.9814	0.9885	0.9923	0.9944
	355.4	0.8829	0.9609	0.9801	0.9877	0.9917	0.9941
	507.1	0.9846	0.9950	0.9975	0.9985	0.9990	0.9992
	602.4	0.8339	0.9451	0.9721	0.9827	0.9883	0.9914
	703.7	0.8474	0.9499	0.9746	0.9843	0.9894	0.9922
cont'd	1021.3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Radio-nuclide	E_γ, keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Zr-97	1148.0	0.8329	0.9455	0.9724	0.9829	0.9884	0.9914
(cont'd)	1276.1	0.9177	0.9736	0.9867	0.9918	0.9945	0.9959
	1362.7	1.0088	1.0028	1.0014	1.0008	1.0005	1.0004
	1750.5	0.9370	0.9809	0.9903	0.9940	0.9958	0.9968
Nb-97m	743.3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Nb-97	657.9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1024.5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Nb-94m	702.6	0.9149	0.9723	0.9860	0.9913	0.9942	0.9958
	871.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Mo-99	181.1	0.8639	0.9560	0.9778	0.9862	0.9908	0.9933
	366.4	0.9967	0.9990	0.9995	0.9997	0.9998	0.9998
	739.5	0.9032	0.9689	0.9846	0.9907	0.9937	0.9951
	778.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Mo-99/Tc-99m	140.5	0.9987	0.9996	0.9998	0.9999	0.9999	0.9999
Mo-101	80.9	0.9074	0.9697	0.9847	0.9905	0.9936	0.9954
	191.9	0.9588	0.9865	0.9932	0.9958	0.9971	0.9979
	195.9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	192.4	0.9588	0.9865	0.9932	0.9958	0.9971	0.9979
	408.7	0.9396	0.9801	0.9898	0.9937	0.9958	0.9970
	499.7	0.8900	0.9640	0.9818	0.9887	0.9924	0.9945
	505.9	0.9073	0.9698	0.9848	0.9906	0.9937	0.9954
	590.7	0.9345	0.9786	0.9892	0.9933	0.9955	0.9968
	695.6	0.9237	0.9750	0.9873	0.9921	0.9947	0.9962
	713.0	0.8928	0.9653	0.9824	0.9891	0.9927	0.9946
	870.9	0.9383	0.9797	0.9897	0.9936	0.9957	0.9969
cont'd	877.4	0.9399	0.9802	0.9900	0.9938	0.9958	0.9970

Radio-nuclide	E_γ, keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Mo-101	934.0	0.8966	0.9661	0.9828	0.9894	0.9929	0.9948
(cont'd)	1012.3	0.9326	0.9783	0.9890	0.9932	0.9954	0.9966
	1161.0	0.9079	0.9700	0.9848	0.9906	0.9937	0.9954
	1251.0	0.8811	0.9617	0.9805	0.9881	0.9919	0.9940
	1304.0	1.0326	1.0104	1.0050	1.0029	1.0019	1.0013
	1532.5	0.9019	0.9686	0.9841	0.9902	0.9934	0.9951
Tc-101	127.2	0.8614	0.9560	0.9779	0.9864	0.9908	0.9930
	179.7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	184.1	0.8639	0.9428	0.9719	0.9831	0.9888	0.9918
	306.8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	531.4	0.8433	0.9391	0.9701	0.9821	0.9880	0.9910
	545.1	1.0032	1.0009	1.0004	1.0002	1.0001	1.0001
	715.5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Ru-97	215.7	0.9991	0.9997	0.9999	0.9999	0.9999	1.0000
	324.5	0.9999	0.9999	1.0000	1.0000	1.0000	1.0000
	569.3	0.8906	0.9664	0.9832	0.9898	0.9930	0.9946
Ru-103	497.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	557.0	0.9970	0.9975	0.9990	0.9994	0.9996	0.9997
	610.3	1.0005	1.0002	1.0001	1.0000	1.0000	1.0000
Ru-105	149.1	0.8546	0.9532	0.9763	0.9854	0.9901	0.9925
	262.8	0.9073	0.9706	0.9852	0.9909	0.9938	0.9954
	316.4	0.9032	0.9692	0.9845	0.9904	0.9935	0.9952
	326.1	0.8981	0.9679	0.9838	0.9901	0.9932	0.9949
	350.2	0.8877	0.9639	0.9820	0.9890	0.9925	0.9943
	393.4	0.8910	0.9662	0.9831	0.9896	0.9929	0.9946
	413.5	0.8910	0.9662	0.9831	0.9896	0.9929	0.9946
	469.4	0.9113	0.9720	0.9859	0.9913	0.9941	0.9956
cont'd	499.3	0.9683	0.9894	0.9943	0.9962	0.9974	0.9980

TABLE IV.2-5 : continued

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Ru-105 (cont'd)	556.2	1.0374	1.0118	1.0057	1.0034	1.0022	1.0016
	676.4	1.0143	1.0044	1.0021	1.0012	1.0008	1.0006
	724.3	1.0020	1.0006	1.0003	1.0002	1.0001	1.0001
	875.9	0.9947	0.9997	0.9947	0.9996	0.9996	0.9952
	969.4	1.0151	1.0045	1.0022	1.0012	1.0008	1.0006
Rh-105m	129.7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Rh-105	306.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	319.2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Rh-104m	51.4	0.9991	0.9995	0.9998	0.9999	0.9999	0.9999
	97.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Rh-104	555.8	0.9972	0.9991	0.9995	0.9997	0.9998	0.9999
Pd-109	311.1	0.9526	0.9843	0.9921	0.9952	0.9967	0.9976
	414.4	0.9282	0.9770	0.9864	0.9928	0.9951	0.9963
	602.5	0.9968	0.9981	0.9991	0.9995	0.9997	0.9998
	636.3	0.9965	0.9981	0.9991	0.9995	0.9996	0.9997
	647.3	0.9974	0.9986	0.9993	0.9996	0.9997	0.9998
	761.4	1.0108	1.0033	1.0015	1.0009	1.0006	1.0004
Ag-109m	88.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Pd-111m	172.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	391.3	0.9027	0.9677	0.9835	0.9897	0.9931	0.9949
	413.5	0.7765	0.9265	0.9634	0.9777	0.9849	0.9886
	415.1	0.9054	0.9654	0.9832	0.9898	0.9932	0.9950
	525.6	0.8152	0.9382	0.9687	0.9806	0.9869	0.9903
	575.0	0.9279	0.9716	0.9863	0.9917	0.9945	0.9962
	632.8	0.8218	0.9405	0.9698	0.9814	0.9874	0.9906
	694.1	0.9558	0.9811	0.9911	0.9947	0.9965	0.9976
	1115.9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1691.1	1.0128	0.9996	1.0004	1.0003	1.0003	1.0002

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Ag-111	342.1	1.0023	1.0007	1.0003	1.0002	1.0001	1.0001
Ag-108	433.9	0.9510	0.9842	0.9920	0.9951	0.9967	0.9976
	510.8	0.8354	0.9459	0.9725	0.9830	0.9885	0.9914
	618.9	0.9011	0.9686	0.9842	0.9903	0.9934	0.9951
	633.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Ag-110m	446.8	0.3546	0.7686	0.8801	0.9252	0.9494	0.9629
	620.4	0.7613	0.9180	0.9579	0.9738	0.9824	0.9871
	657.8	0.8201	0.9391	0.9689	0.9807	0.9870	0.9906
	677.6	0.7659	0.9196	0.9588	0.9744	0.9827	0.9874
	687.0	0.7898	0.9282	0.9632	0.9771	0.9846	0.9888
	706.7	0.7749	0.9229	0.9605	0.9754	0.9834	0.9879
	744.3	0.7887	0.9279	0.9631	0.9770	0.9845	0.9888
	763.9	0.8143	0.9371	0.9679	0.9800	0.9866	0.9903
	818.0	0.7614	0.9182	0.9581	0.9739	0.9824	0.9871
	884.7	0.8178	0.9386	0.9687	0.9805	0.9869	0.9905
	937.5	0.8247	0.9413	0.9701	0.9814	0.9875	0.9909
	1384.3	0.8523	0.9512	0.9751	0.9845	0.9895	0.9923
	1475.8	0.8816	0.9618	0.9804	0.9877	0.9916	0.9938
	1505.0	0.8449	0.9487	0.9739	0.9837	0.9890	0.9920
	1562.3	1.1072	1.0437	1.0216	1.0122	1.0079	1.0053
Cd-111m	150.8	0.8952	0.9676	0.9838	0.9901	0.9932	0.9948
	245.4	0.9793	0.9888	0.9946	0.9967	0.9978	0.9984
Cd-115m	484.3	0.8158	0.9726	0.9861	0.9914	0.9942	0.9958
	939.6	0.8158	0.9726	0.9861	0.9914	0.9942	0.9958
	1290.5	1.0020	1.0006	1.0003	1.0002	1.0001	1.0001
Cd-115	280.8	0.9597	0.9876	0.9938	0.9962	0.9974	0.9980
	492.2	1.0082	1.0025	1.0012	1.0007	1.0005	1.0003
	527.7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
In-115m	336.2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Cd-117m	366.9	0.8402	0.9464	0.9728	0.9831	0.9886	0.9917
	564.0	0.9005	0.9667	0.9832	0.9896	0.9930	0.9950
	631.5	0.8808	0.9603	0.9799	0.9875	0.9916	0.9939
	748.1	0.9317	0.9779	0.9888	0.9931	0.9953	0.9966
	762.7	0.9140	0.9714	0.9855	0.9911	0.9940	0.9957
	860.5	0.9153	0.9722	0.9859	0.9913	0.9942	0.9958
	931.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1029.0	1.0348	1.0110	1.0045	1.0021	1.0012	1.0007
	1065.0	0.9450	0.9820	0.9909	0.9944	0.9962	0.9972
	1234.0	0.9198	0.9739	0.9868	0.9918	0.9945	0.9960
	1339.4	0.9184	0.9733	0.9865	0.9916	0.9944	0.9960
	1432.0	0.9160	0.9729	0.9863	0.9915	0.9943	0.9958
	1997.5	1.0185	1.0055	1.0027	1.0016	1.0011	1.0008
Cd-117	89.7	0.8820	0.9622	0.9809	0.9882	0.9920	0.9940
	273.3	0.9377	0.9794	0.9896	0.9935	0.9957	0.9969
	344.5	0.9998	0.9999	0.9999	1.0000	1.0000	1.0000
	434.2	0.9810	0.9933	0.9963	0.9976	0.9983	0.9988
	831.8	0.8731	0.9588	0.9792	0.9871	0.9913	0.9935
	880.7	0.9067	0.9695	0.9846	0.9904	0.9936	0.9954
	945.7	0.9017	0.9679	0.9837	0.9899	0.9932	0.9951
	1051.7	0.9333	0.9785	0.9891	0.9932	0.9954	0.9966
	1142.5	0.9025	0.9681	0.9840	0.9902	0.9933	0.9950
	1303.3	0.8983	0.9686	0.9842	0.9903	0.9934	0.9949
	1337.4	0.9978	0.9993	0.9998	1.0000	1.0001	1.0001
	1562.5	0.8942	0.9642	0.9822	0.9891	0.9927	0.9946
	1576.8	1.0824	1.0258	1.0125	1.0073	1.0048	1.0034
	1723.3	0.8983	0.9686	0.9842	0.9903	0.9934	0.9949
In-117m	158.6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	315.3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
In-117	156.6	0.9086	0.9708	0.9852	0.9909	0.9938	0.9954
	553.0	0.9426	0.9689	0.9847	0.9908	0.9939	0.9953
In-114m	190.3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	558.4	0.9134	0.9720	0.9859	0.9912	0.9941	0.9957
	725.2	0.9080	0.9705	0.9851	0.9908	0.9938	0.9954
In-116m	137.9	0.8448	0.9475	0.9733	0.9834	0.9889	0.9921
	416.9	0.8864	0.9618	0.9806	0.9879	0.9920	0.9943
	818.7	0.8276	0.9428	0.9709	0.9819	0.9878	0.9911
	1097.2	0.9164	0.9715	0.9856	0.9911	0.9941	0.9958
	1293.5	0.9092	0.9701	0.9849	0.9906	0.9937	0.9955
	1507.5	0.9202	0.9737	0.9867	0.9917	0.9945	0.9961
	1752.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	2112.2	0.9100	0.9719	0.9858	0.9912	0.9940	0.9955
In-113m	391.7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Sn-117m	158.5	0.9973	0.9985	0.9993	0.9996	0.9997	0.9998
Sn-123m	160.3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Sn-125m	331.9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Sn-125	332.1	0.8462	0.9490	0.9740	0.9839	0.9892	0.9921
	469.8	0.9140	0.9718	0.9857	0.9911	0.9941	0.9957
	822.5	0.9140	0.9718	0.9857	0.9911	0.9941	0.9957
	915.5	0.9153	0.9722	0.9859	0.9913	0.9942	0.9958
	1067.1	0.9189	0.9736	0.9867	0.9917	0.9945	0.9960
	1086.9	0.8459	0.9496	0.9744	0.9842	0.9893	0.9919

TABLE IV.2-5 : continued

Radio-nuclide	E_γ, keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Sb-125	176.3	0.9893	0.9967	0.9983	0.9990	0.9993	0.9995
	427.9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	463.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	600.6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	606.6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	635.9	1.0013	1.0004	1.0002	1.0001	1.0001	1.0000
Sb-122	564.1	0.9954	0.9985	0.9993	0.9995	0.9997	0.9998
	692.8	0.9092	0.9709	0.9853	0.9909	0.9939	0.9955
Sb-124m1	498.4	0.8302	0.9437	0.9714	0.9822	0.9880	0.9912
	602.7	0.7378	0.9140	0.9564	0.9730	0.9818	0.9866
	645.8	0.7339	0.9129	0.9558	0.9727	0.9815	0.9863
Sb-124	602.7	0.7946	0.9326	0.9658	0.9788	0.9858	0.9898
	645.9	0.8612	0.9541	0.9767	0.9855	0.9903	0.9929
	709.3	0.8173	0.9390	0.9689	0.9807	0.9870	0.9904
	713.8	0.8360	0.9454	0.9722	0.9828	0.9884	0.9915
	722.8	0.8649	0.9554	0.9773	0.9859	0.9905	0.9931
	968.3	0.8401	0.9469	0.9730	0.9833	0.9887	0.9917
	1045.2	0.8313	0.9441	0.9715	0.9824	0.9881	0.9912
	1325.5	1.1781	1.0582	1.0284	1.0166	1.0108	1.0076
	1368.2	0.8401	0.9469	0.9730	0.9833	0.9887	0.9917
	1436.7	0.9678	0.9808	0.9951	0.9967	0.9977	0.9982
	1526.4	0.8329	0.9447	0.9718	0.9825	0.9882	0.9913
	1691.0	0.9120	0.9718	0.9857	0.9912	0.9940	0.9956
	2090.9	0.9216	0.9751	0.9874	0.9922	0.9947	0.9961
Te-127	417.9	1.0039	1.0012	1.0006	1.0003	1.0002	1.0001
Te-131	149.7	0.9742	0.9918	0.9958	0.9974	0.9983	0.9987
	452.3	0.9441	0.9702	0.9855	0.9913	0.9942	0.9957

Radio-nuclide	E_γ, keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
I-131	364.5	1.0017	1.0005	1.0002	1.0001	1.0001	1.0001
I-128	442.9	0.9913	0.9972	0.9986	0.9991	0.9994	0.9996
	526.6	0.9027	0.9691	0.9844	0.9904	0.9935	0.9951
I-132	667.7	0.8439	0.9478	0.9734	0.9835	0.9889	0.9919
	667.8	0.8434	0.9476	0.9733	0.9834	0.9889	0.9919
	669.8	0.8319	0.9440	0.9715	0.9823	0.9881	0.9913
	772.6	0.8424	0.9475	0.9732	0.9834	0.9888	0.9918
Cs-134m	127.5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Cs-134	475.4	0.8447	0.9486	0.9739	0.9838	0.9891	0.9920
	563.2	0.8429	0.9480	0.9735	0.9836	0.9889	0.9919
	569.3	0.9986	0.9995	0.9998	0.9999	0.9999	0.9999
	604.7	0.9390	0.9797	0.9897	0.9936	0.9957	0.9969
	795.8	0.4279	0.8080	0.9020	0.9392	0.9589	0.9696
	801.9	0.8867	0.9630	0.9813	0.9884	0.9922	0.9943
	1038.5	1.0661	1.0236	1.0113	1.0063	1.0040	1.0027
	1167.9	0.9112	0.9715	0.9856	0.9911	0.9940	0.9956
	1365.1	0.9255	0.9761	0.9879	0.9926	0.9950	0.9963
Ba-131m	79.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	108.5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Ba-131	123.8	0.9076	0.9704	0.9851	0.9908	0.9938	0.9954
	133.6	0.8551	0.9546	0.9772	0.9860	0.9905	0.9928
	216.1	0.9937	0.9978	0.9989	0.9993	0.9995	0.9996
	239.6	0.9503	0.9741	0.9876	0.9927	0.9952	0.9965
	249.4	0.9569	0.9778	0.9895	0.9938	0.9960	0.9972
	373.2	1.0214	1.0064	1.0029	1.0016	1.0010	1.0007
	404.0	0.8978	0.9677	0.9840	0.9902	0.9933	0.9949
cont'd	486.5	0.9567	0.9758	0.9885	0.9932	0.9956	0.9968

Radio-nuclide	E_γ, keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Ba-131 (cont'd)	496.3	0.9606	0.9789	0.9901	0.9942	0.9962	0.9974
	585.0	0.9993	0.9997	0.9998	0.9998	0.9999	0.9999
	620.1	2.9010	1.5730	1.2664	1.1520	1.0977	1.0679
	1047.6	1.0490	1.0149	1.0070	1.0040	1.0026	1.0018
Ba-133m	276.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Ba-139	165.9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1420.5	1.0075	1.0023	1.0011	1.0006	1.0004	1.0003
La-140	328.8	0.8353	0.9450	0.9720	0.9826	0.9883	0.9915
	432.5	0.8353	0.9450	0.9720	0.9826	0.9883	0.9915
	487.0	0.9470	0.9824	0.9911	0.9945	0.9962	0.9971
	751.8	0.9205	0.9736	0.9867	0.9917	0.9945	0.9961
	815.8	0.9717	0.9906	0.9949	0.9966	0.9977	0.9984
	867.8	0.9229	0.9744	0.9870	0.9919	0.9947	0.9962
	919.6	0.9588	0.9897	0.9945	0.9964	0.9976	0.9983
	925.2	0.9250	0.9751	0.9874	0.9921	0.9948	0.9963
	1596.5	0.8919	0.9649	0.9822	0.9890	0.9926	0.9945
Ce-141	145.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Ce-143	231.6	0.8967	0.9672	0.9835	0.9898	0.9931	0.9948
	293.3	0.9980	0.9985	0.9994	0.9996	0.9998	0.9998
	350.6	1.0314	1.0103	1.0047	1.0027	1.0017	1.0012
	490.4	0.8999	0.9691	0.9845	0.9905	0.9935	0.9950
	664.5	0.9998	0.9998	0.9996	0.9998	0.9999	0.9999
	722.0	1.0268	1.0084	1.0040	1.0023	1.0015	1.0011
	880.4	1.0112	1.0026	1.0014	1.0008	1.0005	1.0004
Pr-142	1575.6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Radio-nuclide	E_γ, keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Nd-147	91.1	0.9943	0.9981	0.9990	0.9994	0.9996	0.9997
	120.5	0.8812	0.9582	0.9794	0.9875	0.9916	0.9938
	196.6	0.8887	0.9607	0.9806	0.9882	0.9921	0.9942
	275.4	0.8812	0.9582	0.9794	0.9875	0.9916	0.9938
	319.4	0.9166	0.9619	0.9822	0.9896	0.9932	0.9952
	398.2	0.9615	0.9834	0.9923	0.9955	0.9970	0.9979
	439.9	1.0103	0.9983	0.9994	0.9998	0.9998	0.9999
	531.0	1.0020	1.0006	1.0003	1.0002	1.0001	1.0001
	685.9	1.0155	1.0044	1.0020	1.0011	1.0007	1.0005
Nd-149	97.0	0.9490	0.9763	0.9887	0.9934	0.9957	0.9969
	114.3	0.8693	0.9567	0.9784	0.9869	0.9911	0.9932
	155.9	0.9988	1.0076	1.0027	1.0012	1.0005	1.0000
	188.6	0.9358	0.9789	0.9894	0.9935	0.9955	0.9966
	198.9	0.9264	0.9638	0.9833	0.9903	0.9937	0.9956
	208.1	0.9375	0.9735	0.9874	0.9926	0.9951	0.9964
	211.3	0.9823	0.9942	0.9971	0.9982	0.9988	0.9991
	240.2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	267.7	0.9203	0.9694	0.9849	0.9909	0.9939	0.9954
	270.2	1.0006	1.0000	0.9996	0.9995	0.9996	0.9996
	326.6	0.9093	0.9708	0.9855	0.9912	0.9940	0.9954
	349.1	0.9420	0.9757	0.9885	0.9932	0.9955	0.9967
	423.6	0.9917	0.9899	0.9953	0.9973	0.9983	0.9988
	443.6	0.9180	0.9736	0.9869	0.9920	0.9945	0.9958
	540.5	0.9740	0.9843	0.9927	0.9958	0.9973	0.9981
	556.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	654.8	1.0492	1.0149	1.0070	1.0040	1.0026	1.0018
Pm-149	285.9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Nd-151	255.6	1.0324	1.0089	1.0038	1.0020	1.0012	1.0008
	1180.6	0.9403	0.9678	0.9850	0.9913	0.9944	0.9961

TABLE IV.2-5 : continued

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Pm-151	104.8	0.9214	0.9724	0.9842	0.9888	0.9911	0.9924
	163.3	0.9504	0.9846	0.9923	0.9953	0.9968	0.9976
	168.0	0.9638	0.9887	0.9944	0.9966	0.9977	0.9982
	177.0	0.9138	0.9700	0.9853	0.9912	0.9940	0.9954
	209.0	0.9659	0.9892	0.9946	0.9967	0.9977	0.9983
	240.1	0.9778	0.9877	0.9944	0.9968	0.9979	0.9986
	275.2	0.9972	0.9976	0.9990	0.9994	0.9996	0.9998
	340.1	1.0067	1.0020	1.0009	1.0005	1.0003	1.0002
	344.9	1.1913	1.0573	1.0265	1.0151	1.0096	1.0067
	440.8	1.0065	1.0020	1.0009	1.0005	1.0003	1.0002
	445.7	1.0033	1.0010	1.0005	1.0003	1.0002	1.0001
	717.6	0.9775	0.9875	0.9943	0.9967	0.9979	0.9986
Sm-153	69.7	0.9760	0.9868	0.9939	0.9965	0.9978	0.9985
	103.2	0.9980	0.9987	0.9994	0.9997	0.9998	0.9999
Sm-155	104.3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	141.2	0.9452	0.9702	0.9863	0.9921	0.9950	0.9966
	246.0	1.0398	1.0114	1.0051	1.0028	1.0018	1.0012
Eu-152m1	121.8	0.9140	0.9720	0.9859	0.9912	0.9941	0.9957
	344.2	0.9709	0.9905	0.9952	0.9970	0.9980	0.9986
	563.8	0.9418	0.9740	0.9874	0.9925	0.9951	0.9965
	841.6	0.9202	0.9741	0.9869	0.9919	0.9946	0.9961
	963.5	1.0453	1.0137	1.0063	1.0036	1.0023	1.0016
	1315.0	1.0272	1.0085	1.0041	1.0024	1.0016	1.0011
	1388.9	0.9671	0.9824	0.9917	0.9952	0.9969	0.9978
Eu-152	121.8	0.9124	0.9713	0.9855	0.9910	0.9940	0.9956
	244.7	0.8941	0.9582	0.9794	0.9875	0.9917	0.9941
	344.3	0.9356	0.9781	0.9894	0.9934	0.9956	0.9968
cont'd	411.1	0.8484	0.9509	0.9751	0.9847	0.9896	0.9922

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Eu-152 (cont'd)	444.0	0.8961	0.9616	0.9809	0.9883	0.9923	0.9944
	482.7	0.8723	0.9528	0.9765	0.9857	0.9904	0.9930
	564.0	0.8991	0.9627	0.9814	0.9887	0.9925	0.9946
	778.9	0.9030	0.9696	0.9847	0.9906	0.9936	0.9951
	867.4	0.8676	0.9511	0.9759	0.9854	0.9902	0.9927
	964.0	0.8666	0.9479	0.9742	0.9843	0.9896	0.9926
	1085.8	1.0534	1.0168	1.0080	1.0046	1.0030	1.0021
	1089.7	0.9125	0.9728	0.9863	0.9915	0.9942	0.9956
	1112.1	0.9804	0.9866	0.9938	0.9964	0.9976	0.9983
	1212.9	0.8701	0.9519	0.9763	0.9857	0.9904	0.9928
	1299.1	0.9013	0.9690	0.9844	0.9904	0.9935	0.9951
	1408.1	0.9712	0.9837	0.9924	0.9956	0.9971	0.9980
Eu-154	123.1	0.9117	0.9709	0.9853	0.9909	0.9939	0.9956
	248.0	0.8706	0.9504	0.9753	0.9850	0.9900	0.9928
	591.8	0.8688	0.9499	0.9751	0.9848	0.9899	0.9927
	692.4	0.9090	0.9635	0.9820	0.9890	0.9927	0.9947
	723.3	0.8988	0.9633	0.9817	0.9888	0.9925	0.9946
	756.9	0.8537	0.9463	0.9734	0.9839	0.9891	0.9919
	873.3	0.8960	0.9592	0.9799	0.9878	0.9919	0.9942
	996.4	0.9594	0.9867	0.9929	0.9953	0.9968	0.9976
	1004.8	0.9614	0.9806	0.9907	0.9945	0.9964	0.9974
	1274.4	0.9683	0.9829	0.9920	0.9953	0.9970	0.9979
	1596.5	1.1615	1.0454	1.0228	1.0136	1.0090	1.0064
Gd-153	97.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	103.2	0.9987	0.9992	0.9996	0.9998	0.9999	0.9999
Gd-159	348.2	1.0002	1.0001	1.0000	1.0000	1.0000	1.0000
	363.6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Gd-161	102.3	0.8977	0.9680	0.9839	0.9901	0.9933	0.9949
	165.2	0.8912	0.9641	0.9821	0.9891	0.9926	0.9944
	283.5	0.9980	0.9968	0.9985	0.9992	0.9995	0.9997
	314.9	0.9506	0.9764	0.9890	0.9936	0.9959	0.9971
	338.1	0.9656	0.9862	0.9943	0.9966	0.9977	0.9983
	360.9	0.9998	0.9995	0.9998	0.9999	0.9999	0.9999
	480.1	1.0772	1.0218	1.0103	1.0059	1.0038	1.0027
	529.5	1.0389	1.0115	1.0055	1.0032	1.0021	1.0014
Tb-160	86.8	0.8855	0.9625	0.9810	0.9883	0.9921	0.9942
	197.0	0.8725	0.9555	0.9777	0.9863	0.9908	0.9934
	215.6	0.8911	0.9620	0.9811	0.9884	0.9923	0.9944
	298.6	0.9109	0.9696	0.9848	0.9906	0.9938	0.9955
	392.5	0.9126	0.9702	0.9850	0.9908	0.9939	0.9956
	765.3	0.8514	0.9508	0.9756	0.9852	0.9899	0.9923
	879.4	0.9375	0.9779	0.9892	0.9935	0.9956	0.9967
	962.3	0.9659	0.9896	0.9947	0.9967	0.9977	0.9982
	965.1	0.9589	0.9873	0.9935	0.9959	0.9972	0.9978
	966.2	0.9589	0.9873	0.9935	0.9959	0.9972	0.9978
	1115.1	0.8980	0.9662	0.9834	0.9900	0.9932	0.9949
	1178.0	1.0541	1.0145	1.0072	1.0043	1.0028	1.0020
	1199.9	1.0153	1.0022	1.0013	1.0008	1.0005	1.0004
	1271.9	0.9995	0.9974	0.9990	0.9994	0.9997	0.9998
	1312.1	1.0196	1.0036	1.0019	1.0011	1.0008	1.0006
Dy-165m	108.2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	515.5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Dy-165	94.7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	279.8	0.9099	0.9704	0.9851	0.9908	0.9938	0.9955
	361.7	0.9203	0.9740	0.9869	0.9919	0.9946	0.9960
	633.4	0.9321	0.9787	0.9892	0.9933	0.9955	0.9966
	715.3	0.9139	0.9733	0.9866	0.9917	0.9944	0.9957

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Ho-166	80.6	0.9982	0.9994	0.9997	0.9998	0.9999	0.9999
	1379.4	0.9938	0.9961	0.9983	0.9990	0.9994	0.9996
	1581.9	0.9934	0.9960	0.9983	0.9990	0.9994	0.9996
	1662.4	1.0105	1.0032	1.0015	1.0008	1.0005	1.0004
Er-171	111.6	0.9061	0.9706	0.9852	0.9909	0.9938	0.9953
	116.7	0.8873	0.9647	0.9823	0.9891	0.9926	0.9944
	124.0	0.9700	0.9839	0.9924	0.9956	0.9971	0.9980
	210.6	0.8130	0.9370	0.9685	0.9808	0.9870	0.9902
	237.1	0.9032	0.9681	0.9839	0.9901	0.9933	0.9951
	295.9	0.9700	0.9839	0.9924	0.9956	0.9971	0.9980
	308.3	0.9788	0.9885	0.9947	0.9969	0.9980	0.9986
Tm-170	84.3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Yb-169	93.6	0.9152	0.9697	0.9851	0.9910	0.9940	0.9955
	109.8	0.9253	0.9739	0.9874	0.9924	0.9949	0.9961
	118.2	0.9253	0.9739	0.9874	0.9924	0.9949	0.9961
	130.5	0.9197	0.9715	0.9864	0.9919	0.9945	0.9959
	177.2	0.9672	0.9807	0.9912	0.9949	0.9967	0.9977
	198.0	0.9693	0.9818	0.9918	0.9953	0.9970	0.9980
	307.7	1.1437	1.0387	1.0181	1.0102	1.0065	1.0045
Yb-175	113.8	0.9438	0.9818	0.9909	0.9944	0.9962	0.9971
	137.7	0.9195	0.9563	0.9790	0.9876	0.9918	0.9941
	144.9	0.9253	0.9698	0.9853	0.9912	0.9941	0.9957
	282.5	0.9826	0.9898	0.9952	0.9972	0.9982	0.9988
	396.3	1.0158	1.0047	1.0022	1.0012	1.0008	1.0006
Yb-177	121.6	0.9876	0.9957	0.9978	0.9987	0.9991	0.9994
	138.6	0.9517	0.9745	0.9876	0.9926	0.9951	0.9963
	150.4	0.9799	0.9928	0.9964	0.9978	0.9985	0.9989
cont'd	899.2	0.9550	0.9757	0.9882	0.9929	0.9953	0.9965

TABLE IV.2-5 : continued

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Yb-177	941.7	1.0019	0.9988	0.9994	0.9996	0.9997	0.9998
(cont'd)	1028.0	0.9757	0.9870	0.9939	0.9964	0.9977	0.9984
	1080.1	0.9554	0.9758	0.9882	0.9930	0.9953	0.9965
	1119.6	0.9757	0.9870	0.9939	0.9964	0.9977	0.9984
	1149.7	1.0265	1.0080	1.0037	1.0021	1.0014	1.0009
	1241.4	1.0043	1.0013	1.0006	1.0003	1.0002	1.0002
Lu-176m	88.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Lu-177	112.9	0.9083	0.9719	0.9860	0.9915	0.9942	0.9955
	208.4	0.9667	0.9820	0.9916	0.9952	0.9969	0.9979
Hf-175	89.4	0.9067	0.9707	0.9852	0.9909	0.9938	0.9953
	343.6	0.9902	0.9926	0.9969	0.9983	0.9989	0.9992
	432.6	1.0963	1.0292	1.0134	1.0076	1.0048	1.0033
Hf-179m1	214.1	0.9915	0.9939	0.9974	0.9985	0.9990	0.9993
Hf-180m	93.3	0.7339	0.9080	0.9534	0.9713	0.9805	0.9852
	215.2	0.7962	0.9267	0.9635	0.9777	0.9849	0.9888
	332.3	0.8021	0.9290	0.9649	0.9786	0.9855	0.9892
	443.2	0.7977	0.9273	0.9641	0.9782	0.9852	0.9889
	500.7	0.8518	0.9524	0.9757	0.9848	0.9895	0.9918
Hf-181	133.0	0.9021	0.9675	0.9837	0.9900	0.9932	0.9950
	133.4	0.8960	0.9649	0.9824	0.9892	0.9927	0.9946
	136.3	0.8534	0.9469	0.9736	0.9839	0.9891	0.9919
	345.9	0.9491	0.9725	0.9868	0.9922	0.9949	0.9963
	482.2	0.9757	0.9847	0.9928	0.9958	0.9972	0.9980
Ta-182m2	146.8	0.9048	0.9680	0.9845	0.9907	0.9937	0.9952
	171.6	0.9397	0.9718	0.9866	0.9920	0.9947	0.9961
	185.1	0.9017	0.9589	0.9804	0.9883	0.9922	0.9941

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Ta-182	100.1	0.8662	0.9491	0.9750	0.9848	0.9899	0.9927
	113.7	0.8689	0.9438	0.9723	0.9832	0.9889	0.9920
	152.4	0.8778	0.9552	0.9778	0.9864	0.9910	0.9935
	156.4	0.8747	0.9487	0.9754	0.9852	0.9903	0.9931
	179.4	0.8717	0.9453	0.9730	0.9836	0.9891	0.9921
	198.3	0.8920	0.9540	0.9780	0.9868	0.9914	0.9939
	222.1	0.8958	0.9626	0.9814	0.9886	0.9924	0.9946
	229.3	0.8716	0.9525	0.9764	0.9856	0.9904	0.9930
	264.1	0.9628	0.9816	0.9915	0.9950	0.9967	0.9977
	1001.7	0.8237	0.9367	0.9686	0.9809	0.9871	0.9902
	1121.3	0.9376	0.9638	0.9838	0.9907	0.9940	0.9958
	1157.5	1.0172	0.9990	0.9998	0.9999	1.0000	1.0000
	1189.0	1.0279	1.0051	1.0023	1.0012	1.0007	1.0005
	1221.4	0.9724	0.9790	0.9908	0.9947	0.9965	0.9976
	1231.0	0.9177	0.9674	0.9841	0.9905	0.9936	0.9952
	1257.5	0.9890	0.9934	0.9969	0.9981	0.9988	0.9991
	1289.2	1.6898	1.2152	1.0989	1.0558	1.0355	1.0245
W-183m	107.9	0.9843	0.9899	0.9956	0.9975	0.9984	0.9989
	108.5	0.9843	0.9899	0.9956	0.9975	0.9984	0.9989
W-187	134.2	0.9000	0.9639	0.9823	0.9893	0.9928	0.9948
	479.6	0.9456	0.9660	0.9849	0.9913	0.9944	0.9961
	551.5	0.9781	0.9882	0.9944	0.9967	0.9978	0.9984
	618.3	0.9980	0.9994	0.9997	0.9998	0.9999	0.9999
	625.5	1.0015	1.0004	1.0001	1.0001	1.0000	1.0000
	685.7	1.0050	1.0015	1.0007	1.0004	1.0003	1.0002
	772.9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Re-186	122.3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	137.2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Re-188m	63.6	0.9772	0.9855	0.9937	0.9964	0.9977	0.9984
	92.5	0.9954	0.9968	0.9987	0.9992	0.9995	0.9997
	106.0	0.9954	0.9968	0.9987	0.9992	0.9995	0.9997

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Re-188	155.0	0.9950	0.9983	0.9988	0.9991	0.9992	0.9992
	478.0	0.9382	0.9717	0.9860	0.9915	0.9943	0.9958
	633.3	0.8938	0.9620	0.9809	0.9883	0.9921	0.9941
	829.5	0.8938	0.9620	0.9809	0.9883	0.9921	0.9941
	931.3	0.9655	0.9807	0.9906	0.9944	0.9962	0.9972
Os-185	592.1	0.9752	0.9866	0.9936	0.9962	0.9975	0.9982
	646.1	0.9854	0.9897	0.9957	0.9976	0.9984	0.9989
	717.4	1.0015	0.9991	0.9995	0.9997	0.9998	0.9998
	874.7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	880.5	1.0110	1.0034	1.0016	1.0009	1.0006	1.0004
Os-190m	186.7	0.7451	0.9134	0.9557	0.9725	0.9813	0.9861
	361.1	0.7581	0.9179	0.9583	0.9743	0.9825	0.9869
	502.6	0.7527	0.9163	0.9575	0.9738	0.9822	0.9866
	616.1	0.7485	0.9149	0.9569	0.9734	0.9819	0.9863
Os-191	129.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Os-193	139.0	0.9862	0.9956	0.9978	0.9986	0.9991	0.9993
	180.9	0.9839	0.9961	0.9981	0.9988	0.9993	0.9995
	219.1	0.9102	0.9641	0.9823	0.9893	0.9928	0.9947
	251.6	0.9069	0.9689	0.9844	0.9905	0.9936	0.9952
	280.4	0.9779	0.9894	0.9951	0.9977	0.9988	0.9987
	298.8	0.8894	0.9605	0.9804	0.9881	0.9919	0.9939
	321.6	0.9757	0.9875	0.9940	0.9964	0.9976	0.9983
	361.8	1.0047	1.0012	1.0005	1.0003	1.0002	1.0001
	387.5	1.0056	1.0000	1.0001	1.0000	1.0000	1.0000
	460.5	0.9748	0.9885	0.9942	0.9964	0.9976	0.9982
	557.9	1.0052	1.0014	1.0007	1.0004	1.0002	1.0002
Ir-192	296.0	0.8093	0.9381	0.9686	0.9807	0.9868	0.9900
	308.5	0.8231	0.9427	0.9710	0.9821	0.9878	0.9908
	316.5	0.8726	0.9591	0.9793	0.9872	0.9913	0.9935
	468.1	0.8967	0.9676	0.9837	0.9900	0.9932	0.9948

Radio-nuclide	E_γ,keV	Coincidence correction factor (COI)					
		Position 0	Position 1	Position 2	Position 3	Position 4	Position 5
Ir-194	293.5	0.8420	0.9488	0.9741	0.9840	0.9891	0.9918
	328.4	0.9590	0.9868	0.9933	0.9959	0.9972	0.9979
	645.1	0.8102	0.9383	0.9688	0.9808	0.9869	0.9900
	938.7	0.9681	0.9821	0.9957	0.9970	0.9978	0.9980
	1150.8	0.8884	0.9650	0.9824	0.9892	0.9926	0.9944
Pt-197m	346.5	0.9999	0.9999	1.0000	1.0000	1.0000	1.0000
Au-199	158.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	208.2	1.0002	1.0001	1.0000	1.0000	1.0000	1.0000
Au-198	411.8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	675.9	0.9037	0.9695	0.9846	0.9905	0.9936	0.9952
Hg-197m	134.0	0.9927	0.9954	0.9980	0.9989	0.9993	0.9995
	279.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Hg-203	279.2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Pa-233	94.6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	114.5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	145.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	300.1	0.9978	0.9986	0.9994	0.9997	0.9998	0.9999
	312.0	0.9985	0.9991	0.9996	0.9998	0.9999	0.9999
	340.5	0.9975	0.9984	0.9993	0.9996	0.9998	0.9998
	375.4	1.0289	1.0089	1.0041	1.0023	1.0015	1.0010
	398.6	1.0502	1.0153	1.0070	1.0039	1.0025	1.0017
	415.8	1.0255	1.0077	1.0035	1.0020	1.0013	1.0009
Np-239	103.7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	106.1	0.9341	0.9721	0.9868	0.9922	0.9949	0.9963
	209.8	0.9836	0.9910	0.9959	0.9976	0.9985	0.9990
	228.1	0.9837	0.9911	0.9959	0.9976	0.9985	0.9990
	277.6	0.9833	0.9908	0.9958	0.9976	0.9984	0.9989
	285.5	0.9842	0.9912	0.9960	0.9977	0.9985	0.9990
	315.9	1.0468	1.0140	1.0064	1.0036	1.0023	1.0016
	334.3	1.1262	1.0377	1.0173	1.0098	1.0062	1.0043

3. PRACTICAL ASPECTS

3.1. Full-energy peak detection efficiency (ε_p^{geo})

The value of ε_p should be introduced in the relevant equations for the calculation of γ-γ coincidence summing and (as mentioned below) of coincidence loss. Evidently, ε_p refers to ε_p^{geo} valid for the actual counting condition. ε_p^{geo} can be obtained according to the procedure outlined in III.2.

3.2. Total detection efficiency (ε_t^{geo}); peak-to-total ratio (P/T)

From the equations for the calculation of γ-γ and γ-KX coincidence losses it follows that ε_t, or actually ε_t^{geo}, should be known.

The total detection efficiency can be obtained from the peak efficiency as :

$$\varepsilon_t = \frac{\varepsilon_p}{P/T} \qquad \text{(IV.3-1)}$$

with P/T = peak-to-total ratio. P/T is an experimentally measurable quantity, which is, for a given detector, depending on several parameters such as (in order of decreasing importance) the photon energy, the source-detector separation, the source geometry and composition, and the presence of absorbing and scattering materials (e.g. the lead shielding). Based on the results of Michaelis [MICHAELIS68, MICHAELIS69], it has been accepted and convincingly shown [SIMONITS80, MOENS81] that the P/T-ratio yields a straight line in a log P/T vs log E_γ plot, at least down to $\sim$ 170 keV (in fact, down to the ^{139}Ce 165.9 keV-point). Furthermore, it was proved that the position and the slope of the thus obtained straight line are primarily depending on the source-detector separation, and to a smaller extent on the source geometry and composition [MOENS81]. Thus, in case of not too voluminous and dense samples, it is sufficient for the experimental P/T-determination in the energy region above 170 keV to measure at the detector distances under consideration 2 or 3 "coincidence-free" point sources, with an appropriate spread in gamma-energy. Use can be made of ^{203}Hg (279.2 keV) [or ^{51}Cr (320.1 keV)], ^{137}Cs (661.6 keV) and ^{65}Zn (1115.5 keV). In order to determine the curve at lower energies

(< 170 keV), it is proposed in the present work to measure for instance ^{241}Am (59.5 keV), ^{109}Cd (88.1 keV) and ^{57}Co (122.1 keV). The following corrections should be made to all spectra :

1. background subtraction ;
2. extrapolation to zero energy (the lower energies being filtered by the discriminator). This can be based on a response function of the Compton-continuum (e.g. JIN86), but a linear (even horizontal) extrapolation of the recorded part of the Compton-spectrum [ANISIMOV77] turns out to be sufficiently accurate [MOENS81]. Fig. IV.3-1 shows ^{241}Am, ^{109}Cd and ^{57}Co spectra (background subtracted), recorded by counting point sources at 1.29 cm distance to Ge-detector MK7 (see II.2.1). For ^{241}Am and ^{109}Cd, the horizontal extrapolation is necessarily based on the low-energy tail of the full-energy peaks [containing pulses of various origin (HELMER75)]. For ^{57}Co, the Compton-edge (just visible at the extreme left) can be extrapolated horizontally to zero-energy ;

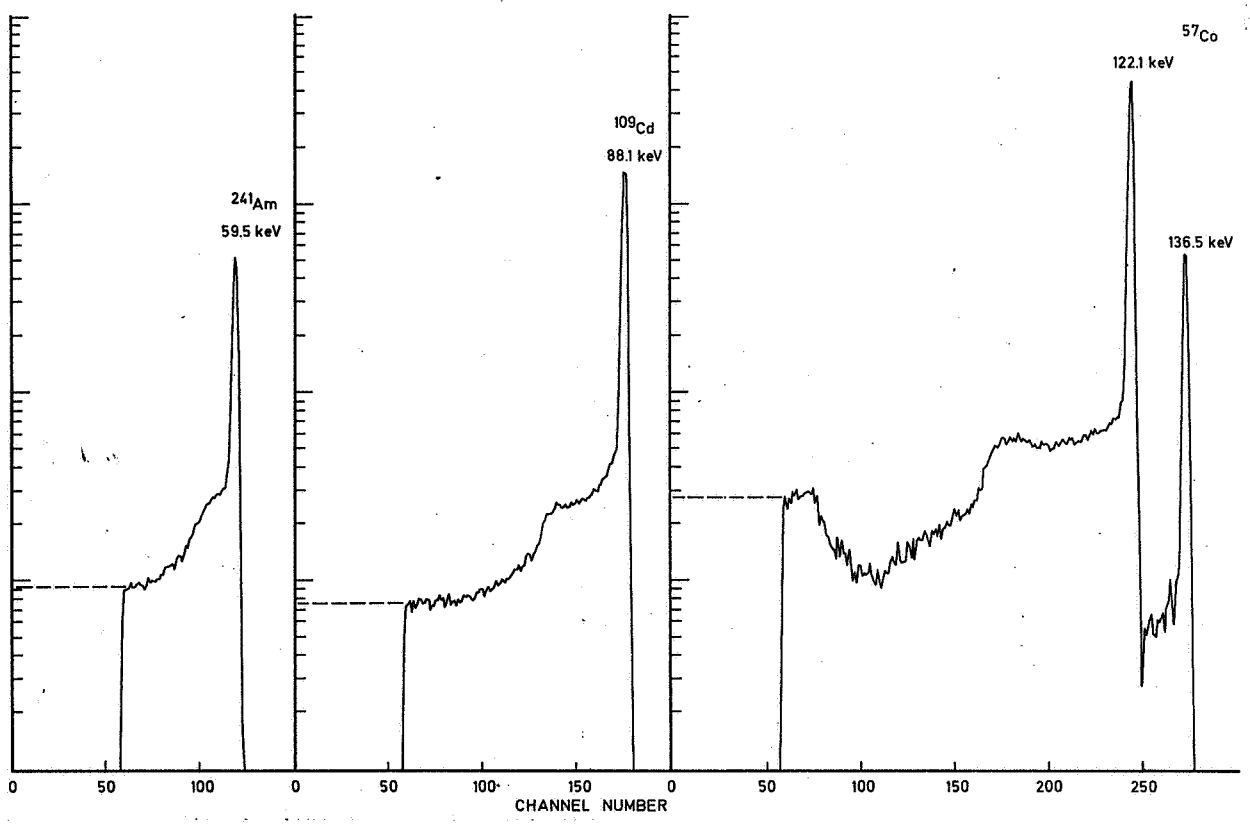


Fig. IV.3-1 : Extrapolation to zero-energy of ^{241}Am, ^{109}Cd and ^{57}Co spectra (background subtracted), recorded by counting point sources at 1.29 cm distance to detector MK7

3. subtraction of "contaminating" counts ($N_{t,con}$), originating from emission of other photon-energies than those mentioned above, particularly the ^{65}Zn 511 keV β^+ annihilation radiation, the ^{203}Hg Tl X-rays and the ^{57}Co 136.5 keV gamma-ray ($\gamma_{136.5}$ being $\sim$ 12% only of $\gamma_{122.1}$). To a first approximation, $N_{p,con}$-values should be subtracted, since at this stage of the operation the relevant $(P/T)_{con}$-ratios are not known. Then, a preliminary log P/T vs log E_γ plot can be made, allowing to calculate $N_{t,con} = N_{p,con}/(P/T)_{con}$ and so on. Thus, this leads to an iteration procedure with final results after a few steps (Fig. IV.3-2). In each step, the log P/T vs log E_γ plot can be drawn manually, but it is advised to apply a least-squares fitting procedure. As illustrated in Fig. IV.3-2, a linear fit - based on the ^{203}Hg, ^{137}Cs and ^{65}Zn points - can be made down to 170 keV, and the ^{241}Am, ^{109}Cd and ^{57}Co points can be fitted by a polynomial of degree 2; so as to ensure a smooth curve over the whole energy region, this polynomial fit is also based on a log P/T-value at 170 keV obtained from the linear fit at higher energy.

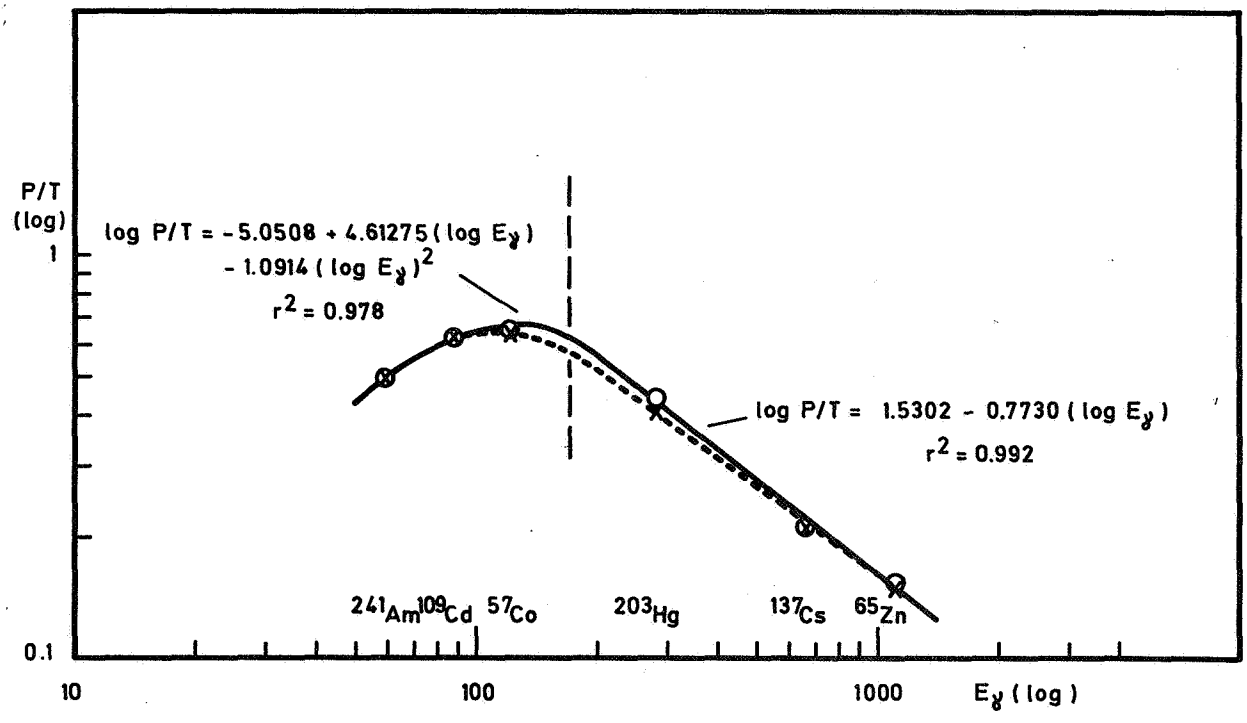


Fig. IV.3-2 : P/T-ratio curve for point-sources measured at 1.29 cm distance to Ge-detector MK7; -x--x : preliminary curve without correction for "contaminating" counts ; —o—o— : final curve after iteration (see text)

The spectra shown in Fig. IV.3-1 might invite thoughts concerning the attainable accuracy on peak area integration, and hence on P/T, in case of such low-energy gamma's. It should be stressed, however, that possible systematic errors of this kind cancel when calculating $\varepsilon_t = \frac{\varepsilon_p}{P/T}$, on condition that the same procedure (or computer code) for peak area integration is used when performing efficiency calibration and P/T-determination.

3.3. Uncertainty and error propagation

In the equations for calculating the probabilities for coincidence summing [S(A)] and coincidence loss [L(A)] the relevant parameters (p_j) are the experimental quantities $\varepsilon_p^{geo} = \varepsilon_p^{ref} . \bar{\Omega}^{geo}/\bar{\Omega}^{ref}$ [to be introduced as such for S(A) calculation] or $\varepsilon_t^{geo} = \varepsilon_p^{geo}/\frac{P}{T}$, and a number of decay scheme data (a, c, γ, etc.). Since $N_{p,A} = N'_{p,A}/COI$ with $COI = [1 - L(A)][1 + S(A)]$ the uncertainty on all these parameters will be reduced towards the analytical results. For instance, it follows from error propagation calculation (I.3.4.4) that :

- for simple γ-γ coincidence loss A - B [$L(A) = a_B c_B \varepsilon_{t,B}^{geo}$] :

$$Z_{N_{p,A}}(p_j) = \left| \frac{L(A)}{1-L(A)} \right| \qquad \text{(IV.3-2)}$$

with $p_j = a_B$, c_B or $\varepsilon_{t,B}^{geo}$. The worst case to be considered is $a_B = c_B = 1$ and counting on top of a large Ge-detector (e.g. $\varepsilon_t^{geo} \simeq 0.2$ for $E_{\gamma,B} \simeq 100$ keV and 1.29 cm distance from point-source to detector MK7); then, $Z_\rho(p_j) = Z_{N_{p,A}}(p_j) \simeq 0.3$, i.e. an error reduction factor of $\simeq 3$.

- for simple γ-γ coincidence summing A = B + C [$S(A) = \frac{\gamma_B}{\gamma_A} a_C c_C \frac{\varepsilon_{p,B}^{geo}\ \varepsilon_{p,C}^{geo}}{\varepsilon_{p,A}^{geo}}$] :

$$Z_{N_{p,A}}(p_j) = \left| \frac{S(A)}{1+S(A)} \right| \qquad \text{(IV.3-3)}$$

with $p_j = \gamma_A$, γ_B, a_C, c_C, $\varepsilon_{p,A}^{geo}$, $\varepsilon_{p,B}^{geo}$, $\varepsilon_{p,C}^{geo}$ (the latter three being correlated). Again, for $a_C = c_C = 1$ and counting on top of a large Ge-detector (taking as an average $\varepsilon_{p,B}^{geo}\ \varepsilon_{p,C}^{geo}/\varepsilon_{p,A}^{geo} \simeq 0.1$), and even when assuming the ana-

lytical gamma-peak to be a small one (e.g. $\gamma_B/\gamma_A = 5$), one obtains $Z_\rho(p_j) = Z_{N_{p,A}}(p_j) \simeq 0.3$, i.e. an error reduction factor of $\simeq 3$.

It has been argued that for more complex cases the error reductions will be even higher [MOENS81].

The total uncertainty on $N_{p,A}$, induced by coincidence correction can be obtained from Eq. (I.3-29). When estimating uncertainties on nuclear data and on P/T of the order of 5%, and since the uncertainties on ε_p^{ref} and $\bar{\Omega}^{geo}/\bar{\Omega}^{ref}$ amount to $\sim$ 1.5% (III.1.2) and 2% (III.2.4) resp., one finds :

- for the above given example $\underline{A}$-B : $s_{N_{p,A}} \simeq 3\%$;
- for the above given example $\underline{A}$ = B+C : $s_{N_{p,A}} \simeq 3\%$.

It should be stressed again that these figures refer to the very unfavourable condition of counting on top of a large Ge-detector. The other extreme is, of course, to count at large distance to the detector, where true-coincidence and hence the uncertainty from true-coincidence correction is negligible. Thus, in practice the average uncertainty can be estimated at $\simeq$ 1.5%.

In addition to the above considerations, reference can be made to the experimental tests of the accuracy of true-coincidence correction, as reported in the present work (IV.2.3 ; IV.2.4) and elsewhere [DEBERTIN79, MOENS81, MOENS82, LIN81 ; see IV.1.1]. For the cases reported in the present work (including γ-KX and delayed γ-γ coincidence), the accuracy obtained is on the average $\simeq$ 2%, for close-in counting geometries.

3.4. Computer programs

Needless to say, the here presented (and in fact any) methodology for true-coincidence correction - including the complex calculations and the voluminous nuclear data library - has to be handled in a computer program. As mentioned in II.3.2, this is done in program COIN, which is actually one of the subroutines of SINGCOMP. Recently, an unsupervised program is being developed [MOENS87], which is based on the (coded) full decay schemes of the radionuclides.

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CHAPTER V

THE CONTRIBUTION OF EPITHERMAL ACTIVATION : THE PARAMETERS α, $\bar{E}_R$, F AND Q_0

1. THE $1/E^{1+\alpha}$ EPITHERMAL NEUTRON FLUX DISTRIBUTION AND THE CONCEPT OF $\bar{E}_r$

1.1. The need of correction for a non-1/E distribution

In the course of the present work it was recognized soon that, in order to preserve the accuracy of the k_0-method, practical and sufficiently accurate procedures had to be developed - applicable in common NAA laboratories - to take into account the non-1/E epithermal neutron flux distribution [DECORTE79A/79B/81B/82, MOENS79]. Thereby it was realized that a non-1/E epithermal spectrum shape is rather a general rule than an exception. This can be illustrated by means of two striking examples;

a. The first example is related to experimental f-determination using two different methods, namely :

- Cd-ratio measurement.
  When neglecting a deviation from the 1/E distribution, Eq. (I.1-15) can be rewritten as :

$$f = (F_{Cd,r}\, R_{Cd,r} - 1).G_{e,r}\, Q_{0,r}/G_{th,r} \qquad (V.1\text{-}1)$$

  with r = flux ratio monitor with well-known Q_0-value.
- The "bare bi-isotopic f-monitor" method (see V.2.2).
  From Eq. (I.3-18) written down for 2 isotopes (1=s, 2=c), and when neglecting a deviation from the 1/E distribution, one can find f as [remembering that $k_{0,2}(1) = k_{0,c}(1)/k_{0,c}(2)$]:

$$f = \frac{G_{e,1}\,\dfrac{k_{0,c}(1)}{k_{0,c}(2)}\,\dfrac{\varepsilon_{p,1}}{\varepsilon_{p,2}}\,Q_{0,1} - G_{e,2}\,\dfrac{A_{sp,1}}{A_{sp,2}}\,Q_{0,2}}{G_{th,2}\,\dfrac{A_{sp,1}}{A_{sp,2}} - G_{th,1}\,\dfrac{k_{0,c}(1)}{k_{0,c}(2)}\,\dfrac{\varepsilon_{p,1}}{\varepsilon_{p,2}}} \qquad (V.1\text{-}2)$$

where 1 and 2 have well-known Q_0-values and k_0-factors.

Table V.1-1 shows - for 4 channels of reactor Thetis - a comparison of some typical results for f determination according to the above techniques, with r = ^{198}Au, 1 = ^{95}Zr and 2 = $^{97}Zr/^{97m}Nb$ (see V.2.1 and V.2.2).

TABLE V.1-1 : f-Ratios obtained from Cd-ratio measurements of Au [Eq. (V.1-1)] and from the bare Zr monitor-method [Eq. (V.1-2)], assuming a $\varphi'_e(E) \sim 1/E$ dependence

THETIS channel	f	
	from $R_{Cd,Au}$	from bare Zr
3	25.4	27.9
13	43.1	47.5
15	82.0	114
8	185	275

Obviously, the results are diverging dramatically in case of high thermalization, i.e. for irradiation sites which are positioned at a large distance to the core of the reactor (cf. Fig. II.1-1).

b. The second example is related to experimental Q_0-determination from Cd-ratio measurements. When neglecting again a deviation from the 1/E distribution, Eq. (V.1-1) leads to :

$$Q_0 = \frac{F_{Cd,r}\, R_{Cd,r} - 1}{F_{Cd}\, R_{Cd} - 1} \cdot \frac{G_{th}}{G_{th,r}} \cdot \frac{G_{e,r}}{G_e}\, Q_{0,r} \qquad \text{(V.1-3)}$$

Table V.1-2 shows the results, with r = ^{198}Au, for the reactions $^{112}Sn(n,\gamma)^{113}Sn$ (effective production), $^{94}Zr(n,\gamma)^{95}Zr$ and $^{96}Zr(n,\gamma)^{97}Zr$ in channel "MILA" of the WWR-M reactor, channels 14, 7 and 16 of the Thetis reactor and channel R4V4 of the DR-3 reactor. Note that here also the sequence of the channels corresponds to an increasing neutron thermalization (see V.1.6). As seen, the Q_0-discrepancies are enormous.

1.2. Introduction of the $1/E^{1+\alpha}$ distribution and the effective resonance energy $\bar{E}_r$

Without making any assumption with respect to the epithermal neutron flux distribution, the reaction rate per nucleus can be expressed as (cf. I.1.3; omitting G_{th} and G_e) :

TABLE V.1-2 : Q_0-values from Cd-ratio measurements (with Au as f-monitor), assuming a $\varphi_e'(E) \sim 1/E$ dependence

Reactor	Channel	Q_0 from cadmium-ratio method		
		$^{112}Sn(n,\gamma)^{113}Sn$	$^{94}Zr(n,\gamma)^{95}Zr$	$^{96}Zr(n,\gamma)^{97}Zr$
WWR-M	"MILA"	46.6	5.53	251
THETIS	14	-	4.32	224
	7	39.1	3.23	182
	16	-	3.16	185
DR-3	R4V4	29.6	1.88	127

$$R = \phi_s \sigma_0 + \int_{E_{Cd}}^{\infty} \varphi_e'(E)\sigma(E)dE \qquad (V.1\text{-}4)$$

The problem of how to treat Eq. (V.1-4) in case of a non-1/E epithermal shape can be solved by one of the following approaches :

a. rigorous evaluation of the $[\int_{E_{Cd}}^{\infty} \varphi_e'(E)\sigma(E)dE]$-term, by introduction of the $\sigma(E)$ and $\varphi_e'(E)$ functions. The latter can be obtained from computer codes for reactor spectrum unfolding, based on a multi-foil activation technique; for a survey of the present state-of-the-art, see Refs ZIJP83/ ZSOLNAY83. It is immediately clear that this methodology, involving irradiation and counting of some 10 activation detectors (including Cd-covered irradiations) is far from being suited for the daily practice of neutron activation analysis ;

b. replacement of the integral $\int_{E_{Cd}}^{\infty} \varphi_e'(E)\sigma(E)dE$ by a simple expression of the form $[\phi_e . I_0(\text{non-}1/E)]$, where $[I_0(\text{non-}1/E)]$ is the resonance integral valid in a non-1/E epithermal neutron flux distribution. To achieve this goal, profit can be taken of the repeatedly reported findings that an actual epithermal neutron flux distribution can be approximated as :

$$\varphi_e'(E) \sim 1/E^{1+\alpha}, \text{ i.e. } \varphi_e'(E) = \phi_e . 1\ eV^{\alpha}/E^{1+\alpha} \qquad (V.1\text{-}5)$$

with α independent of neutron energy, and where 1 eV - omitted in the following equations - represents a reference energy, the role of which will be discussed in detail in V.1.4.

The validity of Eq. (V.1-5) is not only evident from experimental results (as shown later), but has - since the early sixties - been dealt with several times on a theoretical basis, and α (which is only to a first approximation independent of neutron energy) has been related to the physical properties of the reactor system. Reference can be made for instance to BIGHAM61, WILLIAMS66, RYVES68, RYVES69, AHMAD82 and also OPDEBEECK85A.

As shown in I.1.3.3, approximation (V.1-5) enables the definition and introduction of :

$$I_0(\alpha) = \int_{E_{Cd}}^{\infty} \sigma(E)\,dE/E^{1+\alpha} \qquad (V.1\text{-}6)$$

and

$$Q_0(\alpha) = I_0(\alpha)/\sigma_0 \qquad (V.1\text{-}7)$$

so that R can be written as :

$$R = \phi_s \sigma_0 + \phi_e I_0(\alpha) \qquad (V.1\text{-}8)$$

Thus, the Q_0-values in Eqs (V.1-1) - (V.1-3) should be replaced by $Q_0(\alpha)$, leading to :

$$f = (F_{Cd,r}\, R_{Cd,r} - 1).G_{e,r}\, Q_{0,r}(\alpha)/G_{th,r} \qquad (V.1\text{-}9)$$

$$f = \frac{G_{e,1} \cdot \frac{k_{0,c}^{(1)}}{k_{0,c}^{(2)}} \cdot \frac{\varepsilon_{p,1}}{\varepsilon_{p,2}}\, Q_{0,1}(\alpha) - G_{e,2}\, \frac{A_{sp,1}}{A_{sp,2}}\, Q_{0,2}(\alpha)}{G_{th,2}\, \frac{A_{sp,1}}{A_{sp,2}} - G_{th,1} \cdot \frac{k_{0,c}^{(1)}}{k_{0,c}^{(2)}} \cdot \frac{\varepsilon_{p,1}}{\varepsilon_{p,2}}} \qquad (V.1\text{-}10)$$

$$Q_0(\alpha) = \frac{F_{Cd,r}\, R_{Cd,r} - 1}{F_{Cd}\, R_{Cd} - 1} \cdot \frac{G_{th}}{G_{th,r}} \cdot \frac{G_{e,r}}{G_e} \cdot Q_{0,r}(\alpha) \qquad (V.1\text{-}11)$$

Obviously, the problem has now been shifted to the experimental determination of α (see V.1.5) and the calculation of $Q_0(\alpha)$, as defined by Eqs (V.1-6) and (V.1-7). This calculation can in principle be done by actually performing the integration of Eq. (V.1-6), but occasionally a poor or incomplete knowledge of the $\sigma(E)$ function (in fact:of the resonance parameter data) might lead to an unacceptable uncertainty on $Q_0(\alpha)$. Therefore, it looks

more promising to calculate $Q_0(\alpha)$ in a relative way, i.e. by conversion of the evaluated and compiled Q_0-values with the introduction of α and the relevant resonance parameter data, for which it can now be foreseen that the accuracy requirements will not be so stringent, since they serve only as a correction. To achieve this goal, profit was taken of the useful idea of Ryves et al. [RYVES68/69], later developed by Moens et al. [MOENS79], Jovanovic et al. [JOVANOVIC84/84B/86] and De Corte et al. [DECORTE86], to introduce the concept of the effective resonance energy $\bar{E}_r$. This would be the energy of a hypothetic single resonance which gives the same resonance activation rate as the actual resonances for the isotope. From this description it can be felt immediately that $\bar{E}_r$ must depend on the epithermal neutron flux distribution, i.e. - in the above formalism - on the parameter α, and should thus be denoted as $\bar{E}_r(\alpha)$. This follows indeed from its definition :

$$[\bar{E}_r(\alpha)]^{-\alpha} = I_0'(\alpha)/I_0' \qquad \text{(V.1-12)}$$

and, in terms of the Breit-Wigner expression [BREIT36]:

$$[\bar{E}_r(\alpha)]^{-\alpha} = \frac{1}{\sum_i w_i} \cdot \sum_i w_i \, E_{r,i}^{-\alpha} \qquad \text{(V.1-13)}$$

with I_0' and $I_0'(\alpha)$ = reduced resonance integrals (1/v-part subtracted) ;

$w_i = (g \, \Gamma_\gamma \, \Gamma_n/\Gamma)_i/E_{r,i}^2$;
g = statistical weight factor ;
Γ_γ = radiative width of resonance ;
Γ_n = neutron width of resonance ;
Γ = total width of resonance.

It has been shown [MOENS79, JOVANOVIC84] that $\bar{E}_r(\alpha)$ can be reasonably approximated by an α-independent $\bar{E}_r$-value, calculated from :

$$\ln \bar{E}_r = \frac{1}{\sum_i w_i} \cdot \sum_i w_i \ln E_{r,i} \qquad \text{(V.I-14)}$$

and although $\bar{E}_r$ and $\bar{E}_r(\alpha)$ values occasionally differ as much as $\sim$ 20% (for $\alpha \simeq 0.1$), the residual error on $Q_0(\alpha)$ and - a fortiori - on ρ is small (see V.1.3).

Based on these considerations, the $Q_0 \rightarrow Q_0(\alpha)$ conversion can be written as :

$$Q_0(\alpha) = (Q_0 - 0.429) \cdot \bar{E}_r^{-\alpha} + 0.429/[(2\alpha+1)(0.55)^\alpha] \qquad \text{(V.1-15)}$$

q_0

$q_0(\alpha)$

and the $Q_0(\alpha) \rightarrow Q_0$ conversion is :

$$Q_0 = \left(Q_0(\alpha) - 0.429/[(2\alpha+1)(0.55)^{\alpha}]\right) \cdot \bar{E}_r^{\alpha} + 0.429 \qquad (V.1\text{-}16)$$

1.3. Calculation and compilation of $\bar{E}_r$-values ; uncertainties and error propagation

In 1979 a "first generation" of $\bar{E}_r$-values for 96 analytically interesting isotopes was published [MOENS79]. Calculation was based on Eq. (V.1-14) and on resonance parameter data, which were originating mainly from the 1973-edition of BNL-325 [BNL73]. Recently, as an extension and updating, a "second generation" of $\bar{E}_r$-values for 126 isotopes was computed [JOVANOVIC86], with introduction of resonance parameter data from the newest compilations [MUGHABGHAB81/84], and including an uncertainty calculation. The results are summarized in Table V.1-3. Note that $\bar{E}_r$ for ^{96}Ru is an experimental value; procedures for experimental $\bar{E}_r$-determination have been developed for such cases where calculation is questionable or impossible due to the fact that resonance parameter data are incomplete, not accurate or even not known at all (as for ^{96}Ru) [SIMONITS84, JOVANOVIC85].

Before discussing uncertainties and errors on the calculated $\bar{E}_r$-values, one should consider the propagation of the error on $\bar{E}_r$ ($s_{\bar{E}_r}$,%) towards the various quantities which are dependent on $\bar{E}_r$ (see I.3.4.4).

Defining

$$q_0 = Q_0 - 0.429 \qquad (V.1\text{-}17)$$

$$q_0(\alpha) = q_0 \bar{E}_r^{-\alpha} = Q_0(\alpha) - C_\alpha \qquad (V.1\text{-}18)$$

$$C_\alpha = 0.429/[(2\alpha+1)(0.55)^{\alpha}] \qquad (V.1\text{-}19)$$

one obtains :

- for $Q_0 \rightarrow Q_0(\alpha)$ conversion [Eq. (V.1-15)], and thus also for the determination of f from R_{Cd} [Eq. (V.1-9)], of $Q_0(\alpha)$ from R_{Cd} [Eq. (V.1-11)] and of ρ in ENAA [Eq. (I.3-21)] :

$$Z_{Q_0(\alpha)}(\bar{E}_r) = Z_f(\bar{E}_r) = Z_\rho(\bar{E}_r) = \left| \alpha \cdot \frac{q_0(\alpha)}{Q_0(\alpha)} \right| \qquad (V.1\text{-}20)$$

TABLE V.1-3 : Calculated $\bar{E}_r$-values for 126 analytically interesting (n,γ) reactions. Resonance parameter data were taken from Refs MUGHABGHAB81/84
(*- no resonance data available ; ** - no error assignment possible ; + experimental value [SIMONITS84])

Target isotope	$\bar{E}_r$,eV	Target isotope	$\bar{E}_r$,eV	Target isotope	$\bar{E}_r$,eV	Target isotope	$\bar{E}_r$,eV
^{18}O	1140000 ± 80000	^{80}Se	2940 ± 410	^{121}Sb	13.1 ± 0.5	^{169}Tm	4.80 ± 0.10
^{19}F	44700 ± 2200	^{82}Se	8540 ± **	^{123}Sb	28.2 ± 1.7	^{168}Yb	0.61 ± 0.01
^{23}Na	3380 ± 370	^{79}Br	69.3 ± 6.2	^{120}Te	*	^{174}Yb	602 ± 48
^{26}Mg	257000 ± 33000	^{81}Br	152 ± 14	^{122}Te	92.3 ± 3.7	^{176}Yb	412 ± 21
^{27}Al	11800 ± 700	^{85}Rb	839 ± 50	^{124}Te	1210 ± 100	^{175}Lu	16.1 ± 0.8
^{30}Si	2280 ± 10	^{87}Rb	364 ± 11	^{126}Te	285 ± 20	^{174}Hf	29.6 ± 2.1
^{31}P	38500 ± 6900	^{84}Sr	469 ± 33	^{128}Te	738 ± 52	^{177}Hf	2.08 ± **
^{36}S	*	^{86}Sr	795 ± 16	^{130}Te	2950 ± 210	^{178}Hf	8.01 ± 0.16
^{37}Cl	13700 ± 1900	^{89}Y	4300 ± 340	^{127}I	57.6 ± 2.3	^{179}Hf	16.2 ± 1.9
^{40}Ar	31000 ± 5600	^{94}Zr	6260 ± 250	^{133}Cs	9.27 ± 1.02	^{180}Hf	115 ± 7
^{41}K	2960 ± 210	^{96}Zr	338 ± 7	^{130}Ba	69.9 ± 3.5	^{181}Ta	10.4 ± 0.6
^{46}Ca	*	^{93}Nb	574 ± 46	^{132}Ba	143 ± **	^{182}W	9.20 ± 0.55
^{48}Ca	1330000 ± **	^{98}Mo	241 ± 48	^{134}Ba	115 ± 6	^{186}W	20.5 ± 0.2
^{45}Sc	5130 ± 870	^{100}Mo	672 ± 94	^{136}Ba	545 ± 38	^{185}Re	3.40 ± 0.14
^{50}Ti	63200 ± 2500	^{96}Ru	776 ± 124^{+}	^{138}Ba	15700 ± 500	^{187}Re	41.1 ± 1.6
^{51}V	7230 ± 290	^{102}Ru	181 ± 7	^{139}La	76.0 ± 3.0	^{189}Os	12.3 ± 0.4
^{50}Cr	7530 ± 830	^{104}Ru	495 ± 50	^{138}Ce	*	^{190}Os	114 ± 2
^{55}Mn	468 ± 51	^{103}Rh	1.45 ± 0.01	^{140}Ce	7200 ± 1300	^{192}Os	89.7 ± 3.6
^{58}Fe	637 ± 153	^{106}Pd	282 ± 6	^{142}Ce	1540 ± 1850	^{193}Ir	2.21 ± 0.20
^{59}Co	136 ± 7	^{108}Pd	39.7 ± 2.0	^{141}Pr	296 ± 12	^{190}Pt	27.6 ± 0.6
^{64}Ni	14200 ± 1700	^{110}Pd	950 ± 86	^{146}Nd	874 ± 52	^{196}Pt	291 ± 44
^{63}Cu	1040 ± 50	^{107}Ag	38.5 ± 1.9	^{148}Nd	236 ± 14	^{198}Pt	106 ± 3
^{65}Cu	766 ± 130	^{109}Ag	6.08 ± 0.06	^{150}Nd	173 ± 21	^{197}Au	5.65 ± 0.40
^{64}Zn	2560 ± 260	^{108}Cd	243 ± 24	^{152}Sm	8.53 ± 0.09	^{196}Hg	93.5 ± 0.1
^{68}Zn	590 ± 60	^{110}Cd	125 ± 16	^{154}Sm	142 ± 10	^{198}Hg	39.3 ± 2.8
^{69}Ga	201 ± 16	^{114}Cd	207 ± 39	^{153}Eu	5.80 ± 0.23	^{202}Hg	1960 ± 160
^{71}Ga	154 ± 18	^{116}Cd	726 ± 87	^{158}Gd	48.2 ± 3.9	^{204}Hg	*
^{74}Ge	3540 ± 280	^{113}In	6.41 ± 0.96	^{160}Gd	480 ± 34	^{203}Tl	276 ± 28
^{76}Ge	583 ± 23	^{115}In	1.56 ± 0.03	^{159}Tb	18.1 ± 0.9	^{205}Tl	2960 ± 360
^{75}As	106 ± 36	^{112}Sn	107 ± 3	^{164}Dy	224 ± 11	^{206}Pb	10500 ± 1200
^{74}Se	29.4 ± 1.2	^{116}Sn	128 ± 4	^{165}Ho	12.3 ± 0.4	^{208}Pb	145000 ± 4000
^{76}Se	577 ± 46	^{122}Sn	424 ± 59	^{166}Er	59.3 ± 4.2	^{209}Bi	1210 ± 60
^{78}Se	501 ± 35	^{124}Sn	74.2 ± 5.2	^{170}Er	129 ± 3	^{232}Th	54.4 ± 0.5
						^{238}U	16.9 ± 0.2

- for $Q_0(\alpha) \rightarrow Q_0$ conversion [Eq. (V.1-16)] :

$$Z_{Q_0}(\bar{E}_r) = \left|\alpha \cdot \frac{q_0}{Q_0}\right| \qquad \text{(V.1-21)}$$

- for k_0-determination [Eq. (I.3-18)] and ρ-calculation in NAA [Eq. (I.3-20)] :

$$Z_{k_0}(\bar{E}_r) = Z_\rho(\bar{E}_r) = \left|\alpha \cdot \frac{q_0(\alpha)}{f+Q_0(\alpha)}\right| \qquad \text{(V.1-22)}$$

- for f-determination from the bare bi-isotopic monitor method [Eq. (V.1-10)] :

$$Z_f(\bar{E}_{r,1}) = \left|\alpha \cdot \frac{q_{0,1}(\alpha)}{Q_{0,1}(\alpha)-Q_{0,2}(\alpha)} \left(1 + \frac{Q_{0,2}(\alpha)}{f}\right)\right| \qquad \text{(V.1-23)}$$

$$Z_f(\bar{E}_{r,2}) = \left|\alpha \frac{q_{0,2}(\alpha)}{Q_{0,1}(\alpha)-Q_{0,2}(\alpha)} \left(1 + \frac{Q_{0,1}(\alpha)}{f}\right)\right| \qquad \text{(V.1-24)}$$

Table V.1-4 gives an idea of the error propagation factors $Z(\bar{E}_r)$ to be expected in practice. In all cases $Z(\bar{E}_r) << 1$.

In Ref. JOVANOVIC84B the practical implications of Eqs (V.1-20) [$Z_\rho(\bar{E}_r)$ in ENAA] and (V.1-22) [$Z_\rho(\bar{E}_r)$ in NAA] are dealt with in great detail. Numerical data are systematically listed for 126 analytically interesting isotopes in 6 irradiation channels of reactor Thetis (with α ranging from -0.028 to 0.11, and f from 15 to 158). One of the outputs is especially appealing to the imagination : the tolerable $\bar{E}_r$-interval leading to an error of less than 1% on the analytical result. Table V.1-5 shows the data for $^{45}Sc(n,\gamma)^{46}Sc$ and $^{112}Sn(n,\gamma)^{113}Sn$ (F_2m+g ; see Table VIII.3-1). It can be concluded immediately that, in the context of NAA or ENAA, any discussion [OPDEBEECK85B] on the accuracy requirements with respect to $\bar{E}_r$, for such low $-Q_0$ isotopes as ^{45}Sc (with reported $\bar{E}_r$'s indeed shifting from 2120 eV [MOENS79] over 4110 eV [MOENS84] to 5130 eV [JOVANOVIC86]) is unimportant. In general, considerations about ENAA of "nuclides with a very low Q_0-value in a channel with very high f-value" [OPDEBEECK85B] are, as a matter of course, unrealistic. For ^{112}Sn it can be seen (Table V.1-5) that, whereas in NAA a 50% error on $\bar{E}_r$ is allowed, this is not the case in ENAA where, for $\alpha \simeq 0.1$, $\bar{E}_r$ should be known to within 10%. Nevertheless, even this conclusion is quite promising, since the $s_\rho < 1\%$ requirement is rather stringent and because it is not so realistic to perform ENAA in conditions of high α, i.e. high f, where the re-

TABLE V.1-4 : $\bar{E}_r$ error propagation factors, to be multiplied by $s_{\bar{E}_r}$,%. *f from bare bi-isotopic monitor method (with ^{95}Zr-^{97}Zr) ; + ρ from NAA

$z(\bar{E}_r)$	THETIS Channel 17 α=-0.027 ; f=12.5	WWR-M Channel "MILA" α=0.011 ; f=36	THETIS Channel 14 α=0.030 ; f=38	THETIS Channel 16 α=0.079 ; f=104	DR-3 Channel R4V4 α=0.158 ; f=337
	$^{197}Au(n,\gamma)^{198}Au$; Q_0 = 15.71 ; $\bar{E}_r$ = 5.65 ± 0.40 eV (± 7.1%)				
$z_{Q_0(\alpha)}(\bar{E}_r)$	0.026	0.011	0.029	0.077	0.15
$z_{Q_0}(\bar{E}_r)$	0.026	0.011	0.029	0.077	0.15
$z_{k_{0,\rho^+}}(\bar{E}_r)$	0.015	0.0032	0.0082	0.0089	0.0053
	$^{238}U(n,\gamma)^{239}U$; Q_0 = 103.4 ; $\bar{E}_r$ = 16.9 ± 0.2 eV (± 1.2%)				
$z_{Q_0(\alpha)}(\bar{E}_r)$	0.027	0.011	0.030	0.079	0.16
$z_{Q_0}(\bar{E}_r)$	0.027	0.011	0.030	0.079	0.16
$z_{k_{0,\rho^+}}(\bar{E}_r)$	0.024	0.0081	0.021	0.035	0.026
	$^{232}Th(n,\gamma)^{233}Th$; Q_0 = 11.53 ; $\bar{E}_r$ = 54.4 ± 0.5 eV (± 0.92%)				
$z_{Q_0(\alpha)}(\bar{E}_r)$	0.026	0.011	0.029	0.075	0.15
$z_{Q_0}(\bar{E}_r)$	0.026	0.011	0.029	0.076	0.15
$z_{k_{0,\rho^+}}(\bar{E}_r)$	0.013	0.0025	0.0061	0.0057	0.0027
	$^{59}Co(n,\gamma)^{60}Co$; Q_0 = 1.990 ; $\bar{E}_r$ = 136 ± 7 eV (± 5.1%)				
$z_{Q_0(\alpha)}(\bar{E}_r)$	0.022	0.0084	0.023	0.059	0.11
$z_{Q_0}(\bar{E}_r)$	0.021	0.0086	0.024	0.062	0.12
$z_{k_{0,\rho^+}}(\bar{E}_r)$	0.0033	0.00042	0.0010	0.00079	0.00034
	$^{98}Mo(n,\gamma)^{99}Mo$; Q_0 = 53.1 ; $\bar{E}_r$ = 241 ± 48 eV (± 20.%)				
$z_{Q_0(\alpha)}(\bar{E}_r)$	0.027	0.011	0.030	0.078	0.15
$z_{Q_0}(\bar{E}_r)$	0.027	0.011	0.030	0.078	0.16
$z_{k_{0,\rho^+}}(\bar{E}_r)$	0.022	0.0063	0.016	0.020	0.0097

$z(\bar{E}_r)$	THETIS Channel 17 α=-0.027 ; f=12.5	WWR-M Channel "MILA" α=0.011 ; f=36	THETIS Channel 14 α=0.030 ; f=38	THETIS Channel 16 α=0.079 ; f=104	DR-3 Channel R4V4 α=0.158 ; f=337
	$^{96}Zr(n,\gamma)^{97}Zr$; Q_0 = 248 ; $\bar{E}_r$ = 338 ± 7 eV (± 2.1%)				
$z_{Q_0(\alpha)}(\bar{E}_r)$	0.027	0.011	0.030	0.079	0.16
$z_{Q_0}(\bar{E}_r)$	0.027	0.011	0.030	0.079	0.16
$z_{k_{0,\rho^+}}(\bar{E}_r)$	0.026	0.0095	0.025	0.047	0.036
$z_f(\bar{E}_r)$*	0.041	0.014	0.033	0.082	0.16
	$^{55}Mn(n,\gamma)^{56}Mn$; Q_0 = 1.053 ; $\bar{E}_r$ = 468 ± 51 eV (± 11.%)				
$z_{Q_0(\alpha)}(\bar{E}_r)$	0.017	0.0064	0.017	0.039	0.063
$z_{Q_0}(\bar{E}_r)$	0.016	0.0065	0.018	0.047	0.094
$z_{k_{0,\rho^+}}(\bar{E}_r)$	0.0015	0.00017	0.00040	0.00029	0.00011
	$^{100}Mo(n,\gamma)^{101}Mo$; Q_0 = 18.84 ; $\bar{E}_r$ = 672 ± 94 eV (± 14.%)				
$z_{Q_0(\alpha)}(\bar{E}_r)$	0.026	0.011	0.029	0.076	0.15
$z_{Q_0}(\bar{E}_r)$	0.026	0.011	0.029	0.077	0.15
$z_{k_{0,\rho^+}}(\bar{E}_r)$	0.017	0.0035	0.0085	0.0075	0.0030
	$^{64}Zn(n,\gamma)^{65}Zn$; Q_0 = 1.908 ; $\bar{E}_r$ = 2560 ± 260 eV (± 10.%)				
$z_{Q_0(\alpha)}(\bar{E}_r)$	0.022	0.0084	0.022	0.053	0.086
$z_{Q_0}(\bar{E}_r)$	0.021	0.0085	0.023	0.061	0.12
$z_{k_{0,\rho^+}}(\bar{E}_r)$	0.0033	0.00040	0.00089	0.00060	0.00020
	$^{94}Zr(n,\gamma)^{95}Zr$; Q_0 = 5.05 ; $\bar{E}_r$ = 6260 ± 250 eV (± 4.0%)				
$z_{Q_0(\alpha)}(\bar{E}_r)$	0.025	0.010	0.027	0.068	0.12
$z_{Q_0}(\bar{E}_r)$	0.025	0.010	0.028	0.073	0.15
$z_{k_{0,\rho^+}}(\bar{E}_r)$	0.0084	0.0011	0.0025	0.0017	0.00054
$z_f(\bar{E}_r)$*	0.013	0.0015	0.0034	0.0030	0.0024

TABLE V.1-5 : $\bar{E}_r$-tolerance interval to ensure an error of less than 1% on the analytical results. Input data : $^{45}Sc(n,\gamma)^{46}Sc$ [Q_0 = 0.43, $\bar{E}_r$ = 4110 eV]; $^{112}Sn(n,\gamma)^{113}Sn$ [Q_0 = 49.1, $\bar{E}_r$ = 107 eV]

THETIS channel	α	f	Irradiation type	$\bar{E}_r$-tolerance interval (normalized to input $\bar{E}_r$) to ensure s_ρ < 1%	
				^{45}Sc	^{112}Sn
17	-0.028	15	NAA		0.63 - 1.58
			ENAA		0.70 - 1.44
3	0.015	25	NAA		0.35 - 2.82
			ENAA		0.51 - 1.95
5	0.052	42	NAA	from	0.67 - 1.50
			ENAA	< 0.01	0.82 - 1.21
6	0.084	73	NAA	to	0.68 - 1.47
			ENAA	> 100	0.89 - 1.13
7	0.096	130	NAA		0.59 - 1.73
			ENAA		0.90 - 1.11
8	0.11	158	NAA		0.56 - 1.82
			ENAA		0.91 - 1.10

latively low epithermal flux would result in rather poor sensitivity. The examples of Table V.1-5 cannot be generalized to all cases encountered in practice, but they are nevertheless indicative for what is to be expected. As mentioned, full details for 126 isotopes in 6 irradiation positions are published in Ref. JOVANOVIC84B.

In earlier papers [MOENS79, JOVANOVIC84] attention has been paid to the implication of using approximative $\bar{E}_r$-values [from Eq. (V.1-14)] instead of $\bar{E}_r(\alpha)$ [from Eq. (V.1-13)]. It was concluded that the $\bar{E}_r$-$\bar{E}_r(\alpha)$ discrepancy is only significant for isotopes where the energies of some individual resonances - with comparable weighing factor w_i - are widely spread around $\bar{E}_r$.

The use of $\bar{E}_r$ can thus lead, in extreme irradiation conditions, to errors of some percents on the analytical results. If this is judged not to be acceptable, the transformation of $\bar{E}_r$ to $\bar{E}_r(\alpha)$ can be performed in the following simple way. According to the reasoning in [JOVANOVIC84], one can write [JOVANOVIC84B] :

$$\bar{E}_r(\alpha) = \bar{E}_r \, e^{-p\alpha} \qquad \text{(V.1-25)}$$

with p given by

$$p = \frac{1}{\sum_i w_i} \sum_i w_i \left\{ \frac{1}{2!} \left(\ln \frac{E_{r,i}}{\bar{E}_r(\alpha)} \right)^2 - \ldots \right\} \qquad \text{(V.1-26)}$$

Truncation of the higher order terms and replacing $\bar{E}_r(\alpha)$ by $\bar{E}_r$ yields as an α-independent approximation :

$$p \simeq \frac{1}{2\sum_i w_i} \sum_i w_i \left(\ln \frac{E_{r,i}}{\bar{E}_r} \right)^2 \qquad \text{(V.1-27)}$$

For the isotopes showing an unfavorable spread in resonance energies, p-values have been calculated according to Eq. (V.1-27) and are listed in Table V.1-6. Using tabulated $\bar{E}_r$ and p-values and with the knowledge of the

TABLE V.1-6 : Correction factors p for the transformation of $\bar{E}_r$ to $\bar{E}_r(\alpha)$ [Eq. (V.1-25)] ; as an example, $\bar{E}_r(\alpha)/\bar{E}_r = e^{-p\alpha}$ is shown for $\alpha = 0.1$

Target isotope	p	$e^{-p\alpha}$ for α=0.1	Target isotope	p	$e^{-p\alpha}$ for α=0.1
^{58}Fe	1.06	0.899	^{113}In	0.94	0.910
^{65}Cu	1.13	0.893	^{122}Sn	0.95	0.909
^{64}Zn	1.17	0.890	^{159}Tb	0.96	0.908
^{98}Mo	1.82	0.834	^{187}Re	0.95	0.909
^{102}Ru	1.78	0.837	^{205}Tl	1.09	0.897
^{116}Cd	1.52	0.859			

experimentally determined α factor, it is thus easy to generate $\bar{E}_r(\alpha)$ values according to Eq. (V.1-25). It is clear at first sight that the transformation will only be relevant for high α-values. One example might be sufficient to prove the reasonableness of the approximation for the parameter p [Eq. (V.1-27)]. For ^{98}Mo, with $\bar{E}_r$ = 241 eV, one obtains for α = 0.1 : true $\bar{E}_r(\alpha)$ = 197 eV [Eq. (V.1-13)], approximative $\bar{E}_r(\alpha)$ = 201 eV [Eqs (V.1-25) - (V.1-27)]. The $Q_0(\alpha)$-values are : 30.8 (for $\bar{E}_r$ = 241 eV), 31.4^2 [for $\bar{E}_r(\alpha)$ = 197 eV] and 31.3^6 [for $\bar{E}_r(\alpha)$ = 201 eV]; these minor discrepancies are further reduced in concentration calculation.

Turning back to the recently calculated second-generation $\bar{E}_r$'s (Table V.1-3), it is instructive to compare them with those from the first generation [MOENS79]. Only occasionally really large discrepancies are observed, as shown in Table V.1-7 (no low-Q_0 isotopes included). As discussed in Ref. JOVANOVIC84B, these can be attributed to a better and more complete knowledge of the resonance parameter data in the 1980's as compared to the 1970's. For most of the isotopes, however, shifts are not exceeding some tens of percents, having a minor effect on ρ.

TABLE V.1-7 : Discrepancies between former and recent $\bar{E}_r$-values ;
* - no uncertainty assignment

Target isotope	$\bar{E}_r$, eV	
	1st generation (MOENS79) *	2nd generation (JOVANONIC86)
^{64}Zn	428	2560 ± 260
^{93}Nb	184	574 ± 46
^{102}Ru	717	181 ± 7
^{175}Lu	8.47	16.1 ± 1.9
^{187}Re	12.0	41.1 ± 1.6

1.4. Role of the reference energy in $\bar{E}_r$-calculation

In Eq. (V.1-5), 1 eV appears as a reference energy. More generally, the $1/E^{1+\alpha}$ approximation can be described as :

$$\varphi'_e(E) = \varphi'_e(E_{ref})\ E_{ref}^{1+\alpha}/E^{1+\alpha} \qquad (V.1\text{-}28)$$

$$= \phi_e\ E_{ref}^{\alpha}/E^{1+\alpha}$$

defining ϕ_e as :

$$\phi_e = \varphi'_e(E_{ref})\ E_{ref}$$

Accordingly, the epicadmium reaction rate per nucleus is given by :

$$R_e = \int_{E_{Cd}}^{\infty} \varphi'_e(E)\sigma(E)\,dE$$

$$= \phi_e\ E_{ref}^{\alpha} \int_{E_{Cd}}^{\infty} \sigma(E)\ \frac{dE}{E^{1+\alpha}} = \phi_e\ I_0(\alpha)$$

with $I_0(\alpha) = E_{ref}^{\alpha} \int_{E_{Cd}}^{\infty} \sigma(E)\ \frac{dE}{E^{1+\alpha}}$ (V.1-29)

The $\bar{E}_r(\alpha)$-definition [Eq. (V.1-12)] should be written as :

$$[\bar{E}_r(\alpha)]^{-\alpha} = [I'_0(\alpha)/I'_0].E_{ref}^{-\alpha}$$

which gives, in terms of the Breit-Wigner expression :

$$[\bar{E}_r(\alpha)]^{-\alpha} = \left\{ \frac{1}{\sum_i w_i} \sum_i w_i \left(\frac{E_{r,i}}{E_{ref}} \right)^{-\alpha} \right\} E_{ref}^{-\alpha} \qquad (V.1\text{-}30)$$

Obviously, $E_{ref}^{-\alpha}$ cancels in this formula yielding Eq. (V.1-13) which can be rewritten as :

$$\frac{1}{\sum_i w_i} \sum_i w_i \left(\frac{E_{r,i}}{\bar{E}_r(\alpha)} \right)^{-\alpha} = 1 \qquad (V.1\text{-}31)$$

In the above equations E_{ref} can be given any value; however, selecting a value for E_{ref} means fixing energy units and the value of $I_0(\alpha)$ [Eq. (V.1-29)] and also of ϕ_e, since in the non-ideal spectrum $\phi_e.E_{ref}^{\alpha}$ is constant with energy.

The obvious advantages of choosing 1 eV as reference energy are that it can be disregarded when evaluating equations such as Eqs (V.1-6), (V.1-12) and (V.1-15), and that the energy unit eV can be used. Dropping the 1 eV-term leads to formal dimensioning problems, but if all energies are expressed in eV the above formulae unambigously yield correct values. This procedure is quite common in neutron physics and is a.o. applied in the description of the fission neutron spectrum according to [WATT52], [CRANBERG56] and [LEACHMAN56] using formulae which are applicable if neutron energies are expressed in MeV.

Recently it was stated [OPDEBEECK85B] that the accuracy of $\bar{E}_r$-calculation according to Eq. (V.1-14) is influenced by the choice of the reference energy E_{ref} in Eq. (V.1-5). This is contradicted by the fact that - as shown above - E_{ref} cancels from Eq. (V.1-30) prior to the unambiguous expansion of the resulting Eq. (V.1-31), leading to the definition of $\bar{E}_r$ [Eq. (V.1-14)] as an α-independent approximation of $\bar{E}_r(\alpha)$. Since far-reaching conclusions concerning the pretended importance of the reference energy were drawn [OPDEBEECK 85B], it is interesting to elucidate here the underlying erroneous reasoning. First E_{ref} is kept explicitly in Eq. (V.1-30) which is rewritten as :

$$\left(\frac{\bar{E}_r(\alpha)}{E_{ref}}\right)^{-\alpha} = \frac{\sum_i w_i \, (E_{r,i}/E_{ref})^{-\alpha}}{\sum_i w_i} \qquad \text{(V.1-32)}$$

Expansion of $[\bar{E}_r(\alpha)/E_{ref}]^{-\alpha}$ and $(E_{r,i}/E_{ref})^{-\alpha}$ according to

$$\left(\frac{\bar{E}_r(\alpha)}{E_{ref}}\right)^{-\alpha} = 1 - \alpha \ln \frac{\bar{E}_r(\alpha)}{E_{ref}} + \Delta_1 \quad \text{(higher order terms)} \qquad \text{(V.1-33)}$$

and

$$\left(\frac{E_{r,i}}{E_{ref}}\right)^{-\alpha} = 1 - \alpha \ln \frac{E_{r,i}}{E_{ref}} + \delta_i \quad \text{(higher order terms)} \qquad \text{(V.1-34)}$$

leads to the expression

$$\alpha \ln \frac{\bar{E}_r(\alpha)}{E_{ref}} = \alpha \frac{\sum_i w_i \ln (E_{r,i}/E_{ref})}{\sum_i w_i} - (\Delta_2 - \Delta_1) \qquad \text{(V.1-35)}$$

with $\Delta_2 = \dfrac{\sum_i w_i \, \delta_i}{\sum_i w_i}$

Thus far, this approach is valid and it allows to define an α-independent approximation $\bar{E}_r$ of $\bar{E}_r(\alpha)$ as :

$$\ln \frac{\bar{E}_r}{E_{ref}} = \frac{\sum_i w_i \ln (E_{r,i}/E_{ref})}{\sum_i w_i} \qquad \text{(V.1-36)}$$

The elementary consequence of the possibility to cancel E_{ref} in Eq. (V.1-36), as in Eq. (V.1-32), is that the accuracy of the approximation of $\bar{E}_r(\alpha)$ [Eq. (V.1-32)] by $\bar{E}_r$, as defined in Eq. (V.1-36), cannot be dependent on the choice of E_{ref}. This was clearly overlooked in Ref. OPDEBEECK85B, where it is stated that the validity conditions of the truncation of Eq. (V.1-33) on one hand and of Eq. (V.1-34) on the other hand determine the validity of the approximation in Eq. (V.1-36), leading to the erroneous conclusion that all resonances should be close to E_{ref} ($E_{r,i} \simeq E_{ref}$, i = 1, 2,...) (whereas in fact they should only show a limited energy spread [JOVANOVIC84]). The obvious shortcoming in this reasoning is the failure to recognize that the validity conditions of the truncation of Eqs (V.1-35) and (V.1-36) are irrelevant; the accuracy of the approximation by Eq. (V.1-36) does not depend on the individual Δ_1 and Δ_2 (or δ_i, i = 1, 2,...) but only on the value of $(\Delta_2 - \Delta_1)$. Mathematical evidence for the irrelevance of E_{ref} can easily be obtained by derivation of the explicit expression for $\Delta_2 - \Delta_1$ with respect to E_{ref}. After rearrangement one obtains :

$$\frac{\delta(\Delta_2-\Delta_1)}{\delta E_{ref}} = \frac{\alpha}{E_{ref}} \left\{ \frac{\sum_i w_i (E_{r,i}/E_{ref})^{-\alpha}}{\sum_i w_i} - \left(\frac{\bar{E}_r(\alpha)}{E_{ref}} \right)^{-\alpha} \right\}$$

The expression in brackets is identically zero for all values of the involved parameters because of the definition in Eq. (V.1-32). This demonstrates that the validity of approximating $\bar{E}_r(\alpha)$ by $\bar{E}_r$ is not dependent upon the actual choice of E_{ref}.

Irrelevant arguments for the believed role of E_{ref} were also found in the evaluation of the errors on the calculated "specific activity" caused by deviations of α (and $\bar{E}_r$), as shown in Ref. [OPDEBEECK85B, Figs 2 and 3]. There, it was assumed that ϕ_e is independent of α, whereas there is no way to obtain a value for ϕ_e except by determining it experimentally, which necessitates the introduction of $I_{0,m}(\alpha)$ for a flux monitor (index m). Hence, to

be relevant to practice, the term $\ln(E_{ref}/\bar{E}_r)$ in Ref. [OPDEBEECK85B, Eqs (17) and (19)] should be replaced by $\ln(\bar{E}_{r,m}/\bar{E}_r)$. This shows that the error induced by α is not minimized if $\bar{E}_r \simeq E_{ref}$ [OPDEBEECK85B], but if $\bar{E}_r \simeq \bar{E}_{r,m}$, thus refuting the role of E_{ref}.

Another opportunity to ascertain the irrelevance of E_{ref} can be found when the formula for concentration calculation in NAA is derived, thereby introducing the monitor activity. Instead of considering the flux ratio f as α-independent [OPDEBEECK85B], f is obviously an experimental parameter allowing to cancel E_{ref} from the formula for calculation of the concentration of the analyte (index a). The general validity of this statement can be easily proved as follows. Eq. (I.3-20) should be written as (neglecting G_{th} and G_e) :

$$\rho, ppm = K \cdot \frac{f(\alpha) + Q_{0,m}(\alpha)}{f(\alpha) + Q_{0,a}(\alpha)} \qquad (V.1\text{-}37)$$

with K grouping all α-independent parameters. Explicit introduction of f, either obtained from a Cd-ratio measurement of a flux ratio monitor (index r; neglecting G_{th}, G_e and F_{Cd}) :

$$f = (R_{Cd,r} - 1)\, Q_{0,r}(\alpha)$$

or from the bare bi-isotopic monitor method (indices 1 and 2; neglecting G_{th} and G_e) :

$$f = aQ_{0,1}(\alpha) - bQ_{0,2}(\alpha) \quad [a \text{ and } b\ \alpha\text{-independent}]$$

and substitution, for all isotopes involved, of

$$Q_0(\alpha) = \left\{(Q_0 - 0.429)\bar{E}_r^{-\alpha} + 0.429/[(2\alpha+1)(0.55)^{\alpha}]\right\} E_{ref}^{\alpha}$$

makes the E_{ref}-term dropping from Eq. (V.1-37).

It can be concluded that the applicability of the $\bar{E}_r$-concept in describing the epicadmium reaction rate in non-ideal spectra is by no means dependent on the choice of the reference energy E_{ref}. If E_{ref} = 1 eV is chosen and energies are thus expressed in eV, there is no need whatsoever to keep this reference energy explicitly in the relevant formulae.

1.5. Principles and uncertainties of experimental α-determination

In Ref. [DECORTE81] the experimental methods for α-determination were dealt with in great detail. They can be classified into three groups, based

on Cd-ratio measurements, Cd-covered irradiation and bare irradiation, respectively, involving a set of activation monitors with suited characteristics ($\bar{E}_r$, Q_0, etc.).

1.5.1. "Cd-covered multi-monitor"-method

This method is essential for in-situ α-determination in ENAA. A set of N monitors is irradiated simultaneously under Cd-cover and subsequently counted on a Ge-detector with known detection efficiency curve. If all the monitors have a $\sigma(v) \sim 1/v$ dependence up to $\sim$ 1.5 eV, α can be obtained as the slope (-α) of the straight line when plotting

$$\log \frac{(\bar{E}_{r,i})^{-\alpha} (A_{sp,i})_{Cd}}{k_{0,Au}(i).\varepsilon_{p,i}.F_{Cd,i}.Q_{0,i}(\alpha)G_{e,i}} \text{ versus } \log \bar{E}_{r,i} \qquad (V.1\text{-}38)$$

where i denotes isotope 1, 2,...N.
The left hand term of Eq. (V.1-38) is itself a function of α, and thus an iterative procedure should be applied, e.g. by plotting Eq. (V.1-38) for α = 0, which gives as a first approximation of $\alpha = \alpha_1$, and so on. Mathematically, the final α-result of this iteration procedure is identical with solving α from the equation :

$$\alpha + \frac{\sum_i^N \left[\left\{\log \bar{E}_{r,i} - \frac{\sum_i^N \log \bar{E}_{r,i}}{N}\right\}\left\{\log T_i - \frac{\sum_i^N \log T_i}{N}\right\}\right]}{\sum_i^N \left\{\log \bar{E}_{r,i} - \frac{\sum_i^N \log \bar{E}_{r,i}}{N}\right\}^2} = 0 \qquad (V.1\text{-}39)$$

with

$$T_i = \frac{(\bar{E}_{r,i})^{-\alpha} (A_{sp,i})_{Cd}}{k_{0,Au}(i).\varepsilon_{p,i}.F_{Cd,i}.Q_{0,i}(\alpha).G_{e,i}}$$

Note that the minimum number of monitors is two (N = 2), leading to the "Cd-covered dual-monitor"-method.

A detailed and critical error analysis has been performed in Ref. [DECORTE81] and will not be repeated here. As to the choice of the monitors, it was found that the total number of monitors (N) should be large and that the $\bar{E}_{r,i}$ values should be largely different from the average resonance energy of all monitors. It was proved in practice, however, that it is better to

select a limited number of physically suited monitors (e.g. metallic or alloyed foils and wires) with very accurately known nuclear data and with uniformly distributed $\bar{E}_r$-values, ranging from low to high. This offers the possibility of checking the linearity of the curve [Eq. (V.1-38)], thus proving that α is constant over the whole epithermal neutron energy region in the reactor spectrum under consideration. Finally, it should be remarked that, especially when low-Q_0 monitors are involved, the effective Cd cut-off energy E_{Cd} should be very close to 0.55 eV. Thus, one has to stick as close as possible to the prescription that the monitors should be quasi-point sources centered in the middle of a large cylindrical Cd-box with 1 mm wall-thickness and with height/diameter $\simeq$ 2. It is also important to note that the monitors should be counted in conditions of accurate ε_p, preferably in reference position (see III.1), where correction for true-coincidence effects is not needed. Table V.1-8 lists the relevant error propagation factors for α-determination in 5 reactor channels, with ^{197}Au-^{238}U-^{98}Mo-^{100}Mo-^{64}Zn as Cd-covered monitors. The corresponding data for the "Cd-covered triple monitor"-method, with ^{197}Au-^{96}Zr-^{94}Zr, are shown in Table V.1-9, where numerical examples of the resulting uncertainty on α are given as well. It can be seen that, by taking proper experimental care, the uncertainty on α is quite acceptable, especially in view of the large error reduction factors towards the quantities depending on α (k_0, ρ, etc.; see V.1.8).

1.5.2. "Cd-ratio for multi-monitor"-method

This method can be used for a priori α-monitoring when the reactor neutron flux characteristics are known to be stable as a function of time.

A set of N monitors is irradiated with and without Cd-cover, and the induced activities are measured on a Ge-detector. If all the monitors have a $\sigma(v) \sim 1/v$ dependence up to $\sim$ 1.5 eV, α can be obtained as the slope ($-\alpha$) of the straight line when plotting :

$$\log \frac{\bar{E}_{r,i}^{-\alpha}}{(F_{Cd,i}\, R_{Cd,i} - 1)\, Q_{0,i}(\alpha)\, G_{e,i}/G_{th,i}} \text{ versus } \log \bar{E}_{r,i} \qquad \text{(V.1-40)}$$

with i = 1, 2,...N.

TABLE V.1-8 : Error propagation factors, for the "Cd-covered multi-monitor"-method, with ^{197}Au-^{238}U-^{98}Mo-^{100}Mo-^{64}Zn, to be multiplied by the relevant uncertainties; $+Z_\alpha(A_{sp})_{Cd} = Z_\alpha(k_{0,Au}) = Z_\alpha(\varepsilon_p) = Z_\alpha(F_{Cd}) = Z_\alpha(G_e)$ [cf. Eq. (V.1-38)] ; nuclear data and uncertainties : see Table VIII.3-1

	^{197}Au	^{238}U	^{98}Mo	^{100}Mo	^{64}Zn
	ERROR PROPAGATION FACTOR				
THETIS Channel 17 ; f = 12.5 ; α = - 0.027					
$Z_\alpha(A_{sp})_{Cd^+}$	5.3	3.4	1.0	2.7	5.0
$Z_\alpha(Q_0)$	5.3	3.4	1.0	2.7	5.1
$Z_\alpha(\bar{E}_r)$	0.14	0.092	0.027	0.072	0.11
$Z_\alpha(E_{Cd})$			0.42		
WWR-M Channel "MILA" ; f = 36 ; α = 0.011					
$Z_\alpha(A_{sp})_{Cd^+}$	13.5	8.8	2.6	7.0	12.7
$Z_\alpha(Q_0)$	13.5	8.8	2.6	7.0	12.5
$Z_\alpha(\bar{E}_r)$	0.14	0.096	0.028	0.075	0.11
$Z_\alpha(E_{Cd})$			1.4		
THETIS Channel 14 ; f = 38 ; α = 0.030					
$Z_\alpha(A_{sp})_{Cd^+}$	5.1	3.3	0.97	2.6	4.8
$Z_\alpha(Q_0)$	5.1	3.3	0.97	2.6	4.6
$Z_\alpha(\bar{E}_r)$	0.15	0.099	0.028	0.077	0.11
$Z_\alpha(E_{Cd})$			0.62		
THETIS Channel 16 ; f = 104 ; α = 0.079					
$Z_\alpha(A_{sp})_{Cd^+}$	2.1	1.4	0.40	1.1	2.0
$Z_\alpha(Q_0)$	2.1	1.4	0.40	1.1	1.7
$Z_\alpha(\bar{E}_r)$	0.16	0.11	0.031	0.082	0.10
$Z_\alpha(E_{Cd})$			0.36		
DR-3 Channel R4V4 ; f = 337 ; α = 0.158					
$Z_\alpha(A_{sp})_{Cd^+}$	1.2	0.80	0.24	0.64	1.2
$Z_\alpha(Q_0)$	1.2	0.80	0.23	0.62	0.81
$Z_\alpha(\bar{E}_r)$	0.19	0.13	0.037	0.096	0.10
$Z_\alpha(E_{Cd})$			0.34		

Parameter	^{197}Au	^{96}Zr	^{94}Zr
	UNCERTAINTY		
$(A_{sp})_{Cd}$ (a)	0.3%	0.3%	0.3%
$(A_{sp})_{Cd}$ (b)	0.5% ; 1% (c)	0.5%	0.5%
$k_{0,Au}$	-	0.9% (743.3 keV)	0.6% (724.2 + 756.7 keV)
ε_p (d)	0.5% (411.8 keV)	0.5%	0.5%
F_{Cd}	0.2% (e)	-	-
G_e	-	0.4% (f)	0.3% (f)
Q_0	0.3% (g)	1.5%	2.0%
$\bar{E}_r$	7.1%	2.1%	4.0%
E_{Cd}		10%	
	ERROR PROPAGATION FACTOR		
	THETIS Channel 17 ; f = 12.5 ; α = -0.027		
$Z_\alpha(A_{sp})_{Cd}$+	5.9	0.63	5.3
$Z_\alpha(Q_0)$	5.9	0.63	5.4
$Z_\alpha(\bar{E}_r)$	0.16	0.017	0.13
$Z_\alpha(E_{Cd})$		0.10	
		s_α = 14%	
	WWR-M Channel "MILA" ; f = 36 ; α = 0.011		
$Z_\alpha(A_{sp})_{Cd}$+	14.9	1.6	13.3
$Z_\alpha(Q_0)$	14.9	1.6	13.2
$Z_\alpha(\bar{E}_r)$	0.16	0.017	0.13
$Z_\alpha(E_{Cd})$		0.41	
		s_α = 36%	
	THETIS Channel 14 ; f = 38 ; α = 0.030		
$Z_\alpha(A_{sp})_{Cd}$+	5.5	0.58	4.9
$Z_\alpha(Q_0)$	5.5	0.58	4.8
$Z_\alpha(\bar{E}_r)$	0.16	0.018	0.13
$Z_\alpha(E_{Cd})$		0.19	
		s_α = 13%	
	THETIS Channel 16 ; f = 104 ; α = 0.079		
$Z_\alpha(A_{sp})_{Cd}$+	2.2	0.23	2.0
$Z_\alpha(Q_0)$	2.2	0.23	1.8
$Z_\alpha(\bar{E}_r)$	0.17	0.018	0.13
$Z_\alpha(E_{Cd})$		0.13	
		s_α = 5.4%	
	DR-3 Channel R4V4 ; f = 337 ; α = 0.158		
$Z_\alpha(A_{sp})_{Cd}$+	1.2	0.13	1.1
$Z_\alpha(Q_0)$	1.2	0.13	0.93
$Z_\alpha(\bar{E}_r)$	0.19	0.021	0.13
$Z_\alpha(E_{Cd})$		0.15	
		s_α = 3.4%	

TABLE V.1-9 : Error propagation factors and uncertainties on α resulting from the "Cd-covered triple-monitor"-method with ^{197}Au-^{96}Zr-^{94}Zr. + $Z_\alpha(A_{sp})_{Cd} = Z_\alpha(k_{0,Au}) = Z_\alpha(\varepsilon_p) = Z_\alpha(F_{Cd}) = Z_\alpha(G_e)$; (a) = random, from counting statistics ; (b) = systematic, from peak area evaluation ; (c) = from composition of 0.1% Au-Al wire ; (d) = considering that only relative efficiencies are required ; (e) from [ELNIMR81] ; (f) = for 125 μm Zr-foil ; (g) = considering that Q_0's of Zr are relative to Au, but taking into account that $g(T_n)$ [^{197}Au] is slightly deviating from unity. Nuclear data and uncertainties : see Table VIII.3-1

As in the "Cd-covered multi-monitor"-method (see V.1.5.1), α can be solved from the equation :

$$\alpha + \frac{\sum_i^N \left| \left(\log \bar{E}_{r,i} - \frac{\sum_i^N \log \bar{E}_{r,i}}{N} \right) \left(\log \frac{\bar{E}_{r,i}^{-\alpha}}{(F_{Cd,i} R_{Cd,i}^{-1}) Q_{0,i}(\alpha) G_{e,i}/G_{th,i}} - \frac{\sum_i^N \log \frac{\bar{E}_{r,i}^{-\alpha}}{(F_{Cd,i} R_{Cd,i}^{-1}) Q_{0,i}(\alpha) G_{e,i}/G_{th,i}}}{N} \right) \right|}{\sum_i^N \left(\log \bar{E}_{r,i} - \frac{\sum_i^N \log \bar{E}_{r,i}}{N} \right)^2} = 0 \quad \text{(V.1-41)}$$

Note that the minimum number of monitors is two (N=2), leading to the "Cd-ratio for dual monitor"-method.

With respect to the error analysis [DECORTE81], the same conclusions can be drawn as mentioned for the "Cd-covered multi-monitor"-method. It was shown, however, that in the "Cd-ratio for multi-monitor"-method the use of monitors with very high Q_0-value should be avoided, since - as to be expected in Cd-ratio measurements considering the $(R_{Cd}-1)$-term - this would lead to large error propagation factors, especially in low flux-ratio irradiation sites. Also, it should be emphasized that it is absolutely essential to avoid different neutron thermalization by polythene spacers etc. in the containers for bare and Cd-covered irradiation. On the other hand, since only cadmium ratios are involved, any suitable counting geometry can be used.

Table V.1-10 lists the relevant error propagation factors for α-determination in 5 reactor channels according to the "Cd-ratio for multi-monitor"-method, with ^{197}Au-^{238}U-^{98}Mo-^{100}Mo-^{64}Zn as the monitor set. As expected, the use of high-Q_0 isotopes (^{238}U, ^{98}Mo, ^{100}Mo) leads to rather high error propagation factors in the low-f channels. It would, however, not help much to replace them by very low-Q_0 isotopes, e.g. by considering the set ^{197}Au-^{232}Th-^{59}Co-^{55}Mn-^{64}Zn, since then the $Z_\alpha(E_{Cd})$-factors are $\sim$ 2.5 times higher (giving for instance a contribution of 35% to the uncertainty on α in channel "MILA"). The corresponding data for the "Cd-covered triple monitor"-method, with ^{197}Au-^{96}Zr-^{94}Zr, are shown in Table V.1-11, including numerical examples for the uncertainties on α. In principle, the use of ^{197}Au-^{94}Zr (omitting ^{96}Zr with a very high Q_0-value) would yield somewhat lower uncertainties, but in this case any control of the linearity of $\log \varphi'_e(E)E$ vs $\log E$ would be lost. Table V.1-11 reveals that the final uncertainties on α are quite comparable with those obtained in the "Cd-covered triple-monitor"-method (cf. Table V.1-9).

Finally, it is important to remark that the "Cd-ratio" α-monitoring method is the only one which is not leading to a vicious circle in the experi-

TABLE V.1-10 : Error propagation factors, for the "Cd-ratio for multi-monitor"-method with ^{197}Au-^{238}U-^{98}Mo-^{100}Mo-^{64}Zn, to be multiplied by the relevant uncertainties; $+Z_\alpha(A_{sp}) = Z_\alpha(A_{sp})_{Cd} = Z_\alpha(F_{Cd})$; $++Z_\alpha(G_e) = Z_\alpha(G_{th})$ [see Eq. (V.1-40)] ; nuclear data and uncertainties : see Table VIII.3-1

	^{197}Au	^{238}U	^{98}Mo	^{100}Mo	^{64}Zn
	ERROR PROPAGATION FACTOR				
THETIS Channel 17 ; f = 12.5 ; α = -0.027					
$Z_\alpha(A_{sp})^+$	12.2	34.1	6.0	7.6	5.9
$Z_\alpha(G_e)^{++}$	5.3	3.4	1.0	2.7	5.0
$Z_\alpha(Q_0)$	5.3	3.4	1.0	2.7	5.1
$Z_\alpha(\bar{E}_r)$	0.14	0.092	0.027	0.072	0.11
$Z_\alpha(E_{Cd})$	0.42				
WWR-M Channel "MILA" ; f = 36 ; α = 0.011					
$Z_\alpha(A_{sp})^+$	19.3	33.3	6.2	10.4	13.3
$Z_\alpha(G_e)^{++}$	13.5	8.8	2.6	7.0	12.7
$Z_\alpha(Q_0)$	13.5	8.8	2.6	7.0	12.5
$Z_\alpha(\bar{E}_r)$	0.14	0.096	0.028	0.075	0.11
$Z_\alpha(E_{Cd})$	1.4				
THETIS Channel 14 ; f = 38 ; α = 0.030					
$Z_\alpha(A_{sp})^+$	7.1	11.6	2.1	3.7	5.0
$Z_\alpha(G_e)^{++}$	5.1	3.3	0.97	2.6	4.8
$Z_\alpha(Q_0)$	5.1	3.3	0.97	2.6	4.6
$Z_\alpha(\bar{E}_r)$	0.15	0.099	0.028	0.077	0.11
$Z_\alpha(E_{Cd})$	0.62				
THETIS Channel 16 ; f = 104 ; α = 0.079					
$Z_\alpha(A_{sp})^+$	2.4	2.4	0.53	1.2	2.0
$Z_\alpha(G_e)^{++}$	2.1	1.4	0.40	1.1	2.0
$Z_\alpha(Q_0)$	2.1	1.4	0.40	1.1	1.7
$Z_\alpha(\bar{E}_r)$	0.16	0.11	0.031	0.082	0.10
$Z_\alpha(E_{Cd})$	0.36				
DR-3 Channel R4V4 ; f = 337 ; α = 0.158					
$Z_\alpha(A_{sp})^+$	1.3	0.96	0.25	0.65	1.2
$Z_\alpha(G_e)^{++}$	1.2	0.80	0.24	0.64	1.2
$Z_\alpha(Q_0)$	1.2	0.80	0.23	0.62	0.81
$Z_\alpha(\bar{E}_r)$	0.19	0.13	0.037	0.096	0.10
$Z_\alpha(E_{Cd})$	0.34				

Parameter	^{197}Au	^{96}Zr	^{94}Zr
	UNCERTAINTY		
A_{sp} (a)	0.3%	0.3%	0.3%
A_{sp} (b)	0.3% ; 0.5% (c)	0.3%	0.3%
$(A_{sp})_{Cd}$ (a)	0.3%	0.3%	0.3%
$(A_{sp})_{Cd}$ (b)	0.3% ; 0.5% (c)	0.3%	0.3%
F_{Cd}	0.2% (d)	-	-
G_{th}	-	-	-
G_e	-	0.4% (e)	0.3% (e)
Q_0	0.3% (f)	1.5%	2.0%
$\bar{E}_r$	7.1%	2.1%	4.0%
E_{Cd}	10%		
	ERROR PROPAGATION FACTOR		
	THETIS Channel 17 ; f = 12.5 ; α = -0.027		
$Z_\alpha(A_{sp})^+$	13.7	15.1	8.0
$Z_\alpha(G_e)^{++}$	5.9	0.63	5.3
$Z_\alpha(Q_0)$	5.9	0.63	5.4
$Z_\alpha(\bar{E}_r)$	0.16	0.017	0.13
$Z_\alpha(E_{Cd})$	0.10		
	s_α = 20%		
	WWR-M Channel "MILA" ; f = 36 ; α = 0.011		
$Z_\alpha(A_{sp})^+$	21.2	11.7	15.0
$Z_\alpha(G_e)^{++}$	14.9	1.6	13.3
$Z_\alpha(Q_0)$	14.9	1.6	13.2
$Z_\alpha(\bar{E}_r)$	0.16	0.017	0.13
$Z_\alpha(E_{Cd})$	0.41		
	s_α = 36%		
	THETIS Channel 14 ; f = 38 ; α = 0.030		
$Z_\alpha(A_{sp})^+$	7.7	3.8	5.5
$Z_\alpha(G_e)^{++}$	5.5	0.58	4.9
$Z_\alpha(Q_0)$	5.5	0.58	4.8
$Z_\alpha(\bar{E}_r)$	0.16	0.018	0.13
$Z_\alpha(E_{Cd})$	0.19		
	s_α = 13%		
	THETIS Channel 16 ; f = 104 ; α = 0.079		
$Z_\alpha(A_{sp})^+$	2.5	0.58	2.0
$Z_\alpha(G_e)^{++}$	2.2	0.23	2.0
$Z_\alpha(Q_0)$	2.2	0.23	1.8
$Z_\alpha(\bar{E}_r)$	0.17	0.018	0.13
$Z_\alpha(E_{Cd})$	0.13		
	s_α = 5.0%		
	DR-3 Channel R4V4 ; f = 337 ; α = 0.158		
$Z_\alpha(A_{sp})^+$	1.3	0.17	1.1
$Z_\alpha(G_e)^{++}$	1.2	0.13	1.1
$Z_\alpha(Q_0)$	1.2	0.13	0.93
$Z_\alpha(\bar{E}_r)$	0.19	0.021	0.13
$Z_\alpha(E_{Cd})$	0.15		
	s_α = 3.2%		

TABLE V.1-11 : Error propagation factors and uncertainties on α resulting from the "Cd-ratio for triple-monitor"-method, with ^{197}Au-^{96}Zr-^{94}Zr. + $Z_\alpha(A_{sp}) = Z_\alpha(A_{sp})_{Cd} = Z_\alpha(F_{Cd})$; ++ $Z_\alpha(G_e) = Z_\alpha(G_{th})$; (a) = random, from counting statistics ; (b) = systematic, from peak area evaluation (and taking into account partial cancelling of errors) ; (c) = from inhomogeneity of 0.1% Au-Al wire ; (d) = from [ELNIMR81] ; (e) = for 125 µm Zr-foil ; (f) = considering that Q_0's of Zr are relative to Au, but taking into account that $g(T_n)$ [^{197}Au] is slightly deviating from unity. Nuclear data and uncertainties : see Table VIII.3-1

mental α and k_0-determination (except when the latter is performed by the Cd-subtraction method), since the knowledge of k_0 is not required for calculating α.

1.5.3. "Bare multi-monitor"-method

This method is essential for in-situ α-determination in NAA.

A set of N-monitors, together with a "reference" monitor isotope, is irradiated without Cd-cover, whereafter the induced activities are measured on a Ge-detector with known detection efficiency curve. If all the monitors have a $\sigma(v) \sim 1/v$ dependence up to $\sim$ 1.5 eV, α can be obtained as the slope $(-\alpha)$ of the straight line when plotting :

$$\log \left\{ (\bar{E}_{r,i})^{-\alpha} A_i \right\} \quad \text{versus} \quad \log \bar{E}_{r,i}$$

with

$$A_i = \frac{A_{sp,i}/k_{0,Au}(i)\varepsilon_{p,i} - A_{sp,ref}/k_{0,Au}(ref)\varepsilon_{p,ref}}{Q_{0,i}(\alpha)G_{e,i}/G_{th,i} - Q_{0,ref}(\alpha)G_{e,ref}/G_{th,ref}} \qquad \text{(V.1-42)}$$

and where the index "ref" denotes the reference monitor isotope.

Analogously to the above methods (see V.1.5.1 and V.1.5.2), α can be solved from the equation :

$$\alpha + \frac{\sum_i^N \left[\left\{ \log \bar{E}_{r,i} - \frac{\sum_i^N \log \bar{E}_{r,i}}{N} \right\} \left\{ \log \left\{ (\bar{E}_{r,i})^{-\alpha} A_i \right\} - \frac{\sum_i^N \log \left\{ (\bar{E}_{r,i})^{-\alpha} A_i \right\}}{N} \right\} \right]}{\sum_i^N \left\{ \log \bar{E}_{r,i} - \frac{\sum_i^N \log \bar{E}_{r,i}}{N} \right\}^2} = 0 \qquad \text{(V.1-43a)}$$

("ref" not included in the i-series).

Note that the minimum number of monitors is three (N=2, plus one reference monitor), thus leading to the "bare triple-monitor"-method. Then, α can be found from the equation :

$$(a-b)\, Q_{0,1}(\alpha).G_{e,1}/G_{th,1} - a\, Q_{0,2}(\alpha)\, G_{e,2}/G_{th,2} + b\, Q_{0,3}(\alpha)\, G_{e,3}/G_{th,3} = 0 \qquad \text{(V.1-43b)}$$

with

$$a = \left\{ 1 - \frac{A_{sp,2}}{A_{sp,1}} \cdot \frac{k_{0,Au}(1)}{k_{0,Au}(2)} \cdot \frac{\varepsilon_{p,1}}{\varepsilon_{p,2}} \right\}^{-1}$$

$$b = \left\{ 1 - \frac{A_{sp,3}}{A_{sp,1}} \cdot \frac{k_{0,Au}(1)}{k_{0,Au}(3)} \cdot \frac{\varepsilon_{p,1}}{\varepsilon_{p,3}} \right\}^{-1} \qquad \text{(V.1-43c)}$$

As in the "Cd-covered multi-monitor"-method, the monitors should be counted in conditions of accurate ε_p, where true-coincidence effects are negligible (see V.2.2).

As to the number of monitors and the spread of their effective resonance energies, the same conclusions hold as mentioned for the "Cd-covered" and "Cd-ratio" methods (see V.1.5.1 and V.1.5.2). From the error propagation functions [DECORTE81], it is difficult to draw general and practical conclusions concerning the optimum combination of monitors (with respect to their Q_0 and $\bar{E}_r$ values) to be used. Nevertheless, in the "bare triple-monitor"-method it was found that the best results, in case of high-f irradiation positions, are obtained from one low-Q_0 and two high-Q_0 isotopes, whereby it is preferable that the Q_0 and $\bar{E}_r$ sequences are $Q_{0,1} < Q_{0,2} < Q_{0,3}$ and $E_{r,2} < E_{r,1} < E_{r,3}$. In general, the error propagation factors and the resulting uncertainties on α are significantly larger for the "bare multi-monitor"-method than for the "Cd-covered" and "Cd-ratio"-methods. Table V.1-12 lists the relevant error propagation factors and the resulting uncertainties of α-determination in 5 reactor channels according to the "bare triple-monitor"-method, with ^{197}Au-^{96}Zr-^{94}Zr. Analogous data are shown in Table V.1-13 for the triplet ^{238}U-^{96}Zr-^{94}Zr which fulfils better the above requirement with respect to Q_0 and $\bar{E}_r$-values, thus leading to significantly lower error propagation factors and uncertainties. However, even the uncertainties on α quoted in Table V.1-12 are quite acceptable, in view of the large error reduction factors towards the analysis result (see V.1.8). Note that the practical aspects of Au-Zr counting are outlined in V.2.2.

1.6. Validity of the $1/E^{1+\alpha}$ and $\bar{E}_r$ concepts : experimental check

Of special interest is the experimental investigation of the validity of the adopted $1/E^{1+\alpha}$ and $\bar{E}_r$ approximations. If these assumptions are reasonable, a log-log plot of $\varphi'_e(E)E$ versus E should yield a straight line. When using

Parameter	^{197}Au	^{96}Zr	^{94}Zr
	UNCERTAINTY		
A_{sp} (a)	0.3%	0.3%	0.3%
A_{sp} (b)	0.5% ; 1% (c)	0.5%	0.5%
$k_{0,Au}$	-	0.9% (743.3 keV)	0.6% (724.2 + 756.7 keV)
ε_p (d)	0.5% (411.8 keV)	0.5%	0.5%
G_{th}	-	-	-
G_e	-	0.4% (e)	0.3% (e)
Q_0	0.3% (f)	1.5%	2.0%
$\bar{E}_r$	7.1%	2.1%	4.0%
	ERROR PROPAGATION FACTOR		
THETIS Channel 17 ; f = 12.5 ; α = -0.027			
$Z_\alpha(A_{sp})^+$	13.1	4.9	8.2
$Z_\alpha(G_e)^{++}$	7.4	4.7	2.8
$Z_\alpha(Q_0)$	7.4	4.7	2.8
$Z_\alpha(\bar{E}_r)$	0.19	0.13	0.069
	s_α = 22%		
WWR-M Channel "MILA" ; f = 36 ; α = 0.011			
$Z_\alpha(A_{sp})^+$	64.0	15.8	48.2
$Z_\alpha(G_e)^{++}$	19.2	13.7	5.4
$Z_\alpha(Q_0)$	19.2	13.7	5.4
$Z_\alpha(\bar{E}_r)$	0.21	0.15	0.055
	s_α = 98%		
THETIS Channel 14 ; f = 38 ; α = 0.030			
$Z_\alpha(A_{sp})^+$	25.5	6.4	19.1
$Z_\alpha(G_e)^{++}$	7.2	5.4	1.8
$Z_\alpha(Q_0)$	7.2	5.4	1.8
$Z_\alpha(\bar{E}_r)$	0.21	0.16	0.049
	s_α = 39%		
THETIS Channel 16 ; f = 104 ; α = 0.079			
$Z_\alpha(A_{sp})^+$	24.9	3.9	20.6
$Z_\alpha(G_e)^{++}$	2.9	2.3	0.49
$Z_\alpha(Q_0)$	2.9	2.3	0.49
$Z_\alpha(\bar{E}_r)$	0.22	0.18	0.035
	s_α = 37%		
DR-3 Channel R4V4 ; f = 337 ; α = 0.158			
$Z_\alpha(A_{sp})^+$	43.6	5.8	37.8
$Z_\alpha(G_e)^{++}$	1.5	1.3	0.14
$Z_\alpha(Q_0)$	1.5	1.3	0.14
$Z_\alpha(\bar{E}_r)$	0.23	0.21	0.021
	s_α = 67%		

TABLE V.1-12 : Error propagation factors and uncertainties on α resulting from the "bare triple-monitor"-method with ^{197}Au-^{96}Zr-^{94}Zr.
+ $Z_\alpha(A_{sp}) = Z_\alpha(k_{0,Au}) = Z_\alpha(\varepsilon_p)$;
++ $Z_\alpha(G_{th}) = Z_\alpha(G_e)$; (a) = random, from counting statistics ; (b) = systematic, from peak area evaluation ; (c) = from composition of 0.1% Au-Al wire ; (d) = considering that only relative efficiencies are required ; (e) = for 125 μm Zr-foil ; (f) = considering that Q_0's of Zr are relative to Au, but taking into account that $g(T_n)$ [^{197}Au] is slightly deviating from unity. Nuclear data and uncertainties : see Table VIII.3-1

Parameter	^{238}U	^{96}Zr	^{94}Zr
	UNCERTAINTY		
A_{sp} (a)	0.3%	0.3%	0.3%
A_{sp} (b)	0.5% ; 1% (c)	0.5%	0.5%
$k_{0,Au}$	0.8% (277.6 keV)	0.9% (743.3 keV)	0.6% (724.2 + 756.7 keV)
ε_p (d)	0.5%	0.5%	0.5%
G_{th}	-	-	-
G_e	-	0.4% (e)	0.3% (e)
Q_0	1.3%	1.5%	2.0%
$\bar{E}_r$	1.2%	2.1%	4.0%
	ERROR PROPAGATION FACTOR		
	THETIS Channel 17 ; f = 12.5 ; α = -0.027		
$Z_\alpha(A_{sp})^+$	13.4	12.1	1.3
$Z_\alpha(G_e)^{++}$	12.0	11.6	0.43
$Z_\alpha(Q_0)$	12.0	11.6	0.43
$Z_\alpha(\bar{E}_r)$	0.32	0.31	0.011
	s_α = 34%		
	WWR-M Channel "MILA" ; f = 36 ; α = 0.011		
$Z_\alpha(A_{sp})^+$	40.4	33.4	7.0
$Z_\alpha(G_e)^{++}$	29.7	28.9	0.79
$Z_\alpha(Q_0)$	29.7	28.9	0.79
$Z_\alpha(\bar{E}_r)$	0.33	0.32	0.0080
	s_α = 84%		
	THETIS Channel 14 ; f = 38 ; α = 0.030		
$Z_\alpha(A_{sp})^+$	15.3	12.6	2.7
$Z_\alpha(G_e)^{++}$	10.9	10.7	0.25
$Z_\alpha(Q_0)$	10.9	10.7	0.25
$Z_\alpha(\bar{E}_r)$	0.33	0.32	0.0068
	s_α = 35%		
	THETIS Channel 16 ; f = 104 ; α = 0.079		
$Z_\alpha(A_{sp})^+$	9.5	6.9	2.6
$Z_\alpha(G_e)^{++}$	4.2	4.1	0.062
$Z_\alpha(Q_0)$	4.2	4.1	0.062
$Z_\alpha(\bar{E}_r)$	0.33	0.32	0.0045
	s_α = 19%		
	DR-3 Channel R4V4 ; f = 337 ; α = 0.158		
$Z_\alpha(A_{sp})^+$	12.8	9.2	3.6
$Z_\alpha(G_e)^{++}$	2.1	2.1	0.014
$Z_\alpha(Q_0)$	2.1	2.1	0.014
$Z_\alpha(\bar{E}_r)$	0.33	0.33	0.0020
	s_α = 23%		

TABLE V.1-13 : Error propagation factors and uncertainties on α resulting from the "bare triple-monitor"-method with ^{238}U-^{96}Zr-^{94}Zr.
+ $Z_\alpha(A_{sp}) = Z_\alpha(k_{0,Au}) = Z_\alpha(\varepsilon_p)$;
++ $Z_\alpha(G_{th}) = Z_\alpha(G_e)$; (a) = random, from counting statistics ; (b)= systematic, from peak area evaluation ; (c) = from composition of 0.4% U-Al wire ; (d) = considering that only relative efficiencies are required ; (e) = for 125 µm Zr-foil. Nuclear data and uncertainties : see Table VIII.3-1

for instance the "Cd-ratio for multi-monitor"-method, this comes to examining the linearity of $\log\{\bar{E}_{r,i}^{-\alpha}/[(F_{Cd,i}R_{Cd,i} - 1)Q_{0,i}(\alpha)\ G_{e,i}/G_{th,i}]\}$ versus $\log \bar{E}_{r,i}$. Therefore, a set of experiments was performed in 5 irradiation positions of three different reactors with largely diverging neutron thermalization : channel "MILA" in the WWR-M reactor (Budapest, Hungary ; light-water moderated), channels 14, 7 and 16 in the THETIS reactor (Gent, Belgium ; light-water and graphite moderated) and channel R4V4 in the DR-3 reactor (Risø, Denmark; heavy-water moderated). Eight appropriate monitors were used, for which the adopted nuclear data ($\bar{E}_r$, Q_0, T) - to be considered as "standard" data for this application - can be assumed to have an acceptable accuracy (see Table V.1-14).

TABLE V.1-14 : "Standard" monitors and nuclear data for use in the "Cd-ratio for multi-monitor" method for α-determination. $\bar{E}_r$ and Q_0 values are based on Mughabghab et al. [MUGHABGHAB81/84]. Except for Au, all F_{Cd} factors are unity

Monitor	$\bar{E}_r$, eV	Q_0	T
$^{197}Au(n,\gamma)^{198}Au$	5.65 ± 0.40	15.71 ± 0.28 (F_{Cd}=0.991)	2.695 d
$^{238}U(n,\gamma)^{239}U$ / ^{239}Np	16.9 ± 0.2	103.4 ± 1.3	23.50 min 2.355 d
$^{232}Th(n,\gamma)^{233}Th$ / ^{233}Pa	54.4 ± 0.5	11.53 ± 0.42	22.3 min 27.0 d
$^{59}Co(n,\gamma)^{60}Co$	136 ± 7	1.990 ± 0.054	5.271 y
$^{98}Mo(n,\gamma)^{99}Mo$ / ^{99m}Tc	241 ± 48	53.1 ± 3.4	66.02 h 6.02 h
$^{55}Mn(n,\gamma)^{56}Mn$	468 ± 51	1.053 ± 0.028	2.5785 h
$^{100}Mo(n,\gamma)^{101}Mo$ / ^{101}Tc	672 ± 94	18.84 ± 0.81	14.6 min 14.2 min
$^{64}Zn(n,\gamma)^{65}Zn$	2560 ± 260	1.908 ± 0.094	244.0 d

The following materials were irradiated and counted : Al-0.1005% Au wire (1 mm diam.; ATEC/Belgium); Al-0.443% U wire (99.962% ^{238}U; 1 mm diam. ; CBNM/Belgium) ; Al-0.819% Th wire (1 mm diam.; CBNM/Belgium) ; Al-1.00% Co wire (1 mm diam.; ATEC/Belgium) ; 5 μm Mo-foil (99.9%; GOODFELLOW) ; Al-1.00% Mn wire (1 mm diam.; ATEC/Belgium) ; 25 μm Zn-foil (99.95+% ; GOODFELLOW).

Fig. V.1-1 shows for each channel one example of the α-results obtained with ^{197}Au-^{238}U-^{98}Mo-^{100}Mo-^{64}Zn. The adequacy of the linear fits is expressed as $\chi^2_\nu = \frac{1}{N-2} \sum_i \left(\frac{Y-Y_i}{s_i} \right)^2$; averaging over the 5 channels one obtains $\bar{\chi}^2_\nu = 0.904$. Taking into account the error bars, there is no reason - considering the "rectification power" of a log-log representation - to suspect that the experimental points fit better to a curved line than to a perfectly straight one, as stated in Ref. [OPDEBEECK85B]. Although the linearity seems to hold for 5 different channels, this does not absolutely guarantee the accuracy of the 5 α-results, which might be subject to a systematic error caused by the choice of the monitors. Therefore Fig. V.1-2 shows, as an example for one of the considered channels, a comparison of α-results obtained on the one side with the above mentioned monitors, on the other hand with the set ^{197}Au-^{238}U-^{232}Th-^{59}Co-^{55}Mn. For the monitors of the latter set, there is even better reason to believe in the accuracy of the relevant nuclear data. The negligible α-difference revealed in Fig. V.1-2 is considered as a strong proof for the accuracy of the α-values, i.e. of the $1/E^{1+\alpha}$ and $\bar{E}_r$ approximations.

It is interesting to consider the uncertainties on the α-values in Fig. V.1-1. They amount to ≃ 90% (α ≃ 0.01, f ≃ 36 ; Ch. "MILA"), ≃ 30% (α ≃ 0.03, f ≃ 38 ; Ch. 14), ≃ 12% (α ≃ 0.07, f ≃ 110 ; Ch. 7), ≃ 11% (α ≃ 0.08, f ≃ 104; Ch. 16) and ≃ 7% (α ≃ 0.16, f ≃ 340 ; Ch. R4V4), showing that s_α roughly varies as $|1/\alpha|$, according to the error propagation functions [DECORTE81]. These figures reveal also that a higher thermalization (higher f) is associated with a larger positive α-value, i.e. with a softening of the epithermal spectrum as compared to the ideal 1/E-distribution. This is a rather general rule, corresponding with the qualitative picture given by [RYVES69] for small graphite-moderated reactors and by [OPDEBEECK85A] for the Thetis reactor itself. In case of poor thermalization, like in channels 17 of the Thetis reactor (f ≃ 15) or "CSÖPI" of the WWR-M reactor (f ≃ 18), the α-value becomes even negative : ≃ -0.03 (Ch. 17) and ≃ -0.007 (Ch. "CSÖPI") [see II.1], thus corresponding to

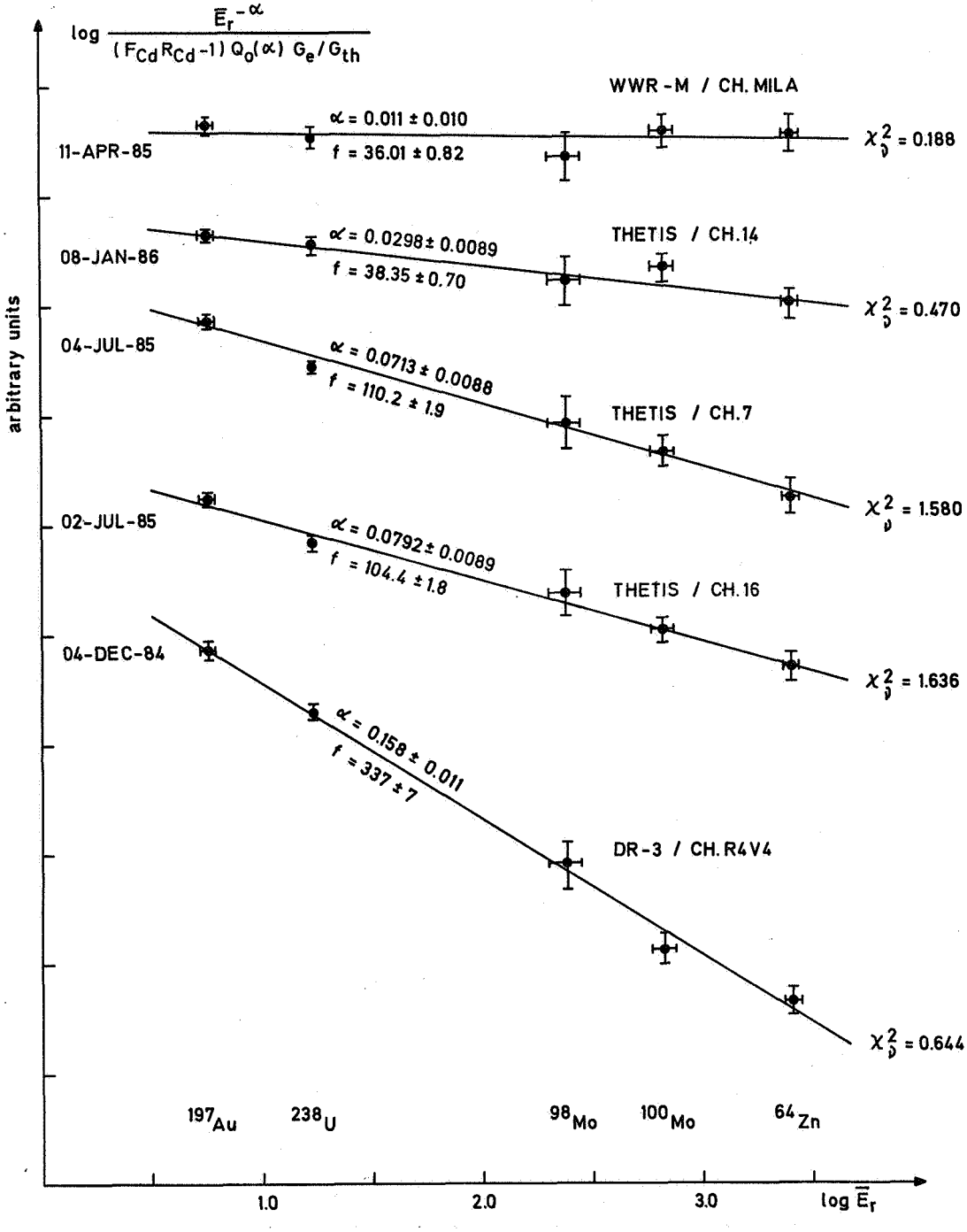


Fig. V.1-1 : Experimental α-determination in various channels of the WWR-M reactor (Budapest), the THETIS reactor (Gent) and the DR-3 reactor (Risø). Use is made of the "Cd-ratio for multi-monitor" method (V.1.5.2) with some "standard" monitors and nuclear data of Table V.1-14

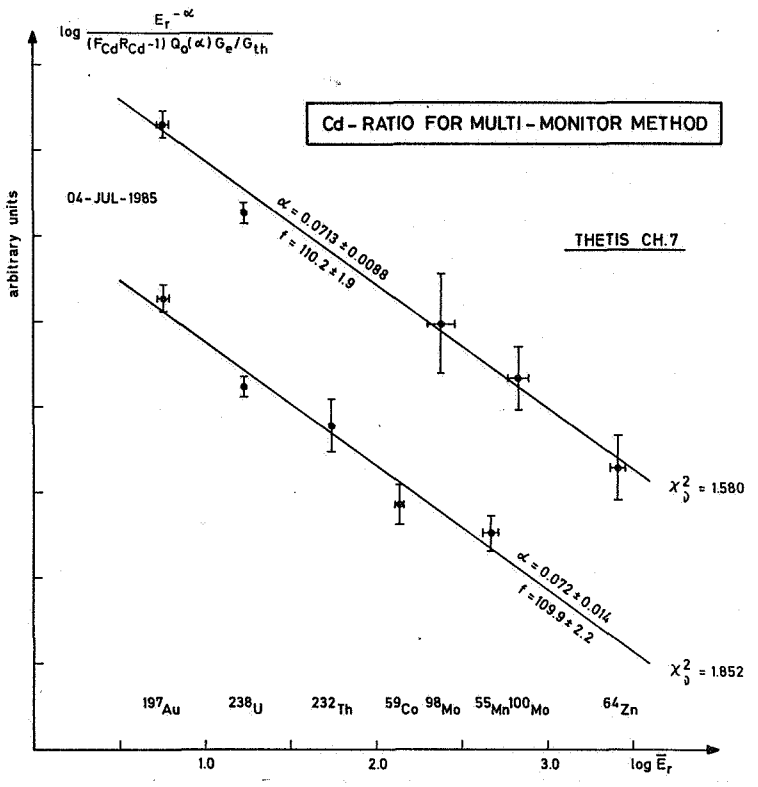


Fig. V.1-2 : Check of the accuracy of α-determination in channel 7 of the THETIS reactor (Gent) by using two different "standard" monitor sets.

a hardening of the epithermal spectrum as compared to the ideal 1/E-distribution.

1.7. α-Mapping of reactor Thetis

Based on the techniques for α-monitoring described in V.1.5.1 - V.1.5.3, a complete α-mapping of the 17 irradiation channels of reactor Thetis has been made [DECORTE81B/84]. The results are shown in Fig. II.1-1. As mentioned, they refer to the reactor configuration as it was before March 1981. No errors on α are given, but the overall uncertainties are of the order of 5-10% for high α's ($\alpha \simeq 0.1$) to 50% or more for α's approaching zero ($\alpha \simeq 0.01$). For channel 9, a zero α-value is quoted, which means in fact that values ranging from -0.005 to +0.005 were found. Thus, in practice, channel 9 can be consi-

dered as an almost ideal irradiation position with respect to the epithermal neutron flux distribution.

From Fig. II.1-1 it appears that reactor Thetis shows a definite symmetry with respect to the α-values, except for channel 2 versus 11, and 3 versus 12. Obviously, this is due to the presence of control plate P4, which is shifting the "fission center" of the core towards channels 11/12. A similar effect has been described in Ref. [SCHUMANN65].

1.8. Propagation of the error on α towards other quantities

Based on the principles explained in I.3.4.4, the following error propagation functions can be obtained :

- for $Q_0 \rightarrow Q_0(\alpha)$ conversion [Eq. (V.1-15)] and for the determination of f from R_{Cd} [Eq. (V.1-9)] :

$$Z_{Q_0(\alpha)}(\alpha) = Z_f(\alpha) = \left| \frac{\alpha}{Q_0(\alpha)} \left\{ q_0(\alpha) \ln \bar{E}_r + 0.60\, C_\alpha \left(\frac{1.67}{\alpha+1/2} - 1 \right) \right\} \right| \qquad \text{(V.1-44)}$$

with $q_0(\alpha)$ and C_α defined in Eqs (V.1-18) and (V.1-19) ;

- for $Q_0(\alpha) \rightarrow Q_0$ conversion [Eq. (V.1-16)] :

$$Z_{Q_0(\alpha)} = \frac{q_0}{q_0(\alpha)} \cdot Z_{Q_0(\alpha)}(\alpha) \qquad \text{(V.1-45)}$$

- for k_0-determination [Eq. (I.3-18)] with f determined from the R_{Cd}-method (flux ratio monitor r) :

$$Z_{k_0}(\alpha) = \left| \alpha \left\{ \frac{q_{0,c}(\alpha) \ln \bar{E}_{r,c} + 0.60\, C_\alpha \left(\frac{1.67}{\alpha+1/2} - 1 \right)}{f + Q_{0,c}(\alpha)} - \frac{q_{0,s}(\alpha) \ln \bar{E}_{r,s} + 0.60\, C_\alpha \left(\frac{1.67}{\alpha+1/2} - 1 \right)}{f + Q_{0,s}(\alpha)} + \frac{f[Q_{0,s}(\alpha) - Q_{0,c}(\alpha)]}{[f + Q_{0,c}(\alpha)][f + Q_{0,s}(\alpha)]} \left[\frac{q_{0,r}(\alpha) \ln \bar{E}_{r,r} + 0.60\, C_\alpha \left(\frac{1.67}{\alpha+1/2} - 1 \right)}{Q_{0,r}(\alpha)} \right] \right\} \right| \qquad \text{(V.1-46)}$$

- for f-determination from the bare bi-isotopic monitor method [Eq. (V.1-10)] :

$$Z_f(\alpha) = \left| \frac{\alpha}{f} \left\{ \frac{[f + Q_{0,1}(\alpha)] q_{0,2}(\alpha) \ln \bar{E}_{r,2} - [f + Q_{0,2}(\alpha)] q_{0,1}(\alpha) \ln \bar{E}_{r,1}}{Q_{0,1}(\alpha) - Q_{0,2}(\alpha)} + 0.60\, C_\alpha \left(\frac{1.67}{\alpha+1/2} - 1 \right) \right\} \right| \qquad \text{(V.1-47)}$$

- for ρ-calculation in ENAA [Eq. (I.3-21)] :

$$Z_\rho(\alpha) = \left| \alpha \left\{ \frac{q_{0,m}(\alpha)\ \ln \bar{E}_{r,m}}{Q_{0,m}(\alpha)} - \frac{q_{0,a}(\alpha)\ \ln \bar{E}_{r,a}}{Q_{0,a}(\alpha)} + \left\{ \frac{1}{Q_{0,m}(\alpha)} - \frac{1}{Q_{0,a}(\alpha)} \right\} .\ 0.60\ C_\alpha \left(\frac{1.67}{\alpha+1/2} - 1 \right) \right\} \right| \qquad (V.1\text{-}48)$$

- for ρ-calculation in NAA [Eq. (I.3-20)] with f determined from the bare bi-isotopic monitor method [Eq. (V.1-10)] :

$$Z_\rho(\alpha) = \left| \alpha \left\{ \frac{q_{0,m}(\alpha)\ \ln \bar{E}_{r,m}}{f + Q_{0,m}(\alpha)} - \frac{q_{0,a}(\alpha)\ \ln \bar{E}_{r,a}}{f + Q_{0,a}(\alpha)} + \frac{Q_{0,m}(\alpha) - Q_{0,a}(\alpha)}{Q_{0,1}(\alpha) - Q_{0,2}(\alpha)} \times \right. \right.$$

$$\left. \left. \times \frac{[f + Q_{0,1}(\alpha)]\ q_{0,2}(\alpha)\ \ln \bar{E}_{r,2} - [f + Q_{0,2}(\alpha)]\ q_{0,1}(\alpha)\ \ln \bar{E}_{r,1}}{[f + Q_{0,m}(\alpha)][f + Q_{0,a}(\alpha)]} \right\} \right| \qquad (V.1\text{-}49)$$

Table V.1-15 gives an idea of the error propagation factors and uncertainties (induced by α) to be expected in NAA.

2. EXPERIMENTAL f-DETERMINATION

2.1. Cd-ratio method

As mentioned earlier, f can be determined from Cd-ratio measurements as :

$$f = (F_{Cd,r}\ R_{Cd,r} - 1).G_{e,r}\ Q_{0,r}(\alpha)/G_{th,r} \qquad (V.2\text{-}1)$$

where r is a flux ratio monitor with well-known Q_0 and $\bar{E}_r$ values, which is irradiated subsequently with and without Cd-cover. Care should be taken to ensure that $E_{Cd} \simeq 0.55$ eV (see I.1.3.2), especially for low-Q_0 monitors; indeed, the percentile error on $Q_{0,r}$ and hence on f (neglecting α), induced by a value of "E_{Cd}" $\neq 0.55$ eV, is given by (cf. ELNIMR81B) :

$$\Delta f,\% = \frac{0.318}{Q_{0,r}} \left\{ ("E_{Cd}")^{-1/2} - (0.55)^{-1/2} \right\} .\ 100 \qquad (V.2\text{-}2)$$

Also, one should avoid different neutron thermalization in the containers for bare and Cd-covered irradiation (see V.1.5.2).

It is interesting to consider the error propagation factor (neglecting F_{Cd}, G_e and G_{th}) :

TABLE V.1-15 : Error propagation factors [Eq. (V.1-49)] and uncertainties induced by α [$s_\rho(\alpha),\% = Z_\rho(\alpha).s_\alpha,\%$] on NAA-results for 5 irradiation sites ; α is determined from the "bare triple-monitor"-method with ^{197}Au-^{96}Zr-^{94}Zr (see Table V.1-12) ; f is determined from the bare bi-isotopic monitor method with ^{96}Zr-^{94}Zr (see V.2.2)

	$^{238}U(n,\gamma)^{239}U$ $Q_0 = 103.4$ $\bar{E}_r = 16.9$ eV	$^{232}Th(n,\gamma)^{233}Th$ $Q_0 = 11.53$ $\bar{E}_r = 54.4$ eV	$^{59}Co(n,\gamma)^{60}Co$ $Q_0 = 1.993$ $\bar{E}_r = 136$ eV	$^{98}Mo(n,\gamma)^{99}Mo$ $Q_0 = 53.1$ $\bar{E}_r = 241$ eV	$^{55}Mn(n,\gamma)^{56}Mn$ $Q_0 = 1.053$ $\bar{E}_r = 468$ eV	$^{100}Mo(n,\gamma)^{101}Mo$ $Q_0 = 18.84$ $\bar{E}_r = 672$ eV	$^{64}Zn(n,\gamma)^{65}Zn$ $Q_0 = 1.908$ $\bar{E}_r = 2560$ eV
THETIS Channel 17 ; f = 12.5 ; α = -0.027 ($\pm$ 22%)							
$Z_\rho(\alpha)$	0.0017	0.035	0.042	0.064	0.043	0.076	0.052
$s_\rho(\alpha),\%$	0.037	0.77	0.92	1.4	0.95	1.7	1.1
WWR-M Channel "MILA" ; f = 36 ; α = 0.011 ($\pm$ 98%)							
$Z_\rho(\alpha)$	0.0091	0.0083	0.012	0.012	0.012	0.016	0.013
$s_\rho(\alpha),\%$	0.89	0.81	1.2	1.2	1.2	1.6	1.3
THETIS Channel 14 ; f = 38 ; α = 0.030 ($\pm$ 39%)							
$Z_\rho(\alpha)$	0.026	0.022	0.030	0.031	0.031	0.040	0.033
$s_\rho(\alpha),\%$	1.0	0.86	1.2	1.2	1.2	1.6	1.3
THETIS Channel 16 ; f = 104 ; α = 0.079 ($\pm$ 37%)							
$Z_\rho(\alpha)$	0.065	0.026	0.035	0.031	0.036	0.042	0.037
$s_\rho(\alpha),\%$	2.4	0.96	1.3	1.1	1.3	1.6	1.4
DR-3 Channel R4V4 ; f = 337 ; α = 0.158 ($\pm$ 67%)							
$Z_\rho(\alpha)$	0.055	0.016	0.021	0.018	0.021	0.024	0.022
$s_\rho(\alpha),\%$	3.7	1.1	1.4	1.2	1.4	1.6	1.5

$$Z_f(R_{Cd,r}) = 1 + \frac{Q_{0,r}(\alpha)}{f} \qquad (V.2\text{-}3)$$

which shows that in case of low f one should avoid the use of high-Q_0 monitors.

The best f-monitors are $^{197}Au(n,\gamma)^{198}Au$ and $^{59}Co(n,\gamma)^{60}Co$, and the former was most frequently used in the present work. Nevertheless, all monitors listed in Table V.1-14 were occasionally used, for instance for the determination of the flux ratios (obtained as a weighted average) quoted in Figs V.1-1 and V.1-2.

2.2. "Bare bi-isotopic monitor"-method using Zr

The relevant expression for f-determination according to the bare bi-isotopic method is (cf. V.1.2) :

$$f = \frac{G_{e,1}\,\frac{k_{0,c}(1)}{k_{0,c}(2)} \cdot \frac{\varepsilon_{p,1}}{\varepsilon_{p,2}}\,Q_{0,1}(\alpha) - G_{e,2}\,\frac{A_{sp,1}}{A_{sp,2}}\,Q_{0,2}(\alpha)}{G_{th,2}\,\frac{A_{sp,1}}{A_{sp,2}} - G_{th,1} \cdot \frac{k_{0,c}(1)}{k_{0,c}(2)} \cdot \frac{\varepsilon_{p,1}}{\varepsilon_{p,2}}} \qquad (V.2\text{-}4)$$

It has been shown that Zr [with $^{94}Zr(n,\gamma)^{95}Zr$ and $^{96}Zr(n,\gamma)^{97}Zr$] is especially suited for this purpose [SIMONITS76]. This is obvious when considering the error propagation factor (neglecting G_{th} and G_e) :

$$Z_f\left(\frac{A_{sp,1}}{A_{sp,2}}\right) = \left|\frac{[f + Q_{0,1}(\alpha)][f + Q_{0,2}(\alpha)]}{f\,[Q_{0,1}(\alpha) - Q_{0,2}(\alpha)]}\right| \qquad (V.2\text{-}5)$$

Eq. (V.2-5) reveals that the difference in Q_0-values should be as large as possible, and this requirement is best fulfilled by the Zr-isotopes : $Q_0(^{94}Zr) = 5.05$, $Q_0(^{96}Zr) = 248$. Note that the Q_0-values, and also the k_0-factors of $^{94}Zr(n,\gamma)^{95}Zr$ and $^{96}Zr(n,\gamma)^{97}Zr/^{97m}Nb$, have been determined very accurately in the present work (see V.3.2.4 and VI.2.2). The $\bar{E}_r$-values of $^{94}Zr(n,\gamma)$ and $^{96}Zr(n,\gamma)$ are 6260 eV and 338 eV, respectively (see Table V.1-3).

Considering that $Z_f(k_{0,1}/k_{0,2}) = Z_f(A_{sp,1}/A_{sp,2})$ [Eq. (V.2-5)], $Z_f(\varepsilon_{p,1}/\varepsilon_{p,2}) \simeq 0$ (see below), and taking into account the relevant expressions for $Z_f(\bar{E}_{r,1}, \bar{E}_{r,2})$ [Eqs (V.1-23) and (V.1-24)] , $Z_f(\alpha)$ [Eq. (V.1-47)] and $Z_f(Q_{0,1}, Q_{0,2})$ [Eq. (V.3-11)], the partial uncertainties on f amount to (for f = 50 and $\alpha = 0.05$) :

$s_f(k_{0,1}/k_{0,2}) \simeq 1.5\%$ [for $s_{k_{0,1}/k_{0,2}} = 1.2\%$; see Table VIII.3-1];

$s_f(A_{sp,1}/A_{sp,2}) \simeq 1.9\%$ [for $s_{A_{sp,1}/A_{sp,2}} = 1.4\%$ assumed] ;

$s_f(\bar{E}_{r,1}) \simeq 0.1\%$ [1 = ^{97}Zr, with $s_{\bar{E}_{r,1}} = 2.1\%$; see Table V.1-3] ;

$s_f(\bar{E}_{r,2}) \simeq 0.02\%$ [2 = ^{95}Zr, with $s_{\bar{E}_{r,2}} = 4\%$; see Table V.1-3] ;

$s_f(\alpha) \simeq 2.8\%$ [with $s_\alpha = 10\%$ assumed] ;

$s_f(Q_{0,1}) \simeq 0.1\%$ [1 = ^{97}Zr, with $s_{Q_{0,1}} = 1.5\%$; see Table VIII.3-1];

$s_f(Q_{0,2}) \simeq 2.2\%$ [2 = ^{95}Zr, with $s_{Q_{0,2}} = 2.0\%$; see Table VIII.3-1].

Quadratic summation leads to a total uncertainty s_f of the order of 4.5%.

Also in practice Zr possesses outstanding characteristics :

a. the neutron absorption cross-sections are low (see Table VIII.3-1), so that neutron self-shielding is negligible (thermal) or small (epithermal); G_e-factors were accurately determined as a function of Zr-foil thickness (see V.3.2.4) ;

b. all the useful gamma-lines are non-coincident (^{95}Zr : 724.2 & 756.7 keV; ^{95}Nb : 765.8 keV ; ^{97m}Nb : 743.3 keV ; ^{97}Nb : 657.9 keV ; see Table IV. 2-4) and fall in a convenient energy range, thus minimizing gamma-attenuation ;

c. when introducing in Eq. (V.2-4) $A_{sp}(^{95}Zr) = A_{sp}$ (724.2 + 756.7 keV), $k_0(^{95}Zr) = k_0$ (724.2 keV) + k_0 (756.7 keV), and when the ^{97}Zr-data refer to the 743.3 keV line, the ε_p-terms can be dropped since, to a very good approximation, ε_p (743.3 keV) = ε_p (E_{eff} of 724.2 and 756.7 keV) [SIMONITS76] ;

d. pure Zr-foils are available with a broad range of thicknesses, thus providing flexibility with respect to neutron fluxes and irradiation times ;

e. when combined with a third isotope, the ^{94}Zr-^{96}Zr-^{197}Au triplet provides a unique possibility to measure f and α values simultaneously without the use of a Cd-cover (cf. V.1-5).

Some attention should be paid to the simultaneous measurement of ^{95}Zr (T = 64.03 d) and ^{97}Zr/^{97m}Nb (T = 16.74 h). Immediately after irradiation of short to moderate duration (e.g. up to 30 hours), it is often impossible to measure the Zr-foil at close-in detector geometry (too high count rate of ^{97}Zr/^{97m}Nb), whereas at large detector distance an excessively long counting time for ^{95}Zr is required. Indeed, the count rate of the 743.3 keV gamma's

of $^{97}Zr/^{97m}Nb$ is then about 20-50 times higher than the count rate of the 724.2 and 756.7 keV gamma's of ^{95}Zr. Evidently, when only f-determination is performed, it suffices to let decay the $^{97}Zr/^{97m}Nb$ for 3-4 days and to measure the Zr-foil at that moment at any suited close-in detector geometry; as mentioned above, one should not take into account true-coincidence or detection efficiency when considering the 743.3 keV and 724.2 + 756.7 keV lines of $^{97}Zr/^{97m}Nb$ and ^{95}Zr, respectively. If both f and α are to be determined (including a Au-monitor), the following simple counting procedure can be applied [denoting $^{97}Zr/^{97m}Nb$ (743.3 keV) = 1, ^{95}Zr (724.2 + 756.7 keV) = 2 and ^{198}Au (411.8 keV) = 3]:

- measure 1 (shortly after irradiation) and 3 at "reference" distance to the detector, for which $\varepsilon_{p,1}$ and $\varepsilon_{p,3}$ are accurately known. From this, factor b of Eq. (V.1-43c) can be calculated ;
- measure 1 and 2, after 3-4 days decay, at any suited close-in detector geometry. Then, factor a of Eq. (V.1-43c) can be calculated [thus allowing to obtain α from Eq. (V.1-43b)], and f can be derived according to Eq. (V.2-4); note that one may put $\varepsilon_{p,1}/\varepsilon_{p,2} = 1$ in Eqs (V.1-43c) and (V.2-4).

In this way all measuring times can be kept short. Evidently, a decay time of 3-4 days, i.e. 4-6 times T (^{97}Zr), requires an accurate knowledge of the ^{97}Zr half-life (see VII.1.2).

2.3. Consistency check ; validity of the $1/E^{1+\alpha}$ and $\bar{E}_r$ concepts

Evidently, the results of f-determination according to the Cd-ratio method and the bare bi-isotopic monitor method must be consistent. This is proved in Table V.2-1 which is in fact an extension of Table V.1-1, but now with introduction of a correction for α. The consistency of the two methods can be considered as a proof for the validity of the $1/E^{1+\alpha}$ and $\bar{E}_r$ concepts.

2.4. f-Mapping of reactor Thetis

Based on Cd-ratio measurements of Au (V.2.1), a complete f-mapping of the 17 irradiation channels of reactor Thetis has been made. The results are shown in Fig. II.1-1. As mentioned, they refer to the reactor configuration existing before March 1981. The overall uncertainties on the listed f-values are estimated at $\sim$ 3%.

TABLE V.2-1 : f-Ratios obtained from Cd-ratio measurements of Au and from the bare Zr-method, showing the consistency when introducing a correction for α

THETIS Channel	f (no correction for α)		f (with correction for α) (rel.err.,%)		
	from $R_{Cd,Au}$	from bare Zr	α	from $R_{Cd,Au}$	from bare Zr
3	25.4	27.9	0.016	24.8 (1.8)	25.6 (1.6)
13	43.1	47.5	0.041	39.8 (2.4)	40.0 (4.3)
15	82.0	114	0.086^5	72.0 (1.0)	69.8 (1.8)
8	185	275	0.105	158 (1.6)	151 (1.3)

2.5. Propagation of the error on f towards other quantities

Based on the principles explained in I.3.4.4, the propagation of the error on f towards k_0 [Eq. (I.3-18)] or ρ [Eq. (I.3-20)] can be calculated as :

$$Z_{k_0}(f) = \left| f \cdot \frac{Q_{0,c}(\alpha) - Q_{0,s}(\alpha)}{[f + Q_{0,c}(\alpha)]\,[f + Q_{0,s}(\alpha)]} \right| \qquad \text{(V.2-6)}$$

$$Z_{\rho}(f) = \left| f \cdot \frac{Q_{0,m}(\alpha) - Q_{0,a}(\alpha)}{[f + Q_{0,m}(\alpha)]\,[f + Q_{0,a}(\alpha)]} \right| \qquad \text{(V.2-7)}$$

It should be kept in mind, however, that uncertainties like $s_\rho(f)$ $[= Z_\rho(f).s_f]$ on one hand and $s_\rho(\alpha)$ $[= Z_\rho(\alpha).s_\alpha]$ on the other hand are strongly correlated.

3. EVALUATION OF Q_0-VALUES

3.1. Critical selection of literature data

k_0-Factors determined according to Eq. (I.3-18) in two irradiation sites with largely different f-values can be consistent only if accurate Q_0-values are introduced. This enables a critical selection of literature

Q_0-data. It is even possible to calculate the uncertainty, at the 67% confidence level, on a thus selected Q_0-value as [SIMONITS84B] :

$$s_{Q_0,\%} = \frac{t\left\{ (s_{k_{0,I},\%})^2 + (s_{k_{0,II},\%})^2 \right\}^{1/2}}{S} \qquad (V.3\text{-}1)$$

with

$$S = \left| \frac{Q_0(\bar{E}_r)^{-\alpha_I}}{f_I + Q_0(\alpha_I)} - \frac{Q_0(\bar{E}_r)^{-\alpha_{II}}}{f_{II} + Q_0(\alpha_{II})} \right| \qquad (V.3\text{-}2)$$

where $s_{k_0,\%}$ = percentile uncertainty on k_0 ;

t = t-value for a two-tailed test corresponding to a 67% confidence level (e.g. if $k_{0,I}$ and $k_{0,II}$ = averages from 3 determinations in channels I and II, respectively ; N=6 ; 4 degrees of freedom, ν=4).

It has been shown [MOENS79B] that the method is increasingly sensitive (S high) when the difference between the f-values of the selected channels increases ; on the other hand, no sensitive evaluation can be performed when both f_I and f_{II} are high even when they are largely different. Obviously, accurate evaluation of too low Q_0's (say $Q_0 < 4$) is also not possible, even with an optimal choice of f-values.

Evidently, a unique possibility to perform this type of critical selection is offered by the irradiation positions of reactor Thetis, with f-values ranging from $\sim$ 15 to $\sim$ 160 (see Fig. II.1-1). Therefore, irradiations for k_0-determination were carried out either in channels 3 ($f \simeq 25$) and 15 ($f \simeq 72$) [for long-lived isotopes] or in channels 9 ($f \simeq 23$) or 17 ($f \simeq 15$) and 8 ($f \simeq 160$) [for short-lived isotopes]. Results of Q_0-evaluation, performed as described above, are included in Table V.3-3. The experimental precautions taken to assure accurate k_0-determination are described in VI.2.1.

3.2. Experimental determination

3.2.1. Cd-ratio method

Q_0 can be determined from Cd-ratio measurements as :

$$Q_0(\alpha) = \frac{f}{F_{Cd}\,R_{Cd}-1} \cdot \frac{G_{th}}{G_e} \qquad (V.3\text{-}3)$$

or

$$Q_0(\alpha) = \frac{F_{Cd,r}\, R_{Cd,r}-1}{F_{Cd}\, R_{Cd}-1} \cdot \frac{G_{th}}{G_{th,r}} \cdot \frac{G_{e,r}}{G_e} \cdot Q_{0,r}(\alpha) \qquad (V.3\text{-}4)$$

thus involving $Q_{0,r} \rightarrow Q_{0,r}(\alpha)$ and $Q_0(\alpha) \rightarrow Q_0$ conversions [Eqs (V.1-15) and (V.1-16), resp.]. The same comments hold as made in V.2.1. From the error propagation factor (neglecting G_{th}, G_e and F_{Cd}) :

$$Z_{Q_0(\alpha)}(R_{Cd}) = 1 + \frac{Q_0(\alpha)}{f} \qquad (V.3\text{-}5)$$

it appears that high Q_0's can preferably be determined in strongly thermalized irradiation positions (high f).

Results of Q_0-determination performed at the INW and the KFKI (and occasionally in Risø) are compiled in Table V.3-3. The experimental precautions taken to assure adequate accuracy were essentially the same as mentioned in VI.2.1, but - evidently - no attention had to be paid to such parameters as detection efficiency and true-coincidence. Also, since $R_{Cd} = A_{sp}/(A_{sp})_{Cd}$, considerations with respect to stoichiometry and purity of materials are not relevant : homogeneity is the only criterion of interest. Based on this feature, a number of Q_0-values was determined as :

$$Q_0(\alpha) = \frac{A\, f\, G_{th}/G_e}{\frac{F_{Cd}}{F_{Cd,ic}}\left\{\frac{f\, G_{th,ic}/G_{e,ic}}{Q_{0,ic}(\alpha)} + 1\right\} - A} \qquad (V.3\text{-}6)$$

with

$$A = \frac{\left(\frac{N_p/t_m}{SDC}\right)_{ic}}{\frac{N_p/t_m}{SDC}} \cdot \frac{\left(\frac{N_p/t_m}{SDC}\right)_{Cd}}{\left\{\left(\frac{N_p/t_m}{SDC}\right)_{Cd}\right\}_{ic}}$$

and ic = internal comparator ;

f = determined by means of a coirradiated flux ratio monitor.

In this way, it was possible to irradiate bare and Cd-covered pellets, made of Whatman-41 paper, on which small aliquants were pipetted (and dried) of a solution containing the investigated isotope and a comparator isotope with well-known Q_0-value. From Eq. (V.3-6) it follows that, with the use of these pellets, no knowledge of weights or even of the weight ratio is required. The only condition is that the weight ratio of investigated and comparator isotope in the bare and Cd-covered pellets is constant. Since all pellets are prepared

from the same homogeneous solution, this condition is certainly met.

As to the flux ratio monitors used in the present work, the same comments hold as made in V.2.1.

3.2.2. Cd-transmission factor for epithermal neutrons, F_{Cd}

F_{Cd}, the Cd-transmission factor for epithermal neutrons, accounts for the fact that the specific count rate $(A_{sp})_{Cd}$ of a cadmium covered isotope is, in some cases, significantly different from $(A_{sp})_e$, the specific count rate of the bare isotope that would be induced by the epithermal neutrons spanning the corresponding energy range. In the present work, F_{Cd} is defined as :

$$F_{Cd} = \frac{(A_{sp})_{Cd}}{(A_{sp})_e} \qquad (V.3\text{-}7)$$

Usually F_{Cd}-factors do not significantly differ from unity. However, when the resonances of Cd and of the Cd-covered isotope partially overlap, F_{Cd} can be markedly lower than unity. This is the case for $^{186}W(n,\gamma)^{187}W$ [^{113}Cd : 18.4 eV resonance; ^{186}W : 18.83 eV resonance]. Moreover, for isotopes with a giant resonance in the 1-10 eV range, F_{Cd} can also be lower than unity due to the high energy tailing of the dominant ^{113}Cd resonance (0.178 eV). Well-known examples are $^{115}In(n,\gamma)^{116m}In$ [resonance at 1.457 eV] and $^{197}Au(n,\gamma)^{198}Au$ [resonance at 4.906 eV]. Finally, F_{Cd} can also be higher than unity if neutrons, which are resonance scattered in the cadmium, enter the correct energy band to be resonantly captured in the Cd-covered isotope. This has been reported [RYVES74] for $^{65}Cu(n,\gamma)^{66}Cu$ [^{111}Cd : 233.4 eV resonance ; ^{65}Cu : 230 eV resonance].

F_{Cd}-data from literature have been compiled and evaluated for 60 (n,γ) reactions [ELNIMR81]. The values adopted in the present work are given in Tables V.3-3 and VIII.3-1 (in the latter case only if different from unity).

F_{Cd}-factors can be calculated [PIERCE68, BELLER67] or experimentally determined. In the latter case, use can be made of the Cd-substitution method [BAUMAN63], the method of varying Cd-thickness [MARTIN55] or the two-channel irradiation method [SIMONITS84].

The F_{Cd}-factors for $^{186}W(n,\gamma)^{187}W$ [ranging in literature from 0.855 to 1.0 ; see ELNIMR81] and for $^{114}Cd(n,\gamma)^{115}Cd$ have been determined according to the two-channel irradiation method. From k_0-determination, according to Eq.

(I.3-18) in two reactor channels with largely spread f-values, a Q_0-value can be calculated which is not subject to effects of Cd epithermal transmission. Then, from Cd-ratio measurements F_{Cd} is obtained as [cf. Eq. (V.3-3)]:

$$F_{Cd} = \frac{f\ G_{th}/G_e}{Q_0(\alpha)\ R_{Cd}} + \frac{1}{R_{Cd}} \qquad (V.3\text{-}8)$$

The results were : $F_{Cd}(^{186}W) = 0.908 \pm 0.021$; $F_{Cd}(^{114}Cd) = 0.45 \pm 0.01^5$.

3.2.3. Consistency check; validity of the $1/E^{1+\alpha}$ and $\bar{E}_r$ concepts

It goes without saying that the results of Q_0-determination in irradiation channels with different f and α must be consistent. Table V.3-1, which is in fact an extension of Table V.1-2, shows that this is indeed the case. The results are especially convincing for $^{94}Zr(n,\gamma)^{95}Zr$, since it had to be assumed that the validity of the $1/E^{1+\alpha}$ approximation, shown to hold up to 2560 eV [$\bar{E}_r(^{64}Zn)$; see Fig. V.1-1], can be extrapolated to $\sim$ 2.5 times higher neutron energy [$\bar{E}_r(^{94}Zr) = 6260$ eV].

TABLE V.3-1 : Q_0-ratios from the cadmium-ratio method (with Au as f-monitor), showing that consistency is obtained when corrections for α are introduced

Reactor	Channel	f	α	Q_0 from cadmium-ratio method					
				$^{112}Sn(n,\gamma)^{113}Sn$		$^{94}Zr(n,\gamma)^{95}Zr$		$^{96}Zr(n,\gamma)^{97}Zr$	
				no corr.for α	corr.for α	no corr.for α	corr.for α	no corr.for α	corr.for α
WWR-M	"MILA"	36.01	0.011	46.6	48.8 ± 2.1	5.53	5.34 ± 0.64	251	245 ± 26
THETIS	14	38.35	0.0298	-	-	4.32	5.15 ± 0.27	224	251 ± 30
	7	110.2	0.0713	39.1	49.2 ± 2.2	3.23	5.02 ± 0.16	182	243 ± 6
	16	104.4	0.0792	-	-	3.16	5.10 ± 0.23	185	254 ± 8
DR-3	R4V4	337	0.158	29.6	46.8 ± 3.6	1.88	4.97 ± 0.22	127	251 ± 7

3.2.4. G_e and Q_0 values for $^{94}Zr(n,\gamma)^{95}Zr$ and $^{96}Zr(n,\gamma)^{97}Zr$

Since in the present work Zr is proposed as a f- and α-monitor (in the latter case in combination with Au), large attention was paid to the accuracy of its nuclear data. The careful determination of the ^{97}Zr half-life and of the $^{95}Zr/^{97}Zr$ k_0-factors is described in VII.1.2 and VI.2.2 respectively.

As calculated from Eq. (I.2-15), thermal neutron self-shielding is negligible at least up to 1 mm thick Zr-foil ($G_{th} \simeq 1$). However, it can be expected that this is not so for epithermal neutron self-shielding. Assuming that the 301.0 eV resonance of $^{96}Zr(n,\gamma)$ is dominant, Eq. (I.2-17) yields, as an approximation, $G_e \simeq 0.95$ for a 125 µm thick Zr-foil. Thus, experimental determination of the G_e-values for $^{94}Zr(n,\gamma)$ and $^{96}Zr(n,\gamma)$ was felt necessary. This was performed by irradiation of Cd-covered Zr-foils with 5, 25, 125, 250 and 500 µm thickness. The induced ^{95}Zr and ^{97}Zr activities were counted on a Ge-detector in "reference" geometry. Small ε_p-differences for the various foil thicknesses were accounted for, using the program SOLANG for ε_p-conversion (III.2.1). The results are shown in Fig. V.3-1, together with polynomial fits enabling to calculate G_e for any Zr-foil thickness up to 500 µm. For the frequently used 125 µm Zr-foils, the G_e-factors are : 0.983 (± 0.3%) for $^{94}Zr(n,\gamma)$; 0.973 (± 0.4%) for $^{96}Zr(n,\gamma)$.

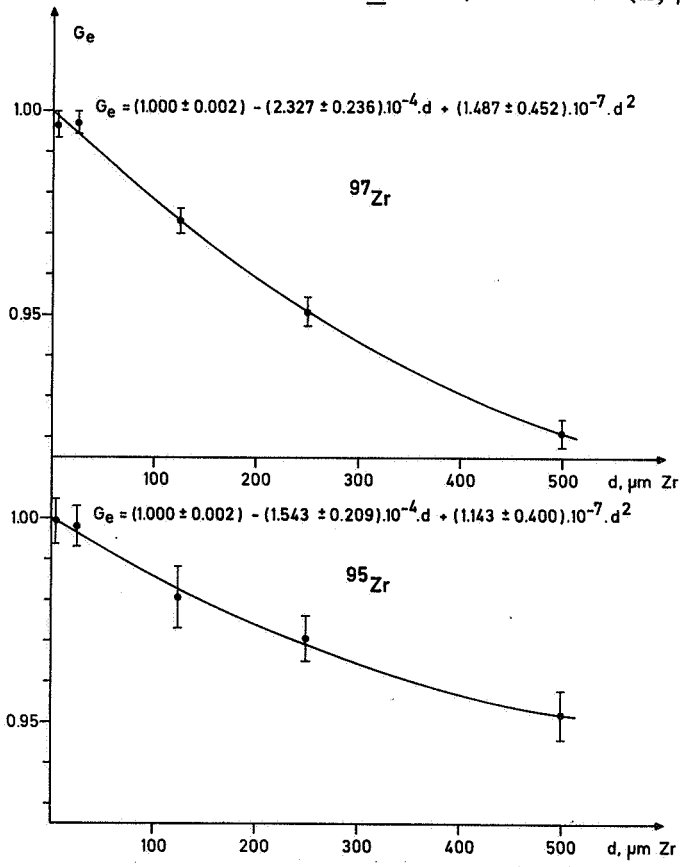


Fig. V.3-1 : G_e, epithermal neutron self-shielding as a function of Zr-foil thickness determined by Cd covered irradiations, using the SOLANG program for counting geometry normalization

Detailed results of Q_0-determination from R_{Cd}-measurements in 3 different reactors/ 5 irradiation channels are shown in Table V.3-2. Note that formerly reported literature data are ranging from 227 to 879 for $^{96}Zr(n,\gamma)$, and from 4.59 to 7.6 for $^{94}Zr(n,\gamma)$ [cf. Table V.3-3]. The reason for this large scatter is not difficult to explain : the high Q_0-value for $^{96}Zr(n,\gamma)$, leading to large error propagation factors in poorly thermalized neutron fluxes [see Eq. (V.3-5)], and the high $\bar{E}_r$-value for $^{94}Zr(n,\gamma)$, making the Q_0-result very sensitive to actual epithermal neutron flux distributions deviating from the ideal 1/E shape.

TABLE V.3-2 : Experimental determination of Q_0 values for the reactions $^{94}Zr(n,\gamma)^{95}Zr$ and $^{96}Zr(n,\gamma)^{97}Zr$

REACTOR Channel	Date	Measured Q_0 values with rel.err. (%)	
		$^{96}Zr(n,\gamma)^{97}Zr$	$^{94}Zr(n,\gamma)^{95}Zr$
RISØ DR3 Ch.R4V4	03-DEC-84	239 ± 17 (1.7)	4.64 ± 0.53 (11.4)
	04-DEC-84	253 ± 12 (4.9)	4.89 ± 0.38 (7.7)
	05-DEC-84	255 ± 13 (5.3)	5.02 ± 0.42 (8.4)
	06-DEC-84	251 ± 14 (5.6)	5.29 ± 0.48 (9.1)
	Weighted average :	251 ± 7 (2.8)	4.97 ± 0.22 (4.4)
INW THETIS Ch. 7	05-FEB-85	253 ± 13 (5.1)	4.94 ± 0.31 (6.2)
	12-FEB-85	229 ± 13 (5.5)	5.16 ± 0.32 (6.2)
	26-FEB-85	235 ± 12 (5.2)	5.09 ± 0.33 (6.5)
	04-JUL-85	250 ± 14 (5.5)	4.91 ± 0.30 (6.1)
	10-DEC-85	251 ± 13 (5.3)	
	Weighted average :	243 ± 6 (2.4)	5.02 ± 0.16 (3.1)
INW THETIS Ch. 16	29-MAY-85	253 ± 13 (5.2)	5.01 ± 0.32 (6.3)
	02-JUL-85	259 ± 13 (5.2)	5.20 ± 0.33 (6.4)
	12-DEC-85	250 ± 13 (5.2)	
	Weighted average :	254 ± 8 (3.0)	5.10 ± 0.23 (4.5)
INW THETIS Ch. 14	19-NOV-85	226 ± 26 (11.4)	4.86 ± 0.43 (8.9)
	08-JAN-86	286 ± 31 (10.8)	5.33 ± 0.34 (6.4)
	Weighted average :	251 ± 30 (12)	5.15 ± 0.27 (5.2)
KFKI WWR-M Ch. "MILA"	27-FEB-85	262 ± 37 (14.3)	-
	06-DEC-85	230 ± 30 (15.7)	5.34 ± 0.64 (11.9)
	Weighted average :	245 ± 26 (10.6)	5.34 ± 0.64 (11.9)
GRAND MEAN (weighted)		248 ± 3.7 (1.5)	5.05 ± 0.10 (2.0)

3.3. Compilation of Q_0-values

The Q_0-values of 107 (n,γ) reactions, resulting from critical selection of literature data (V.3.1) or from experimental determination (V.3.2) are compiled in Table V.3-3. Values quoted in three recent and frequently consulted evaluation works are also listed systematically [NNDC COMPUT.CH.85, MUGHABGHAB81/84, CH.NUCL.84]; whenever felt necessary, data from other sources (older evaluation works or individual papers) are given as well. The origin [from experimental work at the INW and/or KFKI (occasionaly at Risø), or from literature] of the values "adopted" in the present work is indicated by a dotted underlining (...).

In view of the reduced error propagation factors towards the analytical results, the criteria for acceptance of the "adopted" Q_0-values did not have to be as stringent as in case of the k_0-factors (cf. VI.2.1). "Adopted" Q_0-values were considered as "highly accurate" (fully underlined), either when originating from consistent results of determination in at least 2 irradiation sites at the INW or the KFKI (from which the weighted mean is made ; see I.3.4.4), or - by the nature of the case - when Q_0-standards are concerned (cf. Table V.1-14). For the latter, INW/KFKI-results are occasionally reported as well, but these serve only as a check. "Adopted" Q_0-values were considered as being "reasonably accurate" (dashed underlining; ---), when an experimental check in one irradiation site at the INW or the KFKI yielded a value consistent with literature [and the INW/KFKI- or a literature value was then "adopted"; e.g. for $^{65}Cu(n,\gamma)^{66}Cu$ or $^{63}Cu(n,\gamma)^{64}Cu$, resp.]. "Adopted" values which are not underlined were simply taken from literature without experimental check at the INW or the KFKI. It should be noted, however, that in most of these cases low-Q_0 isotopes are involved; thus, the accuracy on this series of "adopted" values is unimportant in practice.

On the average, the uncertainty quoted on the 53 "highly accurate" Q_0-values [excluding $^{164}Dy(n,\gamma)^{165}Dy$ with $Q_0 = 0.19$] is of the order of ∿ 2.8%. The uncertainties on the "reasonably accurate" Q_0-values are estimated to be of the order of ∿ 5%.

It is interesting to dwell a little longer on the literature Q_0-values quoted in Table V.3-3. It should be mentioned first that in cross-section compilations Q_0-values are not given as such, but they can be calculated from

TABLE V.3-3 : Compilation of Q_0-values "adopted" in the present work [.... = data on which "adopted" values are based ; —— = "highly accurate" (average uncertainty ∿ 3%) ; ---- = "reasonably accurate" (uncertainty estimated at ∿ 5%) ; no underlining = accuracy unknown, but unimportant in most cases (low Q_0's)]

REACTION	T	$\bar{E}_r$,eV (JOVANOVIC86)	F_{Cd} (ELNIMR81)	RESONANCE INTEGRAL TO 2200 $m.s^{-1}$ CROSS-SECTION RATIO; $Q_0 = I_0/\sigma_0$							NOTES
				LITERATURE				THIS WORK		ADOPTED	
				NNDC COMPUT.CH.85	MUGHABCHAB 81/84	CH.NUCL.84	OTHERS	KFKI	INW		
$^{23}Na(n,\gamma)^{24}Na$	14.959h	3380	1.00	0.587	0.587	0.60		-	0.59(4.7)	0.59(-)	m+g
$^{26}Mg(n,\gamma)^{27}Mg$	9.458min	257000	1.00	0.68	0.68	0.69	0.64 (RYVES70)	-	-	0.64(-)	
$^{27}Al(n,\gamma)^{28}Al$	2.240min	11800	1.00	0.74	0.74	0.73	0.71 (RYVES70)	-	-	0.71(-)	
$^{36}S(n,\gamma)^{37}S$	5.05min	?	(1)	1.1	1.1	0.74	1.12(7.1) (VDLINDEN74)	-	-	1.12(-)	
$^{37}Cl(n,\gamma)^{38}Cl$	37.21min	13700	1.00	0.69	0.69	0.74		-	0.69(4.1)	0.69(-)	m+g
$^{41}K(n,\gamma)^{42}K$	12.36h	2960	1.00	0.97	0.97	0.89		-	0.99(5.)	0.97(-)	
$^{46}Ca(n,\gamma)^{47}Ca$	4.536h	(?)	(1)	1.30	1.30	1.3	1.3 (STEINNES72)	-	-	1.3(-)	
$^{48}Ca(n,\gamma)^{49}Ca$	8.719min	1330000	(1)	0.82	0.82	0.82	0.58 (HAYODOM69) 0.82(1.2) (VDLINDEN73) 0.45 (CH.NUCL.72, CH.NUCL.77)	-	0.36(8.)	0.45(-)	
$^{45}Sc(n,\gamma)^{46}Sc$	83.82d	5130	(1)	0.44	0.44	0.44	0.43 (STEINNES72)	-	-	0.43(-)	m+g
$^{50}Ti(n,\gamma)^{51}Ti$	5.752min	63200	(1)	0.66	0.66	0.62	0.67 (CH.NUCL.72)	-	0.69(7.2)	0.67(-)	
$^{51}V(n,\gamma)^{52}V$	3.75min	7230	1.00	0.55	0.55	0.55		-	0.53(4.0)	0.55(-)	
$^{50}Cr(n,\gamma)^{51}Cr$	27.69d	7530	(1)	0.49	0.49	0.49	0.53 (IAEA74)	-	0.53(2.4)	0.53(-)	
$^{55}Mn(n,\gamma)^{56}Mn$	2.5785h	468	1.0	1.053	1.053	1.053		1.035(4.5)	1.097(3.9) 1.077(3.3) 1.041(3.9)	1.053(2.6)	ADOPTED AS α-MONITOR; CROSS-SECTION STANDARD (HOLDEN81; MUGHABGHAB81)
$^{58}Fe(n,\gamma)^{59}Fe$ (cont'd)	44.63d	673	1.00	1.33	1.33	1.17	0.96(8.) (BRUNE63) 0.55(-) (DECORTE71)	0.979(2.1)	0.981(1.9) 0.975(1.6) 0.954(2.9)	0.97^5(1.)	

TABLE V.3-3 : continued

REACTION	T	$\bar{E}_r$,eV (JOVANOVIC86)	F_{Cd} (ELNIMR81)	RESONANCE INTEGRAL TO 2200 m.s^{-1} CROSS-SECTION RATIO; $Q_0 = I_0/\sigma_0$						ADOPTED	NOTES
				LITERATURE				THIS WORK			
				NNDC COMPUT.CH.85	MUGHABGHAB 81/84	CH.NUCL.84	OTHERS	KFKI	INW		
$^{58}Fe(n,\gamma)^{59}Fe$ (cont'd)							1.03(5.) (STEINNES72) 1.11(-) (ALIAN73) 0.79(5.) (KIM73) 1.4(6.) (VDLINDEN73) 1.05(4.) (NIKOLOW80)				
$^{59}Co(n,\gamma)^{60}Co$	5.271y	136	(1)	1.993	1.993	2.00	1.993 (HOLDEN85)	-	1.921(2.8) 1.912(3.0)	1.993(2.7)	ADOPTED AS α-MONITOR F_2m+g (F_2 = 0.9976); CROSS-SECTION STANDARD (HOLDEN81, MUGHABGHAB81, HOLDEN85)
$^{64}Ni(n,\gamma)^{65}Ni$	2.520h	14200	1.00	0.76	0.64*	0.65	0.67 (CH.NUCL.72, CH.NUCL.77)	-	0.66(2.9)	0.67(-)	* from MUGHABGHAB84, errata and addenda
$^{63}Cu(n,\gamma)^{64}Cu$	12.701h	1040	1.00	1.10	1.10	1.12	1.14 (CH.NUCL.72, IAEA74)	-	1.15(5.7)	1.14(-)	
$^{65}Cu(n,\gamma)^{66}Cu$	5.10min	766	1.034	1.01	1.01	1.01	1.11 (BNL73) 1.14 (IAEA74)	-	1.06(4.9)	1.06(-)	
$^{64}Zn(n,\gamma)^{65}Zn$	244.0d	2560	(1)	1.908	1.908	1.97		1.99(3.4)	1.96(0.8) 1.97(2.9)	1.908(4.9)	ADOPTED AS α-MONITOR; F_{Cd} = 1.00 for 0.8 mm Cd
$^{68}Zn(n,\gamma)^{69m}Zn$ (cont'd)	13.76h	590	(1)	-	-	3.33	2.18(14.) (BRUNE63) 2.40(6.) (KIM68)	3.21(3.2) 3.10(3.3) (RISØ)	3.37(3.4) 3.28(2.9) 3.13(2.0)	3.19(1.4)	F_{Cd} = 1.00 for 0.8 mm Cd

TABLE V.3-3 : continued

REACTION	T	$\bar{E}_r$,eV (JOVANOVIC86)	F_{Cd} (ELNIMR81)	RESONANCE INTEGRAL TO 2200 $m.s^{-1}$ CROSS-SECTION RATIO; $Q_0 = I_0/\sigma_0$						ADOPTED	NOTES
				LITERATURE				THIS WORK			
				NNDC COMPUT.CH.85	MUGHABGHAB 81/84	CH.NUCL.84	OTHERS	KFK1	INW		
$^{68}Zn(n,\gamma)^{69m}Zn$ (cont'd)							3.73(4.) (RICABARRA69) 3.1(-) (DECORTE71) 2.78(12.) (STEINNES72) 3.1(10.) (VDLINDEN73) 3.3(-) (GLEASON75) 3.52(2.0) (SIMONITS84B)				
$^{71}Ga(n,\gamma)^{72}Ga$	14.1h	154	1.00	6.62	6.62	6.8	6.27(14.) (HEFT79)	6.63(5.5)	6.60(17.)	6.63(5.2)	m+g
$^{75}As(n,\gamma)^{76}As$	26.32h	106	1.00	13.6	13.6	14.4	13.6(10.) (RYVES71) 15.7(4.) (HEFT79)	-	-	13.6(-)	redeterm.desirable
$^{74}Se(n,\gamma)^{75}Se$	119.770d	29.4	(1)	10.0	10.0	11.5	9.43 (SIMS67B) 9.56 (RICABARRA68) 8.2 (VDLINDEN73) 13.0(8.) (HEFT79)	-	-	10.0(-)	mean of SIMS67B, RICABARRA68, VDLINDEN73 and HEFT79; redeterm.desirable
$^{79}Br(n,\gamma)^{80m}Br$	4.42h	69.3	1.00	13.3	13.3	12	13.2(9.) (RYVES70) 11.4(5.) (HEFT79)	-	-	13.2(-)	redeterm.desirable
$^{79}Br(n,\gamma)^{80}Br$	17.68min	69.3	1.00	11.0	11.0	12	11.0(10.) (RYVES70) 11.4(5.) (HEFT79)	-	-	11.(-)	redeterm.desirable

TABLE V.3-3 : continued

REACTION	T	$\bar{E}_r$, eV (JOVANOVIC86)	F_{Cd} (ELNIMR81)	RESONANCE INTEGRAL TO 2200 m.s^{-1} CROSS-SECTION RATIO; $Q_0 = I_0/\sigma_0$							NOTES
				LITERATURE				THIS WORK		ADOPTED	
				NNDC COMPUT.CH.85	MUGHABGHAB 81/84	CH.NUCL.84	OTHERS	KFKI	INW		
$^{81}Br(n,\gamma)^{82}Br$	35.30h	152	(1)	19.0*	19.0*	19.2	23.3(-) (HEFT79)	19.7(2.5)	18.1(5.0) 19.2(5.7)	19.3(3.1)	F_2^{m+g} (F_2= 0.976); * *assuming that quoted* I_0 refers to F_2^{m+g}
$^{85}Rb(n,\gamma)^{86}Rb$	18.66d	839	(1)	15.6	15.6*	14.6	62.4(7.) (SIMS67B) 15.7(6.) (STEINNES72) 7.93(5.) (VDLINDEN73) 16.1(5.) (HEFT79)	14.7(3.0)	14.8(8.2) 15.2(6.0)	14.8(2.5)	m+g; F_{Cd} = 1.00 for 0.8 mm Cd * from MUGHABGHAB84, errata and addenda
$^{87}Rb(n,\gamma)^{88}Rb$	17.8min	364	(1)	15.8	15.8	16.7	28.4(19.) (HEFT79)	23.9(3.2)	22.5(6.7) 22.5(4.7)	23.3(2.9)	
$^{84}Sr(n,\gamma)^{85m}Sr$	67.66min	469	(1)	1.12	1.12*	13.2	13.8(-) (HEFT79)	14.3(3.0)	14.7(2.6)	14.5(2.3)	* from I_0^m = 0.67b in errata and addenda; originally quoted I_0^m = 4.59b gives Q_0^m = 7.65
$^{84}Sr(n,\gamma)^{85}Sr$	64.84d	469	(1)	8.4	8.4*	13.8	14.0(22.) (RICABARRA70) 13.2^5(2.8) (STEINNES72) 25.8(12.) (VDLINDEN73) 11.0(4.6) (HEFT79)	-	-	13.2^5(-)	F_2^{m+g} (F_2 = 0.873); * from I_0^m in errata and addenda; originally $Q_0^{F_2^{m+g}}$ = 12.3b is obtained; redeterm.desirable
$^{86}Sr(n,\gamma)^{87m}Sr$	2.805h	795	(1)	5.70	5.70	5.95	5.70(5.) (VDLINDEN73) 5.00(9.) (HEFT79)	4.14(2.6)	4.08(2.3)	4.11(1.7)	
$^{89}Y(n,\gamma)^{90m}Y$	3.19h	4300	1.00	-	-	-	885(9.) (VDLINDEN73)	6.11(3.5)	5.81(3.3) 5.85(5.6)	5.93(2.3)	
$^{94}Zr(n,\gamma)^{95}Zr$ (cont'd)	64.03d	6260	1.00	4.61	4.61	6.0	6.30(1.) (RICABARRA70B)	5.34(11.9)	5.02(3.1) 5.10(4.5)	5.05(2.0)	ADOPTED AS f- AND α-MONITOR

TABLE V.3-3 : continued

REACTION	T	$\bar{E}_r$, eV (JOVANOVIC86)	F_{Cd} (ELNIMR81)	RESONANCE INTEGRAL TO 2200 m.s^{-1} CROSS-SECTION RATIO; $Q_0 = I_0/\sigma_0$							NOTES
				LITERATURE				THIS WORK		ADOPTED	
				NNDC COMPUT.CH.85	MUGHABGHAB 81/84	CH.NUCL.84	OTHERS	KFKI	INW		
$^{94}Zr(n,\gamma)^{95}Zr$ (cont'd)							5.77(10.) (FULMER71) 4.59(5.) (SANTRY73) 7.6(30.) (VDLINDEN73) 5.38(16.) (HEFT79) 5.88(1.) (SIMONITS84B)	4.97(4.4) (RISØ)	5.15(5.2)		extremely high correction for non-1/E epith.spectrum required; this causes scatter in literature results
$^{96}Zr(n,\gamma)^{97}Zr$	16.74h	338	1.00	231	231	232	879(11.) (RICABARRA70B) 250(8.) (FULMER71) 227(10.) (SANTRY73) < 598 (HEFT79) 282(2.) (SIMONITS84B)	245(10.6) 251(2.8) (RISØ)	243(2.4) 254(3.0) 251(12.0)	248 (1.5)	ADOPTED AS f- and α-MONITOR extremely high Q_0, i.e. low R_{Cd}, causes scatter in literature results
$^{93}Nb(n,\gamma)^{94m}Nb$	6.26min	574	1.00	-	-	-	7.3(3.) (VDLINDEN73)	7.35(2.8)	7.39(12.)	7.35(2.7)	
$^{98}Mo(n,\gamma)^{99}Mo$	66.02h	241	(1)	53.1	53.1	50.0	51.5(2.) (HEFT79)	53.0(2.7)	53.0(2.1) 53.7(4.4) 53.6(5.1)	53.1(6.3)	ADOPTED AS α-MONITOR
$^{100}Mo(n,\gamma)^{101}Mo$	14.6min	672	1.00	18.84	18.84	19.5		19.4(2.4)	19.2(1.1) 19.3(3.9) 19.5(2.4)	18.84(4.3)	ADOPTED AS α-MONITOR
$^{96}Ru(n,\gamma)^{97}Ru$	2.9d	776	(1)	25.3	25.3	27.0	32.1(4.) (HEFT79)	26.5(3.8)	26.2(9.5)	26.5(3.5)	
$^{102}Ru(n,\gamma)^{103}Ru$	39.26d	181	(1)	3.5	3.5	3.5	3.57(16.) (HEFT79)	-	3.63(3.)	3.63(-)	F_{Cd} = 1 for 0.8 mm Cd
$^{104}Ru(n,\gamma)^{105}Ru$	4.44h	495	(1)	13.4	13.4	12.6	16.5 (HEFT79)	12.9(2.9)	12.5(7.5)	12.8(2.7)	

TABLE V.3-3 : continued

REACTION	T	$\bar{E}_r$, eV (JOVANOVIC86)	F_{Cd} (ELNIMR81)	RESONANCE INTEGRAL TO 2200 m.s^{-1} CROSS-SECTION RATIO; $Q_0 = I_0/\sigma_0$						ADOPTED	NOTES
				LITERATURE				THIS WORK			
				NNDC COMPUT.CH.85	MUGHABCHAB 81/84	CH.NUCL.84	OTHERS	KFKI	INW		
$^{103}Rh(n,\gamma)^{104m}Rh$	4.34min	1.45	(1)	7.5	7.5	7.3	8.80(6.) (HEFT79)	-	-	7.5(-)	redeterm.desirable; possibly $F_{Cd} < 1$
$^{103}Rh(n,\gamma)^{104}Rh$	42.3s	1.45	(1)	7.6	7.6	7.6		-	-	7.6(-)	redeterm.desirable; possibly $F_{Cd} < 1$
$^{108}Pd(n,\gamma)^{109}Pd$	13.7h	39.7	(1)	28.7	28.8	29.9	15.5(5.2) (VDLINDEN73)	-	-	28.8(-)	m+g; redeterm.desirable
$^{110}Pd(n,\gamma)^{111m}Pd$	5.5h	950	(1)	19.	19.	-	20.(5.) (VDLINDEN73) 20.0(5.) (HEFT79)	-	-	20.(-)	redeterm.desirable
$^{107}Ag(n,\gamma)^{108}Ag$	2.37min	38.5	1.00	2.65	2.65	2.53		-	2.90(4.)	2.90(-)	
$^{109}Ag(n,\gamma)^{110m}Ag$	249.76d	6.08	1.00	15.4	15.4	15.9	17.5 (SIMS68) 21.2(4.) (HEFT79)	-	-	17.5(-)	redeterm.desirable
$^{114}Cd(n,\gamma)^{115}Cd$	53.46h	207	0.45	43.3+	43.3*+	76.7	77.7(9.) (PEARLSTEIN66) 48.0(5.) (HEFT79)	-	39.6(1.3)	39.6(1.3)	* from errata and addenda + assuming that quoted $I_0 \simeq I_0^g$
$^{113}In(n,\gamma)^{114m}In$	49.51d	6.41	(1)	27.2*	27.2*	27.5	27.3(3.7) (VDLINDEN73)	-	-	27.3(-)	$m+m_2$; possibly $F_{Cd} < 1$; * assuming that quoted σ_0^m and I_0^m refer to $m+m_2$; redeterm.desirable
$^{115}In(n,\gamma)^{116m}In$	54.15min	1.56	0.93	16.4*	16.3*	16.0		16.8(2.8)	16.5(5.8) 16.8(2.8)	16.8(1.9)	$m+m_2$; * assuming that quoted I_0^m refers to $m+m_2$
$^{112}Sn(n,\gamma)^{113}Sn$	115.09d	107	(1)	-	-	-	48.9(-) (MAENHAUT73) 49.8(5.) (HEFT79) 51.0(-) (NIKOLOW80)	48.8(4.3) 47.0(1.9) (RISØ)	49.2(1.5) 48.9(5.9)	48.4(1.2)	F_2^{m+g} (F_2 = 0.911)

TABLE V.3-3 : continued

REACTION	T	$\bar{E}_r$, eV (JOVANOVIC86)	F_{Cd} (ELNIMR81)	RESONANCE INTEGRAL TO 2200 m.s^{-1} CROSS-SECTION RATIO; $Q_0 = I_0/\sigma_0$						ADOPTED	NOTES
				LITERATURE				THIS WORK			
				NNDC COMPUT.CH.85	MUGHABCHAB 81/84	CH.NUCL.84	OTHERS	KFKI	INW		
$^{116}Sn(n,\gamma)^{117m}Sn$	13.61d	128	(1)	82	82	83	72(-) (DECORTE71) 81.(3.7) (VDLINDEN73) 187 (NIKOLOW80)	-	60(-)	56.3(1.9)	strong (n,n') interference
								56.3(1.9) (RISØ)			
$^{122}Sn(n,\gamma)^{123m}Sn$	40.08min	424	(1)	4.5*	4.5*	5.0*	5.55(2.3) (VDLINDEN73) 5.4(-) (MAENHAUT73) 5.6(9.) (RICABARRA73B) 9.55(16.) (HEFT79)	5.37(0.3)	5.47(6.0) 5.45(8.9)	5.40(0.7)	* assuming that quoted $I_0 \simeq I_0^m$
								5.31(3.1) (RISØ)			
$^{124}Sn(n,\gamma)^{125m}Sn$	9.525min	74.2	(1)	61.5*	61.5	61.5*	54.(2.4) (RICABARRA70) 64.(9.4) (RICABARRA73) 62.(5.) (VDLINDEN73) 59.(-) (GLEASON76) 107(5.) (HEFT79) 53.0(2.3) (SIMONITS84B)	-	60.1(2.9) (RISØ)	60.1(2.9)	* assuming that quoted $I_0 \simeq I_0^m$
$^{124}Sn(n,\gamma)^{125}Sn$	9.64d	74.2	(1)	-	-	-	no data	-	-	60.1(-)	assuming that $Q_0^g = Q_0^m$; determ.desirable
$^{121}Sb(n,\gamma)^{122}Sb$	2.70d	13.1	0.99	33.9	33.9	32.0	28.3(3.) (HEFT79)	32.9(4.4)	33.3(6.0)	33.0(3.5)	m+g
$^{123}Sb(n,\gamma)^{124}Sb$	60.20d	28.2	1.00	30.2*	30.2*	31.4*	26.2(2.) (HEFT79)	28.3(4.3)	29.6(5.1)	28.8(3.7)	$F_3(m_2+m_1)+g$; ($F_3 \approx 0.75$); * assuming that quoted I_0 refers to $F_3(m_2+m_1)+g$

TABLE V.3-3 : continued

REACTION	T	$\bar{E}_r$,eV (JOVANOVIC86)	F_{Cd} (ELNIMR81)	RESONANCE INTEGRAL TO 2200 $m.s^{-1}$ CROSS-SECTION RATIO; $Q_0 = I_0/\sigma_0$							NOTES
				LITERATURE				THIS WORK		ADOPTED	
				NNDC COMPUT.CH.85	MUGHABGHAB 81/84	CH.NUCL.84	OTHERS	KFKI	INW		
$^{122}Te(n,\gamma)^{123m}Te$	119.7d	92.3	(1)	-	-	-	no data	-	16.^{5}(1.1)	16.^{5}(-)	
$^{128}Te(n,\gamma)^{129m}Te$	33.6d	738	(1)	5.13	5.13	4.9	4.93(6.5)* (MAXIA69)	-	5.4(5.3)	5.4(-)	* normal.to $Q_{0,Co}$ = 1.993 & $Q_{0,Au}$ = 15.71
$^{130}Te(n,\gamma)^{131m}Te$	30h	2950	(1)	-	-	-	no data	-	2.5(1.5)	2.5(-)	F_{Cd} = 1.00 for 0.8 mm Cd
$^{130}Te(n,\gamma)^{131}Te$	25.0min	2950	(1)	-	-	-	2.3(30.) (RICABARRA68) 1.7(12.) (VDLINDEN73)	-	1.7(2.2)	1.7(-)	F_{Cd} = 1.00 for 0.8 mm Cd
$^{127}I(n,\gamma)^{128}I$	24.99min	57.6	1.00	23.7	23.7	24		25.1(4.4)	24.6(3.4)	24.8(2.7)	
$^{133}Cs(n,\gamma)^{134m}Cs$	2.91h	9.27	1.00	-	-	11.9	11.5(6.) (HEFT79)	11.6(3.4)	12.5(8.6) 12.4(6.7)	11.8(3.)	
$^{133}Cs(n,\gamma)^{134}Cs$	2.062y	9.27	1.00	15.1	15.1	14.2	17.4(3.) (SIMS68) 14.6(3.) (STEINNES72) 12.(25.) (VDLINDEN73) 11.5(6.) (HEFT79)	-	-	12.7(-)	mean of STEINNES72, VDLINDEN73 and HEFT79; m+g; redeterm.desirable
$^{130}Ba(n,\gamma)^{131}Ba$	11.8d	69.9	(1)	17.7	17.7	17.4	24.6(5.2) (STEINNES72) 25.1(3.2) (VDLINDEN73) 23.5(-) (HEFT79) 23.5(9.4) (AHMAD83)	-	-	24.8(-)	weighted mean of STEINNES72, VDLINDEN73 and AHMAD83; m+g
$^{132}Ba(n,\gamma)^{133m}Ba$	38.9h	143	(1)	5.6	5.6	5.0	5.6(5.4) (VDLINDEN73)	-	-	5.6(-)	
$^{134}Ba(n,\gamma)^{135m}Ba$	28.7h	115	(1)	151	151	-	151(5.) (VDLINDEN73)	-	55.9(5.)	55.9(-)	strong (n,n') interference

TABLE V.3-3 : continued

REACTION	T	E_r, eV (JOVANOVIC86)	F_{Cd} (ELNIMR81)	RESONANCE INTEGRAL TO 2200 m.s^{-1} CROSS-SECTION RATIO; $Q_0 = I_0/\sigma_0$							NOTES
				LITERATURE				THIS WORK		ADOPTED	
				NNDC COMPUT.CH.85	MUGHABGHAB 81/84	CH.NUCL.84	OTHERS	KFKI	INW		
$^{138}Ba(n,\gamma)^{139}Ba$	83.06min	15700	(1)	0.89	0.89	0.75	1.00(1.) (RICABARRA68) 0.88(4.5) (VDLINDEN73)	-	-	0.88(-)	F_{Cd} = 1.00 for 0.8 mm Cd
$^{139}La(n,\gamma)^{140}La$	40.22h	76.0	1.00	1.32	1.32	1.28		-	1.24(2.4)	1.24(-)	
$^{140}Ce(n,\gamma)^{141}Ce$	32.501d	7200	(1)	0.82	0.82	0.83	0.83(-) (STEINNES72)	-	-	0.83(-)	F_{Cd} = 1.00 for 0.8 mm Cd
$^{142}Ce(n,\gamma)^{143}Ce$	33.0h	1540	(1)	1.21	1.21	1.16	1.20(-) (RICABARRA68)	-	-	1.20(-)	F_{Cd} = 1.00 for 0.8 mm Cd
$^{141}Pr(n,\gamma)^{142}Pr$	19.12h	296	(1)	1.51	1.51*	1.24*	1.23(1.) (STEINNES72) 1.80(8.3) (VDLINDEN73)	-	-	1.51(-)	mean of STEINNES72 and VDLINDEN73; m+g; * assuming that quoted I_0 refers to m+g
$^{146}Nd(n,\gamma)^{147}Nd$	10.98d	874	1.00	2.3	2.3	2.0	2.31(6.) (ALSTAD67) 1.96(5.) (KIM72) 2.41(3.) (STEINNES72) 1.85(7.) (RICABARRA73) 2.03(7.) (VDLINDEN73)	-	2.01(1.7) 1.98(1.9)	2.00(1.2)	
$^{148}Nd(n,\gamma)^{149}Nd$	1.72h	236	1.00	5.6	5.6	5.6	7.36(3.) (RUIZ64) 7.40(11.) (RIDER64) 5.6(12.) (ALSTAD67) 5.62(5.) (KIM72) 4.65(3.) (RICABARRA73)	-	5.29(0.8) 5.00(0.5)	5.08(2.5)	

(cont'd)

TABLE V.3-3 : continued

REACTION	T	$\bar{E}_r$, eV (JOVANOVIC86)	F_{Cd} (ELNIMR81)	RESONANCE INTEGRAL TO 2200 $m.s^{-1}$ CROSS-SECTION RATIO; $Q_0 = I_0/\sigma_0$							NOTES
				LITERATURE				THIS WORK		ADOPTED	
				NNDC COMPUT.CH.85	MUGHABGHAB 81/84	CH.NUCL.84	OTHERS	KFKI	INW		
$^{148}Nd(n,\gamma)^{149}Nd$ (cont'd)							5.6(5.) (VDLINDEN73) 5.65(6.) (STEINNES75) 6.40(18.) (HEFT79)				
$^{150}Nd(n,\gamma)^{151}Nd$	12.4min	173	1.00	12.	12.	14.2	14.(29.) (ALSTAD67) 13.2(2.) (KIM72) 16.0(5.) (RICABARRA73) 15.8(6.) (VDLINDEN73) 13.5(23.) (STEINNES75) 16.7(9.) (HEFT79) 17.6(4.) (SIMONITS84B)	-	12.4(1.3) 12.3(1.1)	12.3(0.8)	
$^{152}Sm(n,\gamma)^{153}Sm$	46.7h	8.53	(1)	14.6	14.4	14.4		14.5(2.5) 14.2(6.0)	14.5(6.2) 13.8(12.3)	14.4(2.1)	possibly $F_{Cd} < 1$
$^{154}Sm(n,\gamma)^{155}Sm$	22.3min	142	(1)	5.45	3.81	3.75	4.2(5.) (VDLINDEN74) 7.5(34.) (HEFT79)	4.00(3.8)	4.62(3.4) 4.91(33.1)	4.30(7.0)	
$^{153}Eu(n,\gamma)^{154}Eu$	8.561y	5.80	(1)	4.19	4.55	4.00	6.08(2.) (SIMS67) 3.81(5.) (VDLINDEN73) 5.66(4.3) (KIM75)	-	-	5.66(-)	m+g; possibly $F_{Cd} < 1$; redeterm.desirable
$^{158}Gd(n,\gamma)^{159}Gd$ (cont'd)	18.56h	48.2	(1)	24.4	33.2	29.2	24.(24.) (STEINNES72)	-	31.7(6.5) 30.4(6.3)	31.0(4.5)	

TABLE V.3-3 : continued

REACTION	T	$\bar{E}_r$,eV (JOVANOVIC86)	F_{Cd} (ELNIMR81)	RESONANCE INTEGRAL TO 2200 $m.s^{-1}$ CROSS-SECTION RATIO; $Q_0 = I_0/\sigma_0$						ADOPTED	NOTES
				LITERATURE				THIS WORK			
				NNDC COMPUT.CH.85	MUGHABGHAB 81/84	CH.NUCL.84	OTHERS	KFKI	INW		
$^{158}Gd(n,\gamma)^{159}Gd$ (cont'd)							33.3(5.) (VDLINDEN73) 36.3(30.) (STEINNES75) 38.5(8.) (HEFT79)				
$^{160}Gd(n,\gamma)^{161}Gd$	3.66min	480	(1)	9.09*	9.35*	10*	4.81(4.6) (VDLINDEN74)	-	3.88(2.3) 3.73(3.7)	3.83(1.9)	* based on calculated I_0
$^{159}Tb(n,\gamma)^{160}Tb$	72.1d	18.1	0.995	16.9	17.9	17.0		-	18.0(1.9) 16.1(9.7)	17.9(3.8)	
$^{164}Dy(n,\gamma)^{165m}Dy$	1.257min	224	1.00	-	-	-	0.26(4.) (VDLINDEN74)	-	0.25(5.)	0.25(-)	
$^{164}Dy(n,\gamma)^{165}Dy$	2.334h	224	1.00	-	-	-	0.18(-) (JACKS61) 0.29(6.) (ALSTAD72) 0.30(7.) (VDLINDEN73) 0.24(17.) (RYVES74) 0.13(6.) (STEINNES75)	0.22(3.0)	0.16(2.6) 0.25(2.5)	0.19(19.3)	F_2 m+g (F_2 = 0.9776)
$^{165}Ho(n,\gamma)^{166}Ho$	26.80h	12.3	0.99	11.1*	10.6	10.3	11.7(5.) (HEFT79)	10.9(3.9)	11.0(3.1) 10.7(14.3)	10.9^5(2.4)	* assuming that quoted I_0 refer to g
$^{170}Er(n,\gamma)^{171}Er$	7.52h	129	(1)	3.5	4.1	3.8	3.0(-) (PAPPAS67) 4.2(12.) (VDLINDEN73) 4.0(17.) (STEINNES75)	-	4.28(1.5) 4.57(1.5)	4.42(3.3)	
$^{169}Tm(n,\gamma)^{170}Tm$ (cont'd)	128.6d	4.80	(1)	16.7	16.4	16.3	16.3 (ALSTAD72B) 13.5 (STEINNES72)	-	-	14.5(-)	mean of ALSTADT72B, STEINNES72 and VDLINDEN73; redeterm.desirable; possibly $F_{Cd} < 1$

TABLE V.3-3 : continued

REACTION	T	$\bar{E}_r$, eV (JOVANOVIC86)	F_{Cd} (ELNIMR81)	RESONANCE INTEGRAL TO 2200 m.s^{-1} CROSS-SECTION RATIO; $Q_0 = I_0/\sigma_0$						ADOPTED	NOTES
				LITERATURE				THIS WORK			
				NNDC COMPUT.CH.85	MUGHABGHAB 81/84	CH.NUCL.84	OTHERS	KFKI	INW		
$^{169}Tm(n,\gamma)^{170}Tm$ (cont'd)							13.7(3.6) (VDLINDEN73)				
$^{174}Yb(n,\gamma)^{175}Yb$	4.19d	602	(1)	0.51	0.39	0.46	0.46 (STEINNES72)	-	-	0.46(-)	m+g
$^{176}Yb(n,\gamma)^{177}Yb$	1.9h	412	(1)	2.5*	2.21*	2.3*	1.13(11.) (ALSTAD72B) 2.4(8.) (VDLINDEN73) 1.67(-) (STEINNES75) 0.44(10.) (HEFT79)	-	2.45(1.5) 2.55(1.5)	2.50(1.8)	m+g; * assuming that quoted σ_0 and I_0 refer to m+g
$^{175}Lu(n,\gamma)^{176m}Lu$	3.635h	16.1	(1)	-	34.0	34.4		35.6(4.6)	33.8(6.8) 34.3(5.4)	34.8(3.1)	possibly $F_{Cd} < 1$
$^{174}Hf(n,\gamma)^{175}Hf$	70d	29.6	(1)	1.19	0.78	0.88	0.78(5.1) (VDLINDEN73) 0.56(5.) (HEFT79)	-	-	0.78(-)	
$^{179}Hf(n,\gamma)^{180m}Hf$	5.519h	16.2	(1)	-	15.5	-	14.4(3.5) (VDLINDEN73) 17.0(7.) (HEFT79)	14.2(6.5)	14.4(2.9) 14.4(6.4)	14.4(2.4)	
$^{180}Hf(n,\gamma)^{181}Hf$	42.39d	115	(1)	3.4	2.68	2.69	2.58(5.0) (VDLINDEN73)	2.53(5.7)	2.52(4.6)	2.52(3.6)	F_{Cd} = 1.00 for 0.8 mm Cd
$^{181}Ta(n,\gamma)^{182}Ta$	114.43d	10.4	(1)	33.8	32.2	32.4	32.5(9.2) (VDLINDEN73) 33.3(-) (GRYNTAKIS76/78) 32.7(-) (HEFT79)	-	-	33.3(-)	m+g; possibly $F_{Cd} < 1$
$^{186}W(n,\gamma)^{187}W$	23.9h	20.5	0.908	13.2	12.8	12.9	11.6(7.) (HEFT79)	13.6(2.6)	13.7(2.8) 13.7(4.8)	13.7(1.8)	

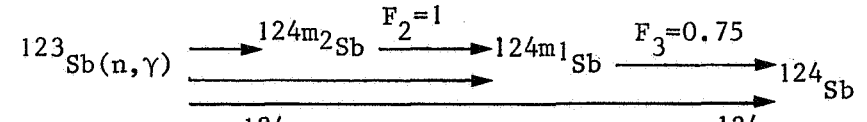
TABLE V.3-3 : continued

REACTION	T	$\bar{E}_r$, eV (JOVANOVIC86)	F_{Cd} (ELNIMR81)	RESONANCE INTEGRAL TO 2200 m.s^{-1} CROSS-SECTION RATIO; $Q_0 = I_0/\sigma_0$						ADOPTED	NOTES
				LITERATURE				THIS WORK			
				NNDC COMPUT.CH.85	MUGHABGHAB 81/84	CH.NUCL.84	OTHERS	KFKI	INW		
$^{185}Re(n,\gamma)^{186}Re$	90.64h	3.40	0.98	15.4*	15.3*	15.3*	15.6(7.) (HEFT79)	15.4(2.8)	15.3(6.0) 16.4(10.8)	15.4(2.5)	* assuming that quoted σ_0 and I_0 refer to g
$^{187}Re(n,\gamma)^{188m}Re$	18.6min	41.1	(1)	-	-	4.3	4.4(9.) (VDLINDEN73)	-	4.59(6.7) 4.4(20.4)	4.57(6.4)	
$^{187}Re(n,\gamma)^{188}Re$	16.98h	41.1	(1)	-	-	4.0		-	4.34(6.4)	4.34(6.4)	from nucl.data evaluation
$^{187}Re(n,\gamma)^{188}Re$**	16.98h	41.1	(1)	4.1*	3.9*	4.0	4.2(9.5) (VDLINDEN73) 4.24(16.) (HEFT79)	4.38(2.8)	4.27(4.5) 4.2(19.9)	4.35(2.4)	** m+g; * assuming that quoted σ_0 and I_0 refer to m+g
$^{184}Os(n,\gamma)^{185}Os$	93.6d	?	(1)	-	0.200	0.43	0.43 (KIM68)	-	-	0.43(-)	
$^{190}Os(n,\gamma)^{191}Os$	15.4d	114	(1)	2.2	2.03	2.5	2.44(1.6) (VDLINDEN73)	-	-	2.03(-)	
$^{192}Os(n,\gamma)^{193}Os$	30.5h	89.7	(1)	2.7	2.3	2.5	2.68(5.) (KIM68) 2.25(3.) (VDLINDEN73)	-	-	2.34(-)	weighted mean of KIM68 and VDLINDEN73
$^{193}Ir(n,\gamma)^{194}Ir$	19.15h	2.21	(1)	-	12.2	11.7	19.2(4.) (HEFT79)	11.7(4.0)	12.5(5.4) 12.0(6.8)	12.0(2.9)	m_1+g; possibly $F_{Cd} < 1$
$^{198}Pt(n,\gamma)^{199}Pt$	30.8min	106	1.00	15.1	14.8	14.7	20.1(3.5) (HEFT79)	16.9(3.2)	17.1(3.9) 17.0(2.5)	17.0(1.8)	m+g
$^{197}Au(n,\gamma)^{198}Au$	2.695d	5.65	0.991	15.8	15.71	15.7	15.71 (HOLDEN81, HOLDEN85)	-	-	15.71(1.8)	ULTIMATE STANDARD
$^{196}Hg(n,\gamma)^{197m}Hg$	23.8h	93.5	(1)	0.54	0.54	0.49	0.49 (CH.NUCL.77, BNL73) 0.44(5.) (HEFT79)	-	0.50(3.4)	0.49(-)	
$^{202}Hg(n,\gamma)^{203}Hg$	46.612d	1960	(1)	1.00	0.86		0.88 (IAEA74)	-	0.91(4.3)	0.88(-)	

TABLE V.3-3 : continued

REACTION	T	$\bar{E}_r$, eV (JOVANOVIC86)	F_{Cd} (ELNIMR81)	RESONANCE INTEGRAL TO 2200 m.s^{-1} CROSS-SECTION RATIO; $Q_0 = I_0/\sigma_0$							NOTES
				LITERATURE				THIS WORK		ADOPTED	
				NNDC COMPUT.CH.85	MUGHABGHAB 81/84	CH.NUCL.84	OTHERS	KFKI	INW		
$^{232}Th(n,\gamma)^{233}Th$	22.3min	54.4	(1)	11.5	11.53	11.5	11.8(4.) (HEFT79)	12.0(2.8)	11.6(2.2) 11.7(2.5)	11.53(3.6)	ADOPTED AS α-MONITOR
$^{238}U(n,\gamma)^{239}U$	23.50min	16.9	(1)	102	103.4	103.4		99.7(8.9)	101.5(5.4) 103.7(4.7)	103.4(1.3)	ADOPTED AS α-MONITOR

listed σ_0 and I_0 data [note that this is not possible for the KFK Nuklidkarte (e.g. NUKLIDK.81) , where I_0-values are missing]. Especially for the listed I_0-values, assumptions have to be made sometimes concerning their definition. One example concerns the direct reaction $^{114}Cd(n,\gamma)^{115}Cd$. MUGHABGHAB81 and NNDC COMPUT.CH.85 specify the 2200 m s^{-1} cross-sections as σ_0^g = 0.30 b and σ_0^m = 0.036 b, but this distinction is not made for the resonance integral which is simply given as I_0 = 13 b; in Table V.3-3 it is assumed that the quoted $I_0 \simeq I_0^g$. Another example is the effective production of ^{124}Sb as :



When measuring the ^{124}Sb activity after decay of $^{124m_2}Sb$ (20.2 min) and $^{124m_1}Sb$ (93 s), σ_0 and I_0 should refer to $F_3(m_2+m_1)+g$. MUGHABGHAB81 and NNDC COMPUT.CH.85 list σ_0^{m2} = 0.019 b , σ_0^{m1} = 0.037 b and σ_0^g = 4.1 b, but only I_0 = 125 b. In Table V.3-3 it is assumed that the quoted $I_0 \simeq F_3\ (I_0^{m2} + I_0^{m1}) + I_0^g$. Other cases, referred to in the notes of Table V.3-3, are ^{82}Br, ^{114m}In, etc.

The σ_0 and I_0 values in some compilations are given together with their associated uncertainties [BNL73, MUGHABGHAB81/84, NNDC COMPUT.CH.85]. However, in the present work no uncertainty is assigned to the thereof derived Q_0's, for the following reason. Since the correlation between $\sigma_0 \pm s_{\sigma_0}$ and $I_0 \pm s_{I_0}$ (certainly existing, since I_0 is usually - although not uniquely - obtained from experimental σ_0 and Q_0 results) is not known, it is not very meaningful to calculate $s_{Q_0} = (s_{\sigma_0}^2 + s_{I_0}^2)^{1/2}$; it can only be expected that $s_{Q_0} < s_{I_0}$. Nevertheless, for lack of something better, quadratic summation was effectively used to arrive at s_{Q_0}-values for the isotopes adopted as α-monitors (^{56}Mn, ^{60}Co, etc.; see Tables V.3-3 and V.1-14); this s_{Q_0}, the knowledge of which is needed for the calculation of s_α, is of course overestimated and should rather be considered as an upper limit.

For completeness, it should be mentioned that another source of information is the "Compilation of Resonance Integrals" by Gryntakis and Kim [GRYNTAKIS83], which lists a survey of all published resonance integrals, mostly extracted from Q_0-measurements. Unfortunately, this compilation does not give any evaluated, recommended or adopted data.

Fig. V.3-2 gives an impression of the discrepancy of literature Q_0-data versus the 53 "highly accurate" values adopted in the present work. Comparison with data from older compilations is made as well, so as to sense the evolution with time. Although this evolution is positive, it can be seen that the situation in literature is far from being satisfactory. Albeit that the best choice from existing literature would be the Chart of the Nuclides 1984 [CH.NUCL.84], it is astonishing to observe that discrepancies of more than 10% occur for ∿ 20% of the cases, not to forget that no data are given for ∿ 10% of the cases. For the "Δ > 10%" and "no data" cases, shown in the expansion of Fig. V.3-2, some additional comments are made in Table V.3-4. Among other observations, it can be seen that an evaluator is not confronted with a simple task, often finding only one or two (mostly conflicting) experimental Q_0-values in literature.

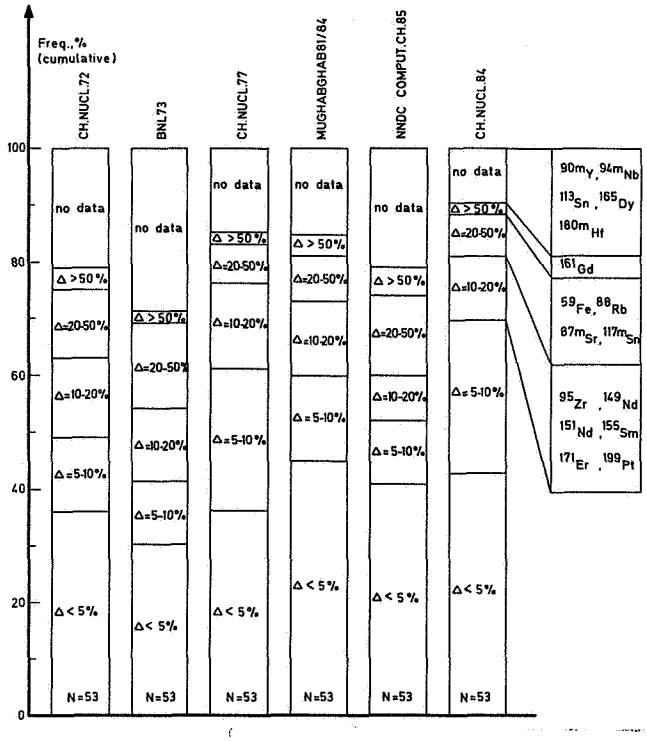


Fig. V.3-2 : Frequency (Freq.,%; cumulalative) of Q_0-discrepancies (Δ,% ; literature data versus the "highly accurate" values adopted in the present work) falling in a specified range (Δ < 5%, Δ = 5-10%, etc.)

3.4. Propagation of the error on Q_0 towards other quantities

Applying the principles outlined in I.3.4.4, the propagation of the error on Q_0 towards other quantities can be calculated as :

- for $Q_0 \rightarrow Q_0(\alpha)$ conversion [Eq. (V.1-15)], determination of f from R_{Cd} [Eq. (V.1-9)] and of ρ from ENAA [Eq. (I.3-21)] :

$$Z_{Q_0(\alpha)}(Q_0) = Z_f(Q_0) = Z_\rho(Q_0)$$

$$= \left| \frac{\bar{E}_r^{-\alpha} \cdot Q_0}{Q_0(\alpha)} \right| \qquad \text{(V.3-9)}$$

TABLE V.3-4 : Comments on the discrepancies (> 10%) of compiled Q_0-data [CH.NUCL.84] versus the "highly accurate" values adopted in the present work

Isotope formed	Q_0 Adopted INW/KFKI	Q_0 CH.NUCL.84	Comments
^{59}Fe	0.97[5] (1.)	1.17	recent compil.data ranging from 1.17 to 1.33; exp.lit.data ranging from 0.55 to 1.4, discrep.possibly due to $E_{Cd} \neq 0.55$ eV (low Q_0 !)
^{88}Rb	23.3 (2.9)	16.7	only two exp.lit.data : 16 (VDLINDEN73, misprinted as 0.16) & 28.4 (HEFT79); puzzling discrepancy; INW/KFKI consistent with $Q_0 = 22.6$ calc.from reson. param. (JOVANOVIC84)
^{87m}Sr	4.11 (1.7)	5.95	only two exp.lit.data : 5.70 (VDLINDEN73) & 5.00 (HEFT79) : $^{87}Sr(n,n')^{87m}Sr$ interference (corr.for by INW/KFKI) causes posit.errors !
^{90m}Y	5.93 (2.3)	-	only one exp.lit.value : 885 (VDLINDEN73, obviously grossly in error !)
^{95}Zr	5.05 (2.0)	6.0	exp.lit.data ranging from 4.59 to 7.6; due to very high $\bar{E}_r$ (6260 eV), large corr.required if non-1/E epith.shape !
^{94m}Nb	7.35 (2.7)	-	only one exp.lit.value : 7.3 (VDLINDEN73), not adopted by evaluators, but consistent with INW/KFKI
^{113}Sn (F_2m+g)	48.4 (1.2)	-	INW/KFKI consistent with former exp. lit.data : 48.9 (MAENHAUT73), 49.8 (HEFT79), 51.0 (NIKOLOW80), not considered by evaluators
^{117m}Sn	56.3 (1.9)	83	three exp.lit.data : 72 (DECORTE71), 81 (VDLINDEN73) & 187 (NIKOLOW80); $^{117}Sn(n,n')^{177m}Sn$ interference (corr. for by INW/KFKI) causes posit.errors (see DECORTE83)
^{149}Nd	5.08 (2.5)	5.6	9 exp.lit.data ranging from 5.12 to 7.4, but 5 authors report 5.6
^{151}Nd	12.3 (0.8)	14.2	exp.lit.data ranging from 13.2 to 17.6; MUGHABGHAB81 & NNDC COMPUT.CH.85 evaluate 11.7 ; puzzling discrepancy; INW/KFKI consistent with $Q_0 = 12.7$ calc.from reson.param. (JOVANOVIC84)
^{155}Sm	4.30 (7.0)	3.75	only two exp.lit.data : 4.2 (VDLINDEN73) & 7.5 (HEFT79); puzzling discrepancy; NNDC COMPUT.CH.85 evaluates 5.45
^{161}Gd	3.83 (1.9)	10	evaluation probably based on calcul.I_0 (cf. MUGHABGHAB84); sole exp.result $Q_0 = 4.81$ (VDLINDEN74), ignored by compilers (GRYNTAKIS83) and not considered by evaluators
^{165}Dy (F_2m+g)	0.19 (19.3)	-	exp.lit.data ranging from 0.13 to 0.30: discrep.(and large uncert.on INW/KFKI) due to $E_{Cd} \neq 0.55$ eV (low Q_0, non 1/v !)
^{171}Er	4.42 (3.3)	3.8	exp.lit.data ranging from 3.0 to 7.5; puzzling discrepancy; MUGHABGHAB84 evaluates 4.1
^{180m}Hf	14.4 (2.4)	-	only two exp.lit.data : 14.4 (VDLINDEN73) & 17.0 (HEFT79); MUGHABGHAB84 evaluates 15.5
^{199}Pt (m+g)	17.0 (1.8)	14.7	CH.NUCL.84 consistent with 7 former exp.lit.data, but not with HEFT79 (20.1); puzzling discrepancy

Practically speaking, this means that the uncertainty on Q_0 is transferred almost fully.

Note that ENAA based on low-Q_0 isotopes makes no sense. Remark also that uncertainties like $s_\rho(Q_{0,a})$ [$= Z_\rho(Q_{0,a}).s_{Q_{0,a}}$] and $s_{Q_{0,a}(\alpha)}(Q_{0,a})$ [$= Z_{Q_{0,a}(\alpha)}(Q_{0,a}) \cdot s_{Q_{0,a}}$] are strongly correlated.

- for k_0-determination [Eq. (I.3-18)] and determination of ρ from NAA [Eq. (I.3-20)] :

$$Z_{k_0}(Q_0) = Z_\rho(Q_0) = \left| \frac{\bar{E}_r^{-\alpha} \cdot Q_0}{f + Q_0(\alpha)} \right| \qquad \text{(V.3-10)}$$

This means that, on the average (with $f = 50$, $\alpha \simeq 0.05$, $Q_0 = 10$, $\bar{E}_r = 100$ eV), the error propagation factor is in the order of 0.15. Thus the residual uncertainty on k_0 and ρ, originating from "highly accurate" Q_0-values (uncertainty $\sim$ 2.8%), amounts to $\sim$ 0.4% ; in case of "reasonably accurate" Q_0-values (uncertainty $\sim$ 5%) this becomes $\sim$ 0.8%. One should be aware of the fact that $s_{k_0}(Q_0)$ [$= Z_{k_0}(Q_0) \cdot s_{Q_0}$] and $s_\rho(Q_0)$ [$= Z_\rho(Q_0) \cdot s_{Q_0}$], both being based on the data of Table V.3-3, are correlated, thus leading to an overestimation of $s_{k_0}(Q_0)$. The fact that the "adopted" and "recommended" Q_0's and k_0's listed in the present work are correlated (be it in a complicated way), makes it highly risky - with respect to the accuracy of the analytical results - when an analyst selects other Q_0-values (even if they are likely to be more accurate) than those listed in Tables V.3-3 and VIII.3-1.

- for determination of f according to the bare bi-isotopic monitor method [Eq. (V.1-10)] :

$$Z_f(Q_{0,1}) = \left| \frac{Q_{0,1}\, \bar{E}_{r,1}^{-\alpha} \left[1 + Q_{0,2}(\alpha)/f \right]}{Q_{0,1}(\alpha) - Q_{0,2}(\alpha)} \right| \qquad \text{(V.3-11)}$$

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CHAPTER VI

EXPERIMENTAL DETERMINATION OF K_0-FACTORS

1. THE COMPARATOR $^{197}Au(n,\gamma)^{198}Au$

Experimental determination of $k_{0,c}(s)$-factors (c = comparator; s = standard) was based on Eqs (I.3-18) and (I.3-19). In the present work, all k_0-factors are expressed versus Au as comparator [c = $^{197}Au(n,\gamma)^{198}Au$; E_γ = 411.8 keV].

Use was made of thin Al-Au alloyed wires of different composition and production : 0.097-0.503% Au-content, 0.1-1 mm diameter, manufactured by ATEC or CBNM (Belgium). Based on NAA in optimized experimental conditions, each lot of Al-Au wire used was checked with respect to the gold homogeneity (always $\leq$ 1% at the 2 mg-level), and its gold content was controlled (and, if necessary, redetermined with $\sim$ 1% uncertainty) versus a home-prepared gold standard. The latter was a dried aliquant of a freshly prepared solution (in aqua regia) of high-purity metallic gold, spotted with a calibrated micropipette. For the Al-Au wires with $\sim$ 0.1% Au content, thermal and epithermal neutron self-shielding effects are negligible, i.e. G_{th} and G_e = 1. For the Al-Au wires with $\sim$ 0.5% Au content, G_{th} = 1 but G_e is 0.985 [HOWE62]. The $F_{Cd}(Au)$-factor to be introduced in the Cd-subtraction method is 0.991 (see V.3.2.2). For irradiation, the Al-Au wires (2-60 mg, depending on the neutron flux and the irradiation time) were positioned versus the standard so as to account optimally for flux gradients, by sandwiching each standard sample between two wires. After irradiation, the wires were spirally rolled up (if they were sufficiently long to do so) and they were counted at a reference distance to the detector (see III.1); with respect to $\varepsilon_{p,c}$, they were either considered as quasi-point sources (when the standard source had a comparable volume, e.g. when it was also an Al-alloyed wire of comparable length), correcting ε_p^{ref} for gamma-attenuation effect only (see III.2.5), or as a quasi-cylindric source, introducing ε_p^{geo} (see III.2).

2. EXPERIMENTAL DETAILS

2.1. Quality assurance

Experimental details of k_0-determination are shown in Table VI.2-1.

Evidently, k_0-determination was performed in such experimental conditions so as to assure the best possible accuracy on the results. As a first essential principle, k_0-factors were determined in a parallel but independent way at the Institute for Nuclear Sciences (INW, Gent) and the Central Research Institute for Physics (KFKI, Budapest). This means that in both laboratories use was made of different experimental setups : chemical and physical characteristics of standards and comparators; reactors and irradiation positions; Ge-detectors and counting geometries; peak area evaluation methods; procedures for dead-time correction, etc. As a rule, a yearly Gent-Budapest meeting was organized, where it was decided for which elements, isotopes and gamma-lines k_0's had to be determined in the course of the following year, and where the fully-documented k_0-results of the past year were critically compared and examined. Possible discrepancies were tracked out, sources of error were uncovered and repetitions were imposed. The sources of error could be attributed to problems associated with stoichiometry of the chemical compounds, micropipetting, contaminations or losses, neutron self-shielding, reaction or spectral interferences, peak area evaluation of multiplets, accuracy of Q_0-values, etc.

Apart from the k_0-determinations being performed in different experimental conditions (at the INW and the KFKI), in general the following precautions were taken with respect to accuracy and traceability (see VIII.1 and VIII.2) :

a. The volume of comparator and standard sources was kept as small as possible, and they were counted at a reference distance (usually 15-20 cm) to the Ge-detector. This procedure rendered true-coincidence effects negligible, and it allowed the introduction [in Eqs (I.3-18) and (I.3-19)] of ε_p^{ref} - corrected for gamma-attenuation effects - or of ε_p^{geo}, calculated from ε_p^{ref} with minor conversions only (see chapter III).
b. Whenever possible, use was made of sufficiently thin and/or dilute standard sources so as to make thermal and epithermal neutron self-shielding effects negligible (G_{th} and G_e = 1) : thin metallic foils or wires, fine

powders spread out over a large area or mixed with inert (i.e. low cross-section) material, dried spots of solutions on Al-foil or W41-paper, dilute Al-alloys (which were standardized as for Al-Au; see VI.1), etc. Occasionally, isotopically enriched compounds (supplied by ORNL) were used to eliminate neutron shielding caused by other isotopes of the studied element. Thanks to the depletion of the shielding isotope(s) a limited dilution can be sufficient, so that adequate activities of the studied isotope could be obtained. This was the case for $^{115}Cd/^{115m}In$, [98.55% ^{114}Cd-enrichment; depleted to 0.60% ^{113}Cd (σ_0 = 20600 barn)], for ^{159}Gd and ^{161}Gd [81.0% ^{158}Gd, 98.71% ^{160}Gd enrichment; depleted to resp. 1.72% and 0.14% ^{155}Gd (σ_0 = 60900 barn), and 9.72% and 0.24% ^{157}Gd (σ_0 = 254000 barn)], and for ^{171}Er [96.89% ^{170}Er enrichment; depleted to 0.72% ^{167}Er (σ_0 = 659 barn)]. The choice of the final physical sample composition (dilution, thickness, etc.) was based on calculation or estimation of the neutron self-shielding effects (see I.2.4).

c. Irradiations were performed in reactor channels with sufficiently stable flux characteristics (ϕ_s, f, α) so as to guarantee negligible errors not only from variations during one irradiation (see VII.5), but also from possible differences between the irradiations of bare and Cd-covered samples (in the Cd-subtraction method). This stability was not only evident from the power recording in the reactor operation logbook, but also from repeated experimental determination - as a function of time - of ϕ_s, f and α (see II.1.1). In fact, this established stability allowed to rely on the a priori determined flux characteristics, which were, however, checked regularly.

d. Precautions were taken in order to avoid errors caused by random coincidence (pulse pile-up) or, in case of short-lived radionuclides, by a decrease of dead-time during counting (see II.2).

e. Care was taken so as to have very accurate knowledge of the weight of comparator and standard (to be introduced in A_{sp}). Whenever possible, use was made of high-purity elementary substances as starting materials (especially feasible for metals, but also for sulphur, etc...). When using dilute Al-alloys, the homogeneity of the alloyed element was checked and its content was accurately determined (as explained in VI.1 for Au). As chemical compounds, preferably primary standards were selected with generally accepted

well-known stoichiometry; to cite the examples of the first page of Table VI.2-1 : NaCl, Na_2CO_3, $KHCO_3$, $KHC_8O_4H_4$ (potassium biphtalate). Whenever necessary, these primary standards were pretreated according to the prescription, e.g. Na_2CO_3 was heated for one hour at 270-300°C. Other compounds were of specpure (J.M.) or ultrapure quality, and again a proper pretreatment was done; e.g. the rare earth oxides were ignited at 900°C for 1 hour. If available, easily soluble specpure (J.M.) compounds were used with a certified concentration of the main element : e.g. $(NH_4)_2Ru(H_2O)Cl_5$ with 30.6% Ru content, $(NH_4)_2OsCl_6$ with 43.6% Os content, etc. Occasionally, when significant discrepancies between the INW and the KFKI results were observed, the content of the main element in the used compound was redetermined experimentally : e.g. Ce in $Ce(SO_4)_2.4H_2O$ (expected 34.7% Ce) by titration of Ce(IV) [after adding ammoniumpersulfate] with As(III), according to the procedure developed by Gleu [OHLWEILER73]; the Ce-content in the compound used was found to be 31.4%. In order to make suited dilutions, the starting materials - weighed on a calibrated (micro) balance-,were dissolved in ultrapure solvents, and the solution was transferred to a volumetric flask. At the KFKI, small aliquants were then spotted on high-purity Al-foil by means of a calibrated micropipette. After drying, the Al-foil was folded up and pressed to a small cylindrical pellet, usually 6.4 mm diameter x 2 mm height. At the INW, use was made of an internal comparator (index ic; with accurately known k_0-factor), a known amount of which was brought in solution together with the standard. From this solution, ∿ 100 or 250 µl was spotted on a circular W41 paper, which was then dried - usually under an I.R. lamp (but occasionally at room temperature, e.g. for mercury). The thus loaded W41 paper was folded up, enveloped in a second W41 paper and finally pressed to a pellet, usually 10 mm diameter x 4 mm height. By means of radioactive tracers it was shown that the spotted substance was homogeneously distributed over the W41 paper. With this technique of the internal comparator, the k_0-factor can be obtained as :

$$k_{0,c}(s) = \frac{w_{ic}}{w_s} \cdot \frac{\left(\frac{N_p/t_m}{SDC}\right)_s}{\left(\frac{N_p/t_m}{SDC}\right)_{ic}} \cdot \frac{G_{th,ic}.f + G_{e,ic}\, Q_{0,ic}(\alpha)}{G_{th,s}.f + G_{e,s}\, Q_{0,s}(\alpha)} \cdot \frac{\varepsilon_{p,ic}}{\varepsilon_{p,s}} \cdot k_{0,c}(ic)$$

(VI.2-1)

From Eq. (VI.2-1) it is clear that only the mass ratio w_{ic}/w_s should be known, thus avoiding quantitative work after simultaneous dissolution of internal comparator and standard. Also, the counting geometry of internal comparator and standard are identical, so that - in spite of the relatively large volume of the W41 pellets - it is allowed to introduce ε_p^{ref}-values, which should only be corrected for gamma-attenuation in the paper. The gamma-attenuation factor was experimentally determined as a function of gamma-energy by measuring various point sources (at reference distance to the detector) with and without screening by means of a 2 mm thick W41 pellet (half height of the usual pellet). To a good approximation, the gamma-attenuation function could be fitted as :

$$F_{att} = 0.953 + 4.86.10^{-5}\ E_\gamma(\text{keV}) \qquad [r^2 = 0.9992]$$

in the energy region 60 keV < $E_\gamma \leq$ 900 keV. Above 900 keV, gamma-attenuation was considered to be negligible (< 0.3%).

f. Experimental conditions were chosen so as to obtain, for the analytically interesting gamma-lines under consideration, a statistically acceptable number of counts in the full-energy peaks, with negligible spectral interference. This could be achieved by using high-purity materials, and by optimizing the irradiation, decay and counting times and the weight of the irradiated element (taking care to minimize neutron self-shielding effects). For instance, when determining the k_0-factor of the 279.2 keV-line of ^{203}Hg (T = 46.612 d), it is mandatory to wait for the decay of ^{197m}Hg (T = 23.8 h), the 279.0 keV line of which can cause a spectral interference. For k_0-determination of the ^{239}Np gamma-lines, use was made of a U-standard (a Al-0.443% U wire) depleted to a 0.0375% ^{235}U content (and enriched to 99.962% ^{238}U); this reduced strongly the dead-time, background and interfering lines due to the ^{235}U(n,f) fission products. For k_0-determination of the ^{147}Nd, ^{149}Nd/^{149}Pm and ^{151}Nd/^{151}Pm gamma-lines, use was made of isotopically enriched oxides (ORNL); this reduced drastically the complexity of the spectra, otherwise showing numerous interfering lines. Optimization of the irradiation, decay and counting times can also lead to considerable reduction of the uncertainty on T, due to (partial) compensation of terms in the function describing the propagation of the error on T towards k_0 [see VII.1; Eq. (VII.1-2)].

For peak area integration, the computer codes mentioned in II.3.2 were used.

g. As outlined in V.3.1 and V.3.2, Q_0-values and F_{Cd}-factors were either critically selected from literature or experimentally determined. As to the Q_0-values, it follows from error propagation calculation (see V.3.4) that the residual uncertainties on k_0, determined according to Eq. (I.3-18), do not exceed 1%. When using the Cd-subtraction method [Eq. (I.3-19)], no Q_0-values are involved.

The final results of the k_0-determinations for 112 radionuclides of interest in neutron activation analysis are shown in Table VI.2-1. Note that each entry under the heading "Measured $k_{0,Au}$" is the average of 3-5 repetitions. Thus, a recommended k_0-factor is the average of 3-5 repetitions x 1-2 irradiation channels x 2 reactors (THETIS, Gent and WWR-M, Budapest), and the quoted uncertainty is the standard deviation on the mean (see I.3.4.4), [except for the k_0's of the Zr-isotopes, where the weighted mean and the larger of the internal or external error was calculated; see VI.2.2]. At the INW, the irradiations in 2 different reactor positions were always associated with countings on 2 different Ge-detectors. For a number of isotopes, 4 determinations in channel R4V4 of the DR-3 reactor (Risø, Denmark) were included : the high thermal-to-epithermal neutron flux ratio of this channel ($f \simeq 320$) was especially interesting when studying (n,γ) reactions with high Q_0-values [$^{96}Zr(n,\gamma)^{97}Zr$, $^{98}Mo(n,\gamma)^{99}Mo$, $^{124}Sn(n,\gamma)^{125}Sn$, etc.], the k_0-factors of which were determined by the Cd-subtraction method [Eq. (I.3-19)]. It should be remarked that a k_0-factor, even when obtained according to the above outlined procedure, is only recommended when the standard deviation on the mean is less than 2%. A k_0-factor is considered to be "tentative" (between brackets in Table VI.2-1, and with no mention of uncertainty) when the standard deviation is exceeding 2% or when for a particular isotope, or for a particular gamma line of a given isotope, the determinations were only performed in one reactor. Even then, the average is usually resulting from 3-5 measurements x 2 irradiation channels, and the accuracy is probably not worse than $\sim$ 5%.

TABLE VI.2-1 : Experimental determination of $k_{0,Au}$-factors (activation/decay type : see Table I.3-1)

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Na	KFKI : 1 mg NaCl on Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : Na_2CO_3 powder; 20 mg (CH 3); 50 mg (CH 15)	^{24}Na (IV/b)	1368.6 2754.0	$4.71.10^{-2}$(2.2) $4.60.10^{-2}$(1.6)	$4.74.10^{-2}$(2.4) $4.74.10^{-2}$(1.6)	$4.61.10^{-2}$(2.5) $4.56.10^{-2}$(1.8)	$4.65.10^{-2}$(1.8) $4.59.10^{-2}$(0.5)	$\underline{4.68.10^{-2}}$(0.6) $\underline{4.62.10^{-2}}$(0.9)	
Mg	KFKI : 1-2 mg Mg granules (etched with dil. HNO_3) INW : Mg (diss. in dil. HNO_3); spotted in polythene vial and dried	^{27}Mg (I)	170.7 843.8 1014.4	$3.10.10^{-6}$(4.0) $3.01.10^{-6}$(4.4) $2.54.10^{-4}$(2.1) $2.58.10^{-4}$(2.1) $9.80.10^{-5}$(1.9) $9.91.10^{-5}$(1.9)	$3.11.10^{-6}$(4.8) $3.03.10^{-6}$(4.8) $2.51.10^{-4}$(1.2) $2.54.10^{-4}$(1.2) $9.70.10^{-5}$(1.2) $9.80.10^{-5}$(1.2)	$2.94.10^{-6}$(3.2) $2.54.10^{-4}$(1.3) $9.79.10^{-5}$(0.3)	$3.02.10^{-6}$(2.2) $2.50.10^{-4}$(0.7) $9.80.10^{-5}$(0.5)	$\underline{3.02.10^{-6}}$(1.0) $\underline{2.53.10^{-4}}$(0.5) $\underline{9.80.10^{-5}}$(0.2)	
Al	KFKI : Al wire, 0.127 mm diam. INW : Al wire, 1 mm diam.	^{28}Al (I)	1778.9	$1.79.10^{-2}$(3.0)	$1.76.10^{-2}$(1.7)	$1.73.10^{-2}$(0.7)	$1.73.10^{-2}$(0.7)	$\underline{1.75.10^{-2}}$(0.8)	
S	KFKI : S powder, 50-70 mg INW : S powder in W 41, 100 mg (CH 3); pellet 10 mm diam. x 2.5 mm; 850 mg (CH 8), pellet 10 mm diam. x 10 mm	^{37}S (I)	3103.8	$1.92.10^{-6}$(1.8)	$1.90.10^{-6}$(2.0)	$1.97.10^{-6}$(1.5)	$2.06.10^{-6}$(3.0)	$\underline{1.96.10^{-6}}$(1.8)	
Cl	KFKI : 1 mg NaCl on Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : 1.5 mg NaCl on W 41; pellet 10 mm diam. x 4 mm	^{38}Cl (IV/b)	1642.4 2167.5	$1.95.10^{-3}$(2.7) $2.70.10^{-3}$(1.3)	$1.92.10^{-3}$(1.8) $2.65.10^{-3}$(1.7)	$1.95.10^{-3}$(0.6) $2.57.10^{-3}$(0.8)	$2.05.10^{-3}$(0.5) $2.72.10^{-3}$(1.0)	$\underline{1.97.10^{-3}}$(1.4) $\underline{2.66.10^{-3}}$(1.3)	
K	KFKI : 10 mg $KHCO_3$ or KNO_3 in W 41; pellet 6.4 mm diam. x 3 mm INW : $KHC_8O_4H_4$ (in H_2O) on W 41; 9 mg (CH 3), 30 mg (CH 15); pellet 10 mm diam. x 4 mm	^{42}K (I)	312.7 1524.7	- $9.65.10^{-4}$(2.0) $9.46.10^{-4}$(1.3)	$1.62.10^{-5}$(1.8) $9.35.10^{-4}$(0.5)	$1.56.10^{-5}$(3.7) $9.46.10^{-4}$(1.4)	$1.58.10^{-5}$(1.3) $9.36.10^{-4}$(0.7)	$\underline{1.59.10^{-5}}$(1.1) $\underline{9.46.10^{-4}}$(0.6)	

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Ca	KFKI : ∿ 2.5 mg $CaCO_3$ packed in Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : ∿ 300 mg $CaCO_3$ in polythene vial	^{47}Ca (I)	489.2	-	$9.20.10^{-8}$(5.0)	$9.16.10^{-8}$(1.1)	$9.50.10^{-8}$(0.8) $8.71.10^{-8}$(1.3)	$\underline{9.14.10^{-8}}$(1.8)	
		I_β ↓ E_2=1	807.9	-	$9.20.10^{-8}$(6.0)	$9.23.10^{-8}$(1.4)	$9.17.10^{-8}$(1.2)	$\underline{9.20.10^{-8}}$(0.2)	
			1297.1	-	$9.11.10^{-7}$(1.2)	$9.58.10^{-7}$(0.3)	$9.88.10^{-7}$(0.2) $9.60.10^{-7}$(0.4)	$\underline{9.54.10^{-7}}$(1.7)	
		^{47}Sc (II/a)	159.4	-	$8.25.10^{-7}$(1.0)	$8.54.10^{-7}$(0.2)	$8.91.10^{-7}$(0.3) $8.57.10^{-7}$(0.2)	$\underline{8.57.10^{-7}}$(1.6)	
	KFKI : 20 mg $CaCO_3$ powder in W 41; pellet 6.4 mm diam. x 1.5 mm INW : $CaCO_3$ powder in W 41; 30 mg (CH 9), 200 mg (CH 8); pellet 10 mm diam. x 3.7 mm	^{49}Ca (I)	3084.4	$1.02.10^{-4}$(1.5)	$1.02.10^{-4}$(1.6)	$9.81.10^{-5}$(1.2)	$9.99.10^{-5}$(0.8)	$\underline{1.01.10^{-4}}$(0.9)	
Sc	KFKI : 2.6 µg Sc_2O_3 (in HNO_3) on Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : 2 mg Sc_2O_3 (in HNO_3) on W 41; pellet 10 mm diam. x 4 mm	^{46}Sc (IV/b)	889.3	1.22(0.5)	1.21(0.8)	1.23(0.2)	1.23(0.2)	$\underline{1.22}$(0.4)	
			1120.5	1.21(0.5)	1.19(1.0)	1.24(0.4)	1.25(0.8)	$\underline{1.22}$(1.1)	
Ti	KFKI-INW : Ti wire, 0.127 mm diam.	^{51}Ti (I)	320.1	$3.77.10^{-4}$(1.5)	$3.79.10^{-4}$(1.2)	$3.63.10^{-4}$(0.8)	$3.77.10^{-4}$(0.4)	$\underline{3.74.10^{-4}}$(1.0)	
			928.6	$2.62.10^{-5}$(0.8)	$2.74.10^{-5}$(2.2)	$2.65.10^{-5}$(1.4)	$2.58.10^{-5}$(2.4)	$\underline{2.65.10^{-5}}$(1.3)	
V	KFKI : 4.5 µg V (diss. in HNO_3) on W 41 INW : 1 mg V granules	^{52}V (I)	1434.0	$1.91.10^{-1}$(2.2)	$2.02.10^{-1}$(1.8)	$1.95.10^{-1}$(0.9)	$1.94.10^{-1}$(0.1)	$\underline{1.96.10^{-1}}$(1.2)	
Cr	KFKI : 142 µg Cr (in HNO_3) on Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : Cr (in HNO_3) on W 41; 0.4 mg (CH 3), 0.7 mg (CH 4), 1 mg (CH 13); pellet 12 mm diam. x 3 mm	^{51}Cr (I)	320.1	$2.66.10^{-3}$(0.8) $2.67.10^{-3}$(1.0)	$2.64.10^{-3}$(0.9) $2.60.10^{-3}$(1.5)	$2.57.10^{-3}$(0.8) $2.61.10^{-3}$(0.1)	$2.60.10^{-3}$(0.1)	$\underline{2.62.10^{-3}}$(0.5)	INW : internal comparator ^{65}Zn

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Mn	KFKI : Al-1% Mn wire, 0.2 mm diam. INW : Mn_3O_4 powd., 1 mg (CH 3), 2 mg (CH 15) RISØ : 1 µg Mn on Al-foil; pellet 6.4 mm diam. x 0.2 mm	^{56}Mn (I)	846.8	$4.95.10^{-1}$(0.6) $5.06.10^{-1}$(2.3) (RISØ)	$4.93.10^{-1}$(0.8) $4.84.10^{-1}$(1.8)* (RISØ)	$4.98.10^{-1}$(1.8)	$4.97.10^{-1}$(1.0)	$\underline{4.96.10^{-1}}$(0.6)	*Cd-subtr.method
			1810.7	$1.34.10^{-1}$(1.0)	$1.34.10^{-1}$(1.0)	$1.36.10^{-1}$(2.9)	$1.36.10^{-1}$(2.2)	$\underline{1.35.10^{-1}}$(0.4)	
			2113.1	$7.20.10^{-2}$(1.2)	$7.15.10^{-2}$(0.8)	$7.17.10^{-2}$(2.8)	$7.15.10^{-2}$(1.4)	$\underline{7.17.10^{-2}}$(0.2)	
Fe	KFKI-RISØ : Fe foil 25 µm INW : 1) Fe foil 85 µm 2) 70 mg Fe_2O_3 in W 41; pellet 6 mm diam. x 1.5 mm	^{59}Fe (I)	142.6	$1.34.10^{-6}$(2.4) $1.27.10^{-6}$(1.5) $1.30.10^{-6}$(4.0) $1.33.10^{-6}$(5.0)	$1.37.10^{-6}$(1.4) $1.45.10^{-6}$(1.8) $1.33.10^{-6}$(6.0)	$1.21.10^{-6}$(1.6)	$1.38.10^{-6}$(7.2) $1.29.10^{-6}$(1.7) (RISØ)	$\underline{1.33.10^{-6}}$(1.6)	
			192.3	$3.73.10^{-6}$(2.1) $3.72.10^{-6}$(7.0) $3.88.10^{-6}$(2.0) $3.82.10^{-6}$(1.0)	$3.83.10^{-6}$(1.6) $3.73.10^{-6}$(1.5) $3.68.10^{-6}$(3.0)	$3.78.10^{-6}$(0.3)	$3.70.10^{-6}$(0.8) $3.89.10^{-6}$(1.2) (RISØ)	$\underline{3.78.10^{-6}}$(0.6)	
			334.8	-	-	-	- $3.82.10^{-7}$(3.3) (RISØ)	($3.82.10^{-7}$)	
			1099.2	$7.75.10^{-5}$(0.6) $7.68.10^{-5}$(0.6) $7.88.10^{-5}$(1.0) $7.74.10^{-5}$(0.8)	$7.64.10^{-5}$(0.8) $7.75.10^{-5}$(1.3) $7.67.10^{-5}$(1.3)	$7.76.10^{-5}$(1.5)	$7.77.10^{-5}$(1.2) $8.07.10^{-5}$(0.8) (RISØ)	$\underline{7.77.10^{-5}}$(0.5)	
			1291.6	$5.88.10^{-5}$(0.6) $5.89.10^{-5}$(0.6) $6.00.10^{-5}$(1.0) $5.94.10^{-5}$(0.8)	$5.88.10^{-5}$(0.9) $5.91.10^{-5}$(1.3) $5.85.10^{-5}$(1.3)	$5.94.10^{-5}$(1.3)	$5.95.10^{-5}$(1.2) $6.10.10^{-5}$(0.9) (RISØ)	$\underline{5.93.10^{-5}}$(0.4)	
Co	KFKI : 1) Al-2% Co wire, 1 mm diam. 2) Al-1% Co wire, 0.2 mm diam. INW : Al-2% Co wire, 1 mm diam.	^{60}Co (IV/b)	1173.2 1332.5	1.30(0.5) 1.30(0.8)	1.33(0.7) 1.33(1.2)	1.32(1.1) 1.32(1.2)	1.31(0.4) 1.32(0.7)	$\underline{1.32}$(0.4) $\underline{1.32}$(0.5)	Al-2% Co wires at KFKI and INW are of different origin

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Ni	KFKI : Ni foil 0.127 mm INW : Ni wire, 0.25 mm diam.	^{65}Ni (I)	366.3 1115.5 1481.8	$2.50.10^{-5}$(0.7) $8.07.10^{-5}$(0.7) $1.26.10^{-4}$(0.6)	$2.50.10^{-5}$(0.4) $8.09.10^{-5}$(0.8) $1.27.10^{-4}$(0.5)	$2.45.10^{-5}$(1.3) $8.13.10^{-5}$(0.5) $1.26.10^{-4}$(0.7)	$2.57.10^{-5}$(1.1) $8.25.10^{-5}$(0.6) $1.29.10^{-4}$(0.4)	$\underline{2.51.10^{-5}}$(1.0) $\underline{8.14.10^{-5}}$(0.5) $\underline{1.27.10^{-4}}$(0.6)	
Cu	KFKI : 1) Cu wire, 0.127 mm diam. 2) Al-1% Cu wire, 0.2 mm diam. INW : Cu foil, 0.0256 mm	^{64}Cu (I)	511.0 (annih.) 1345.9	$3.41.10^{-2}$(1.4) $4.86.10^{-4}$(2.4)	$3.44.10^{-2}$(1.2) $4.90.10^{-4}$(2.9)	$3.43.10^{-2}$(1.4) $4.85.10^{-4}$(1.5)	$3.47.10^{-2}$(1.4) $5.03.10^{-4}$(1.8)	$\underline{3.44.10^{-2}}$(0.4) $\underline{4.91.10^{-4}}$(0.9)	KFKI : Al-1% Cu wire
		^{66}Cu (I)	1039.2	$1.87.10^{-3}$(1.1)	$1.88.10^{-3}$(2.3)	$1.84.10^{-3}$(1.2)	$1.86.10^{-3}$(1.1)	$\underline{1.86.10^{-3}}$(0.5)	KFKI : Cu wire
Zn	KFKI-INW-RISØ : Zn foil 25 μm	^{65}Zn (I)	1115.5	$5.76.10^{-3}$(0.5) $5.64.10^{-3}$(0.7) $5.57.10^{-3}$(1.9) $5.65.10^{-3}$(1.4)	$5.75.10^{-3}$(1.0) $5.59.10^{-3}$(2.3) $5.72.10^{-3}$(0.8) $5.87.10^{-3}$(0.4) (RISØ)	$5.70.10^{-3}$(0.7) $5.76.10^{-3}$(0.8)* $5.79.10^{-3}$(0.4)* $5.80.10^{-3}$(0.9)* $5.69.10^{-3}$(0.9)*	$5.62.10^{-3}$(0.9) $5.79.10^{-3}$(0.3)* $5.80.10^{-3}$(0.5)* $5.88.10^{-3}$(0.9)*	$\underline{5.72.10^{-3}}$(0.4)	*Cd-subtr.method
		^{69m}Zn (I)	438.6	$3.83.10^{-4}$(1.0) $3.97.10^{-4}$(0.3) $3.87.10^{-4}$(2.9) $4.14.10^{-4}$(2.0)	$3.95.10^{-4}$(0.9) $3.96.10^{-4}$(1.5)* $3.87.10^{-4}$(2.4) $4.07.10^{-4}$(2.3) $4.08.10^{-4}$(0.9)* (RISØ)	$3.90.10^{-4}$(0.8) $3.88.10^{-4}$(1.0)* $4.08.10^{-4}$(1.0)* $4.12.10^{-4}$(0.9)* $4.02.10^{-4}$(1.0)*	$3.87.10^{-4}$(0.3) $3.85.10^{-4}$(0.9)* $4.06.10^{-4}$(0.9)* $4.07.10^{-4}$(1.5)*	$\underline{3.98.10^{-4}}$(0.6)	*Cd-subtr.method
Ga	KFKI : 552 μg Ga (in HNO_3) on Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : Ga granules; 1 mg (CH 3), 2 mg (CH 15)	^{72}Ga (IV/b)	629.9 834.0 894.2 1050.8 2201.7 2491.0 2501.8 2507.9	- $5.16.10^{-2}$(3.6) $5.33.10^{-3}$(2.7) $3.93.10^{-3}$(1.2) $1.47.10^{-2}$(2.8) $4.26.10^{-3}$(3.0) $1.15.10^{-2}$(3.0) $7.26.10^{-3}$(2.6)	- $5.32.10^{-2}$(1.2) $5.47.10^{-3}$(1.4) $3.81.10^{-3}$(1.2) $1.52.10^{-2}$(1.8) $4.36.10^{-3}$(1.2) $1.19.10^{-2}$(1.2) $7.51.10^{-3}$(0.6)	$1.51.10^{-2}$(1.9) $5.24.10^{-2}$(2.1) $5.56.10^{-3}$(1.7) $3.80.10^{-3}$(2.0) $1.48.10^{-2}$(1.6) $4.14.10^{-3}$(0.9) $1.15.10^{-2}$(1.6) $7.39.10^{-3}$(2.1)	$1.47.10^{-2}$(1.4) $5.24.10^{-2}$(0.5) $5.52.10^{-3}$(1.1) $3.83.10^{-3}$(3.8) $1.45.10^{-2}$(0.1) $4.03.10^{-3}$(0.9) $1.11.10^{-2}$(1.3) $7.06.10^{-3}$(0.6)	$(1.49.10^{-2})$ $\underline{5.24.10^{-2}}$(0.6) $\underline{5.47.10^{-3}}$(0.9) $\underline{3.84.10^{-3}}$(0.8) $\underline{1.48.10^{-2}}$(1.0) $\underline{4.20.10^{-3}}$(1.7) $\underline{1.15.10^{-2}}$(1.4) $\underline{7.31.10^{-3}}$(1.3)	E_{eff} of 2491.0, 2507.8 & 2515.4 E_{eff} of 2507.8 & 2515.4

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
As	KFKI : 53 µg As (in HNO_3) on W 41; pellet ; 5 mm diam. x 3 mm	^{76}As (I)	559.1	-	-	-	-	$\underline{4.83.10^{-2}}$(1.6)	INW : intern.comp. 2) ^{69m}Zn
	INW :					$4.90.10^{-2}$(0.3)	$4.75.10^{-2}$(0.4)		
	1) 0.66 mg As_2O_3 (in NH_4OH) on W 41; pellet 10 mm diam. x 4 mm		559.2	$4.88.10^{-2}$(2.0)	$5.03.10^{-2}$(0.9)	$4.99.10^{-2}$(0.2)	$4.99.10^{-2}$(0.9)	$\underline{4.97.10^{-2}}$(0.6)	E_{eff} of 559.1 & 563.2
						$5.04.10^{-2}$(0.3)	$4.89.10^{-2}$(0.4)		
			563.2	-	-	-	-	$(1.40.10^{-3})$	
						$1.44.10^{-3}$(1.9)	$1.36.10^{-3}$(3.4)		
	2) As_2O_3 (in NH_4OH) on W 41; 0.24 mg As (CH 3), 0.48 mg As (CH 15); pellet 10 mm diam. x 4 mm		657.1	$6.42.10^{-3}$(2.1)	$6.73.10^{-3}$(1.4)	$6.63.10^{-3}$(0.5)	$6.72.10^{-3}$(0.4)	$\underline{6.61.10^{-3}}$(1.3)	
						$6.87.10^{-3}$(0.7)	$6.31.10^{-3}$(5.4)		
			1212.9	-	-	-	-	$(1.49.10^{-3})$	
						$1.48.10^{-3}$(7.3)	$1.50.10^{-3}$(5.1)		
			1215.1	$5.26.10^{-3}$(3.0)	$5.36.10^{-3}$(1.1)	$5.15.10^{-3}$(0.1)	$5.19.10^{-3}$(0.7)	$\underline{5.25.10^{-3}}$(0.8)	E_{eff} of 1212.9 & 1216.1
						$5.37.10^{-3}$(2.2)	$5.17.10^{-3}$(2.5)		
			1216.1	-	-	-	-	$(3.78.10^{-3})$	
						$3.89.10^{-3}$(1.3)	$3.67.10^{-3}$(2.9)		
Se	KFKI : 256 µg Se (in HNO_3) on Al-foil; pellet 6.4 mm diam. x 0.2 mm	^{75}Se (I)	121.1	$1.98.10^{-3}$(2.2)	$2.03.10^{-3}$(1.8)	$1.98.10^{-3}$(1.8)	$1.93.10^{-3}$(1.0)	$\underline{1.98.10^{-3}}$(1.0)	
	INW : Se granules 1.5 mm diam.; 4 mg (CH 3), 10 mg (CH 15)		136.0	$6.80.10^{-3}$(1.9)	$7.14.10^{-3}$(1.3)	$6.85.10^{-3}$(1.1)	$6.75.10^{-3}$(1.0)	$\underline{6.89.10^{-3}}$(1.3)	
			264.7	$7.18.10^{-3}$(1.9)	$7.34.10^{-3}$(1.8)	$7.18.10^{-3}$(1.3)	$7.28.10^{-3}$(1.0)	$\underline{7.25.10^{-3}}$(0.5)	
			279.5	$3.02.10^{-3}$(2.3)	$3.12.10^{-3}$(1.6)	$3.00.10^{-3}$(0.7)	$3.10.10^{-3}$(1.2)	$\underline{3.06.10^{-3}}$(0.9)	
			400.7	$1.43.10^{-3}$(1.6)	$1.47.10^{-3}$(1.9)	$1.44.10^{-3}$(1.5)	$1.46.10^{-3}$(1.0)	$\underline{1.45.10^{-3}}$(0.6)	
Br	INW : KBr (in H_2O) on W 41; 0.4 mg Br (CH 8), 0.1 mg Br (CH 9); pellet 6 mm diam. x 6 mm	^{80m}Br I.T. $F_2=1$ ^{80}Br (IV/a)	616.3	-	-	$6.61.10^{-3}$(0.7)	$6.73.10^{-3}$(0.9)	$(6.67.10^{-3})$	Internal.compar.: ^{82}Br THIS WORK : $\frac{F_2 \sigma_0^m}{\sigma_0^g} = 0.261$
			665.8	-	-	$1.17.10^{-3}$(1.2)	$1.15.10^{-3}$(0.5)	$(1.16.10^{-3})$	
	KFKI : 1) 200 µg $KBrO_3$ (in H_2O) on Al-foil; pellet 6.4 mm diam. x 0.2 mm 2) 115 µg NH_4Br (in H_2O) on W 41; pellet 6.4 mm diam. x 0.2 mm	^{82m}Br I.T. $F_2=0.976$ ^{82}Br (IV/b)	554.3	$2.41.10^{-2}$(1.6)	$2.36.10^{-2}$(1.2) $2.35.10^{-2}$(0.7)	$2.44.10^{-2}$(1.3)	$2.33.10^{-2}$(0.8)	$\underline{2.38.10^{-2}}$(1.1)	INW : internal.compar.: ^{42}K
(cont'd)			619.1	$1.46.10^{-2}$(1.7)	- $1.44.10^{-2}$(0.5)	$1.48.10^{-2}$(1.5)	$1.43.10^{-2}$(0.7)	$\underline{1.45.10^{-2}}$(0.8)	

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Br (cont'd)	INW : 1) $KBrO_3$ (in H_2O) on W41; 12 mg (CH 3), 30 mg (CH 15); pellet 10 mm diam. x 4 mm 2) KBr (in H_2O) on W41; 8 mg (CH 3), 20 mg (CH 15); pellet 10 mm diam. x 4 mm		698.4	$9.60.10^{-3}$(0.6)	$9.32.10^{-3}$(2.0) $9.23.10^{-3}$(0.7)	$9.44.10^{-3}$(0.7)	$9.24.10^{-3}$(0.9)	$\underline{9.38.10^{-3}}$(0.9)	
			776.5	$2.77.10^{-2}$(0.7)	$2.81.10^{-2}$(2.0) $2.75.10^{-2}$(0.6)	$2.80.10^{-2}$(0.9)	$2.70.10^{-2}$(1.0)	$\underline{2.76.10^{-2}}$(0.8)	
			827.8	$8.15.10^{-3}$(1.0)	$7.97.10^{-3}$(2.0) $7.96.10^{-3}$(1.7)	$8.03.10^{-3}$(1.1)	$7.82.10^{-3}$(0.8)	$\underline{7.99.10^{-3}}$(0.9)	
			1044.0	$9.30.10^{-3}$(1.7)	$9.06.10^{-3}$(2.0) $9.07.10^{-3}$(0.7)	$9.16.10^{-3}$(0.9)	$9.02.10^{-3}$(1.0)	$\underline{9.14.10^{-3}}$(0.7)	
			1317.5	$8.95.10^{-3}$(2.2)	$8.72.10^{-3}$(2.0) $8.93.10^{-3}$(0.6)	$8.99.10^{-3}$(0.8)	$8.88.10^{-3}$(0.7)	$\underline{8.91.10^{-3}}$(0.4)	
			1474.9	$5.38.10^{-3}$(1.0)	-	$5.47.10^{-3}$(0.8)	$5.42.10^{-3}$(0.6)	$\underline{5.42.10^{-3}}$(0.5)	
Rb	KFKI : 1) 835 µg RbCl in Al-foil; pellet 6.4 mm diam. x 0.2 mm 2) 1 mg $RbNO_3$ (in H_2O) on Al-foil; pellet 6.4 mm diam. x 0.2 mm	^{86}Rb (IV/b)	1076.6	$7.44.10^{-4}$(1.2) $7.89.10^{-4}$(1.2)	$7.67.10^{-4}$(1.2) $7.90.10^{-4}$(0.7) (RISØ)	$7.32.10^{-4}$(1.2) $7.88.10^{-4}$(0.5)	$7.49.10^{-4}$(0.5) $7.61.10^{-4}$(0.1)	$\underline{7.65.10^{-4}}$(1.0)	INW : internal compar.: ^{134}Cs
	INW : 1) 10 mg RbCl in W41; pellet 10 mm diam. x 5 mm 2) RbCl (in H_2O) on W41; 70 mg (CH 3); 170 mg (CH 15); pellet 12 mm diam. x 3 mm RISØ : 2 mg $RbNO_3$ (in H_2O) on Al-foil; pellet 6.4 mm diam. x 0.2 mm	^{88}Rb (I)	898.0	$1.04.10^{-4}$(1.0) $1.05.10^{-4}$(0.9)	$1.01.10^{-4}$(0.4)	$9.78.10^{-5}$(0.9)	$9.89.10^{-5}$(1.8)	$\underline{1.01.10^{-4}}$(1.5)	INW : internal compar.: ^{27}Mg
			1836.0	$1.61.10^{-4}$(1.1) $1.59.10^{-4}$(1.7)	$1.57.10^{-4}$(0.2)	$1.52.10^{-4}$(1.1)	$1.59.10^{-4}$(1.1)	$\underline{1.57.10^{-4}}$(1.1)	
			2677.9	$1.44.10^{-5}$(6.0) $1.53.10^{-5}$(3.6)	$1.44.10^{-5}$(1.6)	-	-	($1.47.10^{-5}$)	
Sr	KFKI : $Sr(NO_3)_2$ (in H_2O); 120 µg Sr on Al-foil; pellet 6.4 mm diam. x 0.2 mm RISØ : $Sr(NO_3)_2$ (in H_2O); 4.5 mg Sr on Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : $Sr(NO_3)_2$ in W41; 1.5 mg Sr (CH 9, CH 3); pellet 6 mm diam. x 3 mm	^{85m}Sr (I) I.T. F_2=0.873 ^{85}Sr (IV/b)	231.7	-	-	$7.00.10^{-5}$(0.2)	$6.86.10^{-5}$(1.8)	($6.92.10^{-5}$)	
			514.0	$9.21.10^{-5}$(1.1)	$9.30.10^{-5}$(1.8) $9.17.10^{-5}$(1.9)	-	- $8.92.10^{-5}$(1.0) (RISØ)	$\underline{9.15.10^{-5}}$(0.9)	

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Sr	KFKI : 15 mg $Sr(NO_3)_2$ (in H_2O) on Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : 3.5 mg $Sr(NO_3)_2$ in W 41; pellet 6 mm diam. x 3 mm	^{87m}Sr (I)	388.4	$1.50.10^{-3}$(1.9)	$1.47.10^{-3}$(1.8)	$1.50.10^{-3}$(0.1)	$1.50.10^{-3}$(1.8)	$\underline{1.49.10^{-3}}$(0.5)	corrected for slight interference from $^{87}Sr(n,n')^{87m}Sr$
Y	KFKI : 5 mg Y_2O_3 powder in Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : 30 mg Y_2O_3 powder	^{90m}Y (I)	202.5 479.5	$2.41.10^{-5}$(2.0) $2.19.10^{-5}$(2.5)	$2.46.10^{-5}$(0.8) $2.22.10^{-5}$(1.5)	$2.33.10^{-5}$(1.8) $2.27.10^{-5}$(0.9)	$2.24.10^{-5}$(0.4) $2.22.10^{-5}$(0.7)	$\underline{2.36.10^{-5}}$(2.0) $\underline{2.23.10^{-5}}$(0.9)	
Zr	KFKI, INW, RISØ : 125 µm Zr foil	^{95}Zr (I) β^- F_{24}=0.989; β^- F_2=0.0111 ^{95m}Nb I.T. F_3=0.944 ^{95}Nb (III/a)	724.2	$9.387.10^{-5}$(1.1)*	-	$9.354.10^{-5}$(0.9)*	$9.167.10^{-5}$(1.4)* $9.271.10^{-5}$(1.9)*	$\underline{9.321.10^{-5}}$(0.6)+	* Cd-subtr.method
			756.7	$1.150.10^{-4}$(1.1)*	-	$1.145.10^{-4}$(0.9)*	$1.154.10^{-4}$(1.6)* $1.157.10^{-4}$(1.7)*	$\underline{1.149.10^{-4}}$(0.6)+	
			724.2 + 756.7	$2.088.10^{-4}$(0.9)*	- $2.152.10^{-4}$(1.0)* (RISØ)	$2.083.10^{-4}$(0.6)*	$2.071.10^{-4}$(1.0)* $2.112.10^{-4}$(1.3)*	$\underline{2.094.10^{-4}}$(0.6)+	E_{eff} = 742.2 keV
			765.8	-	- $2.27.10^{-6}$(0.9) (RISØ)	-	-	$\underline{2.27.10^{-6}}$(0.9)	associated with F_{24}/F_2F_3 = 94.38 + weighted mean
	KFKI, INW, RISØ : 125 µm Zr foil	^{97}Zr (I) β^- F_{24}=0.032; β^- F_2=0.968	254.2	-	- $1.91.10^{-7}$(2.1) (RISØ)	-	-	$(1.91.10^{-7})$	
			355.4	-	- $3.06.10^{-7}$(2.4) (RISØ)	-	-	$(3.06.10^{-7})$	

(cont'd)

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Zr (cont'd)		β^- F_{24}=0.032; β^- F_2=0.968	507.7	-	- $7.11.10^{-7}$(2.2) (RISØ)	-	-	($7.11.10^{-7}$)	* Cd-subtr.method
			602.4	-	- $1.99.10^{-7}$(4.0) (RISØ)	-	-	($1.99.10^{-7}$)	+ weighted mean
			703.7	-	- $1.42.10^{-7}$(3.3) (RISØ)	-	-	($1.42.10^{-7}$)	
			1148.0	-	- $3.57.10^{-7}$(2.0) (RISØ)	-	-	($3.57.10^{-7}$)	
		^{97m}Nb (II/a)	743.3	$1.318.10^{-5}$(10.1)*	- $1.310.10^{-5}$(1.2)* (RISØ)	$1.307.10^{-5}$(2.2)*	$1.253.10^{-5}$(2.0)* $1.287.10^{-5}$(6.3)*	$\underline{1.296.10^{-5}}$(0.9)+	
		I.T. F_3=1							
		^{97}Nb (III/a)	657.9	$1.319.10^{-5}$(10.1)*	- $1.299.10^{-5}$(1.3)* (RISØ)	$1.333.10^{-5}$(1.9)*	$1.294.10^{-5}$(2.0)* $1.243.10^{-5}$(5.3)*	$\underline{1.304.10^{-5}}$(0.9)+	
Nb	KFKI, INW : Nb wire, 0.127 mm diam.	^{94m}Nb (I)	871.0	$9.66.10^{-5}$(1.0)	$9.73.10^{-5}$(1.6)	$9.66.10^{-5}$(1.5)	$9.76.10^{-5}$(1.6)	$\underline{9.70.10^{-5}}$(1.6)	
Mo (cont'd)	KFKI, INW : Mo foil 25 µm RISØ : Mo foil 5 µm	^{99}Mo (I)	181.1	$4.09.10^{-5}$(1.8) $4.17.10^{-5}$(2.2) $4.05.10^{-5}$(0.4) $4.05.10^{-5}$(1.4)*	$4.19.10^{-5}$(0.8) $4.20.10^{-5}$(1.1)	$4.22.10^{-5}$(0.9)	$4.22.10^{-5}$(1.1) $4.14.10^{-5}$(0.2)* (RISØ)	$\underline{4.15.10^{-5}}$(0.6)	* Cd-subtr.method
		β^- β^- F_2=0.880	366.4	$8.37.10^{-6}$(0.4)	$8.34.10^{-6}$(0.3)	$8.10.10^{-6}$(1.1)	$8.64.10^{-6}$(1.0)	$\underline{8.36.10^{-6}}$(1.3)	
			739.5	$8.20.10^{-5}$(1.9) $8.63.10^{-5}$(0.7) $8.21.10^{-5}$(0.4) $8.20.10^{-5}$(3.0)*	$8.31.10^{-5}$(0.9) $8.47.10^{-5}$(0.9)	$8.50.10^{-5}$(0.6)	$8.48.10^{-5}$(0.9) $8.64.10^{-5}$(1.5)* (RISØ)	$\underline{8.46.10^{-5}}$(0.7)	

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Mo (cont'd)		β^- F_2=0.880 ^{99m}Tc I.T. β^-	778.0	$3.02.10^{-5}$(2.0) $2.96.10^{-5}$(2.6) $2.89.10^{-5}$(1.8) $2.79.10^{-5}$(8.0)*	$3.03.10^{-5}$(2.1) $3.09.10^{-5}$(1.6)	$2.99.10^{-5}$(0.4)	$2.97.10^{-5}$(0.4)	$\underline{2.97.10^{-5}}$(1.1)	
		140.5 keV level (II/d)	140.5	$5.22.10^{-4}$(1.7) $5.26.10^{-4}$(3.0) $5.19.10^{-4}$(0.4) $5.09.10^{-4}$(1.9)*	$5.35.10^{-4}$(0.3) $5.31.10^{-4}$(0.2)	$5.43.10^{-4}$(0.8) $5.20.10^{-4}$(2.0)* $5.17.10^{-4}$(0.6)* $5.27.10^{-4}$(0.8)*	$5.32.10^{-4}$(1.9) $5.21.10^{-4}$(0.8)* $5.24.10^{-4}$(0.6)* $5.46.10^{-4}$(1.1)* (RISØ)	$\underline{5.27.10^{-4}}$(0.5)	$\frac{\gamma_{140,Mo}}{F_2 \cdot \gamma_{140,Tc}} = 0.0675$ (THIS WORK)
(cont'd)	KFKI, INW : Mo foil 25 μm RISØ : Mo foil 5 μm	^{101}Mo (I) β^- F_2=1	80.9	- $1.77.10^{-5}$(1.4)* (RISØ)	- $1.83.10^{-5}$(3.0) (RISØ)	-	-	($1.80.10^{-5}$)	* Cd-subtr.method
			191.9	- $7.70.10^{-5}$(1.5)* (RISØ)	- $7.71.10^{-5}$(1.6) (RISØ)	-	-	($7.71.10^{-5}$)	
			195.9	- $9.84.10^{-6}$(7.4)* (RISØ)	- $1.06.10^{-5}$(3.6) (RISØ)	-	-	($1.02.10^{-5}$)	
			192.4	- $8.42.10^{-5}$(2.4)* (RISØ)	- $8.77.10^{-5}$(1.8) (RISØ)	$8.36.10^{-5}$(0.8)	$8.14.10^{-5}$(0.3)	$\underline{8.36.10^{-5}}$(1.6)	E_{eff} = 191.9 & 195.9
			408.7	- $5.85.10^{-6}$(3.3) (RISØ)	-	-	-	($5.85.10^{-6}$)	

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Mo (cont'd)		β^- F_2=1	499.7	-	-	-	-	$(5.63.10^{-6})$	
				$5.63.10^{-6}$(3.2) (RISØ)					
			505.9	$4.62.10^{-5}$(3.6) $4.32.10^{-5}$(2.2)	$4.71.10^{-5}$(0.5) $4.79.10^{-5}$(1.6)	$4.79.10^{-5}$(0.2)	$4.55.10^{-5}$(0.4)	$\underline{4.71.10^{-5}}$(1.9)	E_{eff} = 505.1 & 505.9
				$4.98.10^{-5}$(1.4)* (RISØ)	$4.98.10^{-5}$(1.3) (RISØ)				
			590.7	$8.55.10^{-5}$(1.5) $8.08.10^{-5}$(2.1)	$8.40.10^{-5}$(1.0) $8.36.10^{-5}$(1.6)	$8.02.10^{-5}$(0.3)	$7.97.10^{-5}$(0.3)	$\underline{8.30.10^{-5}}$(1.8)	E_{eff} = 590.1 & 590.9
				$8.79.10^{-5}$(0.8)* (RISØ)	$8.80.10^{-5}$(0.8) (RISØ)				
			695.6	$2.85.10^{-5}$(1.9) $2.72.10^{-5}$(5.1)	$2.87.10^{-5}$(1.1) $2.84.10^{-5}$(3.0)	$2.71.10^{-5}$(0.8)	$2.68.10^{-5}$(0.8)	$\underline{2.79.10^{-5}}$(1.6)	interfer.: 694.7 keV (^{101}Tc)
					$2.92.10^{-5}$(1.9) (RISØ)				
			713.0	-	-	-	-	$(1.37.10^{-5})$	
				$1.37.10^{-5}$(3.5) (RISØ)					
			870.9	-	-	-	-	$(8.61.10^{-6})$	E_{eff} = 869.7 & 871.1
				$8.61.10^{-6}$(7.3) (RISØ)					
			877.4	-	-	-	-	$(1.53.10^{-5})$	
				$1.53.10^{-5}$(1.5) (RISØ)					
(cont'd)									

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Mo (cont'd)		β^- F_2=1	934.0	-	-	-	-	$(1.75.10^{-5})$	E_{eff} = 933.3 & 934.2
				$1.75.10^{-5}$(3.1) (RISØ)					
			1012.3	$6.20.10^{-5}$(1.5) $5.78.10^{-5}$(2.5)	$6.25.10^{-5}$(2.0) $6.36.10^{-5}$(1.9)	$5.94.10^{-5}$(0.8)	$6.00.10^{-5}$(0.6)	$\underline{6.18.10^{-5}}$(2.2)	E_{eff} = 1011.1 & 1012.5
					$6.67.10^{-5}$(1.1) (RISØ)				
			1161.0	-	-	-	-	$(1.82.10^{-5})$	
				$1.82.10^{-5}$(1.2) (RISØ)					
			1251.0	-	-	-	-	$(2.14.10^{-5})$	E_{eff} = 1249.4 & 1251.1
				$2.14.10^{-5}$(0.6) (RISØ)					
			1304.0	-	-	-	-	$(1.30.10^{-5})$	
				$1.30.10^{-5}$(7.1) (RISØ)					
			1532.5	-	-	-	-	$(2.73.10^{-5})$	
				$2.73.10^{-5}$(2.5) (RISØ)					
		^{101}Tc (II/a)	127.2	-	-	-	-	$(1.20.10^{-5})$	
				$1.20.10^{-5}$(2.1)* (RISØ)	$1.20.10^{-5}$(1.8) (RISØ)				
			184.1	-	-	-	-	$(5.50.10^{-6})$	
				$5.50.10^{-6}$(3.7) (RISØ)					
(cont'd)									

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, % KFKI "WWR-M"		Measured $k_{0,Au}$ and relative error, % INW "THETIS"		Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
Mo (cont'd)			306.8	$3.75.10^{-4}$(1.9) $3.68.10^{-4}$(2.4) $3.90.10^{-4}$(0.9)* (RISØ)	$3.73.10^{-4}$(1.6) $3.81.10^{-4}$(1.4) $3.90.10^{-4}$(1.0) (RISØ)	$3.53.10^{-4}$(0.4) $3.63.10^{-4}$(0.7)* $3.60.10^{-4}$(1.0)* $3.61.10^{-4}$(0.3)* $3.73.10^{-4}$(0.6)*	$3.65.10^{-4}$(0.8) $3.73.10^{-4}$(0.8)* $3.57.10^{-4}$(1.0)* $3.71.10^{-4}$(0.7)*	$\underline{3.73.10^{-4}}$(1.3)	
			531.4	- $5.01.10^{-6}$(5.2) (RISØ)	-	-	-	($5.01.10^{-6}$)	
			545.1	$2.52.10^{-5}$(2.5) $2.45.10^{-5}$(3.0) $2.55.10^{-5}$(1.1)* (RISØ)	$2.51.10^{-5}$(0.6) $2.54.10^{-5}$(2.4) $2.55.10^{-5}$(1.0) (RISØ)	$2.49.10^{-5}$(0.6)	$2.41.10^{-5}$(1.1)	$\underline{2.49.10^{-5}}$(1.0)	
Ru	KFKI : 3 mg Ru powder in Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : 1) 7 mg Ru sponge in polythene vial 2) $(NH_4)_2Ru(H_2O)Cl_5$ (certif. Ru: 30.6%)(in H_2O) on W 41; 4 mg (CH 3), 10 mg (CH 15); pellet 10 mm diam. x 4 mm	^{97}Ru (I)	215.7	$2.21.10^{-4}$(1.0)	$2.24.10^{-4}$(1.0)	$2.28.10^{-4}$(1.4) $2.25.10^{-4}$(1.2) $2.25.10^{-4}$(1.4)	$2.20.10^{-4}$(1.7) $2.28.10^{-4}$(1.5) $2.27.10^{-4}$(0.1)	$\underline{2.25.10^{-4}}$(0.5)	INW : internal compar.: ^{69m}Zn
		^{103}Ru (I)	497.1	$6.94.10^{-3}$(0.7)	$6.97.10^{-3}$(0.7)	$6.80.10^{-3}$(0.9) $6.79.10^{-3}$(1.2)	$6.91.10^{-3}$(0.9) $6.90.10^{-3}$(1.0)	$\underline{6.89.10^{-3}}$(0.4)	INW : internal compar.: ^{69m}Zn
			610.3	$4.34.10^{-4}$(4.0)	-	$4.26.10^{-4}$(1.2)	$4.29.10^{-4}$(3.4)	$\underline{4.30.10^{-4}}$(0.5)	
(cont'd)	KFKI : 3 mg Ru powder in Al-foil; pellet 6.4 mm diam. x 0.3 mm INW : 1) 7 mg Ru sponge in polythene vial 2) $(NH_4)_2Ru(H_2O)Cl_5$ (30.6% Ru certified)(in H_2O) on W 41; 1.3 mg Ru (CH 3), 3.2 mg Ru (CH 15); pellet 10 mm diam. x 4 mm	^{105}Ru (I) β^- F_{24}=0.755 β^- F_2=0.245	262.8	$1.28.10^{-4}$(2.0)	$1.34.10^{-4}$(1.5)	$1.33.10^{-4}$(1.2) $1.26.10^{-4}$(0.3)	$1.39.10^{-4}$(0.9) $1.24.10^{-4}$(1.1)	$\underline{1.31.10^{-4}}$(1.8)	INW : internal compar.: ^{69m}Zn
			469.4	$3.42.10^{-4}$(1.8)	$3.56.10^{-4}$(1.6)	$3.53.10^{-4}$(0.9) $3.35.10^{-4}$(0.9)	$3.60.10^{-4}$(1.1) $3.35.10^{-4}$(0.8)	$\underline{3.47.10^{-4}}$(1.3)	E_{eff} of 469.4 & 470.1
			676.4	-	-	$3.08.10^{-4}$(1.0) $2.82.10^{-4}$(0.8)	$3.07.10^{-4}$(2.1) $2.84.10^{-4}$(1.3)	($2.95.10^{-4}$)	
			724.3	$8.75.10^{-4}$(1.6)	$9.12.10^{-4}$(1.4)	$9.18.10^{-4}$(0.9) $8.46.10^{-4}$(1.0)	$9.27.10^{-4}$(0.6) $8.43.10^{-4}$(0.9)	$\underline{8.87.10^{-4}}$(1.7)	

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Ru (cont'd)		^{105m}Rh (II/a) β^- $F_{24}=0.755$ I.T. $F_3=1$ ^{105}Rh (III/c)	129.7	$9.36.10^{-5}$(2.5)	$9.24.10^{-5}$(1.3)	$8.70.10^{-5}$(0.2) $9.49.10^{-5}$(0.2)	$9.01.10^{-5}$(2.1) $9.41.10^{-5}$(1.6)	$\underline{9.20.10^{-5}}$(1.3)	
			306.1	$9.86.10^{-5}$(3.0)	$1.04.10^{-4}$(3.0)	$9.78.10^{-5}$(3.5)	$1.03.10^{-4}$(2.5)	$\underline{1.01.10^{-4}}$(1.5)	
			319.2	$3.59.10^{-4}$(2.4)	$3.85.10^{-4}$(2.4)	$3.61.10^{-4}$(1.4) $3.38.10^{-4}$(1.5)	$3.63.10^{-4}$(0.8) $3.34.10^{-4}$(0.3)	$\underline{3.57.10^{-4}}$(2.1)	
Rh	INW : 1) $(NH_4)_3RhCl_6.1\frac{1}{2}H_2O$ (J.M. certif. Rh content)(in dil.HNO_3) on W 41; 16 µg Rh (CH 9), 305 µg Rh (CH 8); pellet 10 mm diam. x 4 mm 2) 6.6 mg Rh powder (5 µm diam.) mixed with 600 mg wax; pellet 10 mm diam. x 5.3 mm (CH 8)	^{104m}Rh I.T. $F_2=0.9987$ ^{104}Rh (IV/a)	555.8	-	-	$6.15.10^{-2}$(1.8)	$6.15.10^{-2}$(1.9) $6.04.10^{-2}$(1.5)	$(6.11.10^{-2})$	intern.compar. : 1) ^{52}V $F_2\sigma_0^m/\sigma_0^g \approx 0.082$ (THIS WORK)
Pd	INW : $(NH_4)_2PdCl_4$ (J.M. certif. Pd content)(in HCl) on W 41; 1.8 mg Pd (CH 3), 4.5 mg Pd (CH 15); pellet 10 mm diam. x 4 mm	^{109m}Pd I.T. $F_2=1$ ^{109}Pd (IV/b) β^- $F_3=1$ ^{109m}Ag (V/c)	311.1	-	-	$1.57.10^{-5}$(1.3)	$1.61.10^{-5}$(1.2)	$(1.59.10^{-5})$	intern.compar. : ^{69m}Zn E_{eff} = 309.1 & 311.4
			414.4	-	-	$8.63.10^{-6}$(2.5)	$9.08.10^{-6}$(4.3)	$(8.85.10^{-6})$	E_{eff} = 413.0 & 415.2
			602.5	-	-	$3.56.10^{-6}$(2.4)	$3.29.10^{-6}$(1.3)	$(3.43.10^{-6})$	
			636.3	-	-	$4.60.10^{-6}$(2.8)	$4.65.10^{-6}$(2.9)	$(4.62.10^{-6})$	
			647.3	-	-	$1.07.10^{-5}$(3.8)	$1.12.10^{-5}$(3.5)	$(1.09.10^{-5})$	
			781.4	-	-	$4.78.10^{-6}$(4.9)	$4.44.10^{-6}$(4.2)	$(4.61.10^{-6})$	
			88.0	-	-	$1.85.10^{-3}$(0.8)	$1.73.10^{-3}$(2.9)	$(1.79.10^{-3})$	

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Pd	INW : $(NH_4)_2PdCl_4$ (J.M. certif. Pd content) (in HCl) on W 41; 1.8 mg Pd (CH 3), 4.5 mg Pd (CH 15); pellet 10 mm diam. x 4 mm	^{111m}Pd (I)	172.1	-	-	$8.64.10^{-6}$(0.3)	$9.44.10^{-6}$(1.9)	$(9.04.10^{-6})$	intern.compar. : ^{69m}Zn
Ag	KFKI :	^{108}Ag (I)	433.9	$1.71.10^{-3}$(0.4)	-	$1.56.10^{-3}$(0.9)	$1.57.10^{-3}$(0.5)	$\underline{1.59.10^{-3}}$(1.8)	INW : intern.compar.:
	1) 580 µg Ag on W 41; pellet 6.4 mm diam. x 1.5 mm			$1.71.10^{-3}$(2.8)	$1.65.10^{-3}$(2.9)	$1.49.10^{-3}$(1.9)	$1.49.10^{-3}$(0.1)		1) ^{66}Cu
						$1.54.10^{-3}$(1.7)	$1.56.10^{-3}$(0.6)		2) ^{69m}Zn
	2) 2.8 µg Ag on W 41; pellet 6.4 mm diam. x 1.5 mm		618.9	$9.12.10^{-4}$(0.2)	-	-	-	$(9.33.10^{-4})$	3) ^{52}V
				$9.49.10^{-4}$(2.4)	$9.38.10^{-3}$(5.1)				
	INW :								
	1) $AgNO_3$ (in dil.HNO_3) on W 41; 1 mg Ag (CH 9, CH 8); pellet 10 mm diam. x 4 mm		633.0	$6.01.10^{-3}$(0.3)	-	$5.95.10^{-3}$(1.1)	$5.93.10^{-3}$(1.4)	$\underline{6.01.10^{-3}}$(1.9)	
				$6.37.10^{-3}$(3.1)	$6.43.10^{-3}$(0.5)	-	-		
						$5.71.10^{-3}$(0.5)	$5.67.10^{-3}$(0.4)		
	2) $AgNO_3$ (in dil.HNO_3) on W 41; 1.7 mg Ag (CH 17), 4 mg Ag (CH 8); pellet 10 mm diam. x 4 mm								
	3) $AgNO_3$ (in dil.HNO_3) on W 41; 0.2 mg Ag (CH 9), 0.5 mg Ag (CH 8); pellet 10 mm diam. x 4 mm								
	KFKI :	^{110m}Ag (I)	446.8	$1.27.10^{-3}$(2.0)	$1.32.10^{-3}$(4.5)	$1.33.10^{-3}$(0.4)	$1.30.10^{-3}$(1.9)	$\underline{1.34.10^{-3}}$(1.7)	INW : intern.compar.: ^{69m}Zn & ^{65}Zn
	1) 11 µg Ag (in HNO_3) on Al-foil; pellet 6.4 mm diam. x 0.2 mm			$1.41.10^{-3}$(1.6)	$1.40.10^{-3}$(1.8)				
			620.4	$9.94.10^{-4}$(0.9)	$9.87.10^{-4}$(1.6)	-	-	$\underline{1.00.10^{-3}}$(0.8)	
						$1.02.10^{-3}$(1.7)	$1.00.10^{-3}$(0.8)		
	2) Al (0.2 ± 0.004)% Ag wire, 1 mm diam.		657.8	$3.47.10^{-2}$(1.4)	$3.47.10^{-2}$(1.4)	$3.40.10^{-2}$(0.6)	$3.33.10^{-2}$(1.0)	$\underline{3.44.10^{-2}}$(0.6)	
				$3.52.10^{-2}$(0.6)	$3.45.10^{-2}$(0.3)	$3.39.10^{-2}$(0.3)	$3.46.10^{-2}$(1.9)		
	INW :								
	1) $AgNO_3$ (in H_2O) on W 41; 3 mg (CH 3), 6 mg (CH 15); pellet 10 mm diam. x 4 mm		677.6	$3.87.10^{-3}$(2.5)	$3.84.10^{-3}$(2.2)	$3.86.10^{-3}$(0.9)	$3.69.10^{-3}$(2.0)	$\underline{3.86.10^{-3}}$(1.1)	E_{eff} : 676.6 & 677.6
				$4.01.10^{-3}$(1.0)	$3.91.10^{-3}$(1.1)				
			687.0	$2.31.10^{-3}$(0.7)	$2.41.10^{-3}$(2.5)	$2.40.10^{-3}$(0.8)	$2.33.10^{-3}$(1.2)	$\underline{2.39.10^{-3}}$(1.0)	
				$2.48.10^{-3}$(1.5)	$2.38.10^{-3}$(0.4)				
	2) Ag (in HNO_3) on W 41; 0.4 mg (CH 2); 1 mg (CH 6); pellet 12 mm diam. x 3 mm		706.7	$6.05.10^{-3}$(2.5)	$6.05.10^{-3}$(2.2)	$5.94.10^{-3}$(0.8)	$5.86.10^{-3}$(0.8)	$\underline{6.01.10^{-3}}$(0.7)	E_{eff} : 706.7 & 708.1
(cont'd)				$6.15.10^{-3}$(0.9)	$6.01.10^{-3}$(0.7)				

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, % KFKI "WWR-M"		Measured $k_{0,Au}$ and relative error, % INW "THETIS"		Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
Ag (cont'd)			744.3	$1.61.10^{-3}$(2.8) $1.73.10^{-3}$(1.1)	$1.64.10^{-3}$(2.7) $1.71.10^{-3}$(1.3)	$1.65.10^{-3}$(1.1)	$1.64.10^{-3}$(1.2)	$\underline{1.66.10^{-3}}$(1.1)	
			763.9	$8.17.10^{-3}$(1.0) $8.36.10^{-3}$(0.7)	$8.14.10^{-3}$(1.4) $8.12.10^{-3}$(1.0)	$7.94.10^{-3}$(0.8) $8.12.10^{-3}$(0.6)	$7.87.10^{-3}$(0.9) $8.32.10^{-3}$(1.0)	$\underline{8.13.10^{-3}}$(0.7)	
			818.0	$2.58.10^{-3}$(1.6) $2.75.10^{-3}$(1.0)	$2.59.10^{-3}$(1.8) $2.72.10^{-3}$(1.3)	$2.62.10^{-3}$(1.3)	$2.58.10^{-3}$(0.9)	$\underline{2.64.10^{-3}}$(1.2)	
			884.7	$2.68.10^{-2}$(1.2) $2.71.10^{-2}$(0.5)	$2.68.10^{-2}$(1.4) $2.63.10^{-2}$(0.5)	$2.58.10^{-2}$(0.6) $2.63.10^{-2}$(0.4)	$2.56.10^{-2}$(0.7) $2.71.10^{-2}$(1.4)	$\underline{2.65.10^{-2}}$(0.8)	
			937.5	$1.25.10^{-2}$(1.5) $1.28.10^{-2}$(0.6)	$1.26.10^{-2}$(0.9) $1.27.10^{-2}$(0.3)	$1.21.10^{-2}$(0.7) $1.25.10^{-2}$(1.4)	$1.21.10^{-2}$(0.8) $1.26.10^{-2}$(2.3)	$\underline{1.25.10^{-2}}$(0.7)	
			1384.3	$8.89.10^{-3}$(1.6) $9.12.10^{-3}$(1.0)	$8.94.10^{-3}$(0.9) $8.94.10^{-3}$(1.4)	$8.66.10^{-3}$(0.9) $9.11.10^{-3}$(1.6)	$8.72.10^{-3}$(0.9) $9.34.10^{-3}$(1.2)	$\underline{8.96.10^{-3}}$(0.9)	
			1475.8	$1.45.10^{-3}$(2.4) $1.50.10^{-3}$(1.8)	$1.48.10^{-3}$(2.9) $1.47.10^{-3}$(1.8)	$1.46.10^{-3}$(2.4)	$1.45.10^{-3}$(0.4)	$\underline{1.47.10^{-3}}$(0.5)	
			1505.0	$4.73.10^{-3}$(2.1) $4.89.10^{-3}$(1.1)	$4.80.10^{-3}$(1.8) $4.67.10^{-3}$(0.6)	$4.65.10^{-3}$(0.8)	$4.69.10^{-3}$(1.0)	$\underline{4.74.10^{-3}}$(0.8)	
			1562.3	$4.30.10^{-4}$(1.5) $4.34.10^{-4}$(3.7)	$4.36.10^{-4}$(4.5) $4.07.10^{-4}$(3.2)	$4.24.10^{-4}$(2.2)	$4.34.10^{-4}$(0.4)	$\underline{4.28.10^{-4}}$(1.0)	
Cd	INW : ^{114}CdO (98.55% ^{114}Cd enrichm.)(in HNO_3) on W 41; 200 µg Cd (CH 3), 700 µg Cd (CH 15); pellet 6 mm diam. x 2 mm	^{115}Cd (I) $\xrightarrow[p_n=1]{I_\gamma}$ ^{115m}In (II/a)	527.9	-	-	$3.19.10^{-4}$(1.8)*	$3.48.10^{-4}$(1.0)* $3.58.10^{-4}$(0.2)+	($3.42.10^{-4}$)	* Cd-subtr.method (F_{Cd} = 0.45) + 2-channel method
			336.2	-	-	$5.28.10^{-4}$(1.9)*	$5.64.10^{-4}$(1.9)* $5.78.10^{-4}$(0.4)+	($5.57.10^{-4}$)	
In	KFKI : Al - 0.099% In wire, 1 mm diam.	^{114m}In (IV/b)	190.3	$1.03.10^{-3}$(0.2)	$9.96.10^{-3}$(0.3)	-	-	($1.01.10^{-3}$)	
			558.4	$2.75.10^{-4}$(0.7)	$2.75.10^{-4}$(1.1)	-	-	($2.75.10^{-4}$)	
			725.2	$2.75.10^{-4}$(0.7)	$2.71.10^{-4}$(1.3)	-	-	($2.73.10^{-4}$)	
(cont'd)	KFKI : 1) 1 µg In (in HNO_3) on Al-foil; pellet 6.4 mm diam. x 0.2 mm 2) Al - 119 ppm In wire	^{116m}In (IV/b)	137.9	$1.04.10^{-1}$(1.1) $9.95.10^{-2}$(1.0)	$1.05.10^{-1}$(1.1) $1.03.10^{-1}$(2.1)	$1.00.10^{-1}$(0.3)	$9.75.10^{-2}$(0.9)	$\underline{1.01.10^{-1}}$(1.4)	INW : intern.compar.: ^{69m}Zn
			416.9	$7.57.10^{-1}$(1.0) $7.46.10^{-1}$(2.2)	$7.79.10^{-1}$(1.6) $7.67.10^{-1}$(1.6)	$7.32.10^{-1}$(0.5)	$7.58.10^{-1}$(0.4)	$\underline{7.54.10^{-1}}$(1.1)	

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
In (cont'd)	INW : In (in HNO_3) on W 41; 1.8 µg (CH 3); 3.6 µg (CH 15); pellet 10 mm diam. x 4 mm		818.7	$3.38.10^{-1}$(1.3) $3.37.10^{-1}$(3.2)	$3.49.10^{-1}$(1.0) $3.43.10^{-1}$(1.7)	$3.36.10^{-1}$(0.7)	$3.26.10^{-1}$(0.8)	$\underline{3.36.10^{-1}}$(1.2)	
			1097.2	1.62(1.3) 1.61(3.0)	1.64(1.4) 1.65(0.9)	1.57(0.8)	1.55(0.5)	$\underline{1.60}$(1.3)	
			1293.5	2.32(1.1) 2.35(2.1)	2.38(1.2) 2.25(1.1)	2.26(0.7)	2.26(0.5)	$\underline{2.29}$(0.8)	
			1507.5	$2.70.10^{-1}$(1.3) $2.66.10^{-1}$(3.1)	$2.79.10^{-1}$(1.5) $2.80.10^{-1}$(2.6)	$2.62.10^{-1}$(2.0)	$2.65.10^{-1}$(1.7)	$\underline{2.69.10^{-1}}$(1.4)	
			2112.2	$4.16.10^{-1}$(1.5) $4.19.10^{-1}$(3.0)	$4.28.10^{-1}$(1.4) $4.34.10^{-1}$(1.8)	$4.18.10^{-1}$(0.5)	$4.06.10^{-1}$(0.6)	$\underline{4.18.10^{-1}}$(1.2)	
Sn	KFKI : Sn wire 0.25 mm diam., and Sn foil 40 µm INW : 1) Sn foil 1 mm 2) Sn (in HF + fuming HNO_3) on W 41; 5.7 mg (CH 3), 15 mg (CH 15); pellet 10 mm diam. x 4 mm RISØ : Sn foil 25 µm	^{113m}Sn —I.T., F_2=0.911→ ^{113}Sn —E.C., F_3=1→ ^{113m}In (V/c)	391.7	$5.88.10^{-5}$(0.5) $5.81.10^{-5}$(0.9)	$5.92.10^{-5}$(2.0) $5.90.10^{-5}$(0.8)	$5.97.10^{-5}$(3.4) $6.22.10^{-5}$(0.3)	$6.06.10^{-5}$(0.8) $6.06.10^{-5}$(0.8) $6.04.10^{-5}$(0.9) (RISØ)	$\underline{5.99.10^{-5}}$(0.8)	KFKI, INW : corrected for gamma-attenuation INW : corrected for G_e INW : internal compar. ^{65}Zn
(cont'd)	INW, RISØ : Sn foil 25 µm	^{117m}Sn (I)	158.5	- $1.37.10^{-5}$(1.0)* (RISØ)	-	-	$1.31.10^{-5}$(1.6)* $1.37.10^{-5}$(1.2)* $1.36.10^{-5}$(5.8)*	$\underline{1.35.10^{-5}}$(1.1)	E_{eff} : 156.0 & 158.6 * Cd-subtr.method NOT SUITED FOR COMPARATOR-TYPE NAA DUE TO STRONG $^{117}Sn(n,n')$ ^{117m}Sn INTERFERENCE

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Sn (cont'd)	KFKI : Sn foil 40 μm INW : 1) Sn foil 1 mm 2) Sn (in HF + fuming HNO_3) on W 41; 5.7 mg (CH 9), 15 mg (CH 8); pellet 10 mm diam. x 4 mm RISØ : Sn foil 25 μm	^{123m}Sn (I)	160.3	$1.03.10^{-4}$(1.4) $1.01.10^{-4}$(0.5)	$1.04.10^{-4}$(0.9) $1.02.10^{-4}$(1.2) $1.02.10^{-4}$(1.4)* (RISØ)	$9.94.10^{-5}$(0.8) $9.88.10^{-5}$(2.0)* $1.02.10^{-4}$(1.1)*	$1.01.10^{-4}$(1.1) $1.02.10^{-4}$(1.0)* $1.04.10^{-4}$(1.1)*	$\underline{1.02.10^{-4}}$(0.5)	INW : internal compar. ^{65}Zn corrected for slight interference $^{124}Sn(n,2n)^{123m}Sn$ * Cd-subtr.method
	KFKI : Sn foil 40 μm INW : ultrapure Sn (in HF + few drops fuming HNO_3) on W 41; 5.7 mg (CH 9), 15 mg (CH 8); pellet 10 mm diam. x 4 mm RISØ : Sn foil 25 μm	^{125m}Sn (I)	331.9	$1.17.10^{-4}$(1.2)	$1.13.10^{-4}$(1.1)	$1.14.10^{-4}$(0.4)	$1.26.10^{-4}$(1.2) $1.21.10^{-4}$(1.4)* (RISØ)	$\underline{1.18.10^{-4}}$(2.0)	INW : internal compar. ^{65}Zn * Cd-subtr.method
		^{125}Sn (I)	332.1	-	-	-	-	$(5.40.10^{-8})$	
							$5.40.10^{-8}$(17.) (RISØ)		
			822.5	-	-	-	-	$(1.98.10^{-7})$	
							$1.98.10^{-7}$(7.6) (RISØ)		
			1067.1	-	-	-	-	$(4.37.10^{-7})$	
							$4.37.10^{-7}$(2.9) (RISØ)		
			1088.9	-	-	-	-	$(2.48.10^{-7})$	E_{eff} of 1087.1 & 1089.2
							$2.48.10^{-7}$(11.) (RISØ)		
		^{125}Sb (VII/b)	176.3	-	-	-	-	$(2.47.10^{-7})$	
							$2.47.10^{-7}$(1.8) (RISØ)		

(β^-, $F_{24}=1$; β^-, $F_3=1$)

(cont'd)

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Sn (cont'd)			427.9	-	-	-	-	$(1.23.10^{-6})$	
							$1.23.10^{-6}$(0.7) (RISØ)		
			463.4	-	-	-	-	$(4.43.10^{-7})$	
							$4.43.10^{-7}$(2.9) (RISØ)		
			600.6	-	-	-	-	$(7.05.10^{-7})$	
							$7.05.10^{-7}$(2.0) (RISØ)		
			606.6	-	-	-	-	$(1.71.10^{-7})$	
							$1.71.10^{-7}$(5.1) (RISØ)		
			635.9	-	-	-	-	$(4.91.10^{-7})$	
							$4.91.10^{-7}$(0.3) (RISØ)		
Sb (cont'd)	KFKI : 1) Al~108ppm Sb wire; 0.5 mm diam. 2) Al~0.49% Sb wire; 0.5 mm diam. INW : 1) Al~0.494% Sb wire; 1 mm diam. 2) Sb (in HNO_3 + tartaric acid) on W 41; 2 mg (CH 3), 5 mg (CH 15); pellet 10 mm diam. x 4 mm	^{122m}Sb → (I.T., F_2=1) ^{122}Sb (IV/b)	564.1	$4.40.10^{-2}$(1.0)	$4.46.10^{-2}$(1.4)	$4.28.10^{-2}$(1.7)	$4.23.10^{-2}$(1.6)	$\underline{4.38.10^{-2}}$(1.5)	INW : internal compar. ^{65}Zn
				$4.48.10^{-2}$(2.6)	$4.56.10^{-2}$(5.5)	$4.43.10^{-2}$(0.1)	$4.19.10^{-2}$(0.4)		
			692.8	$2.37.10^{-3}$(2.2)	$2.50.10^{-3}$(0.4)	$2.36.10^{-3}$(2.6)	$2.28.10^{-3}$(1.7)	$\underline{2.38.10^{-3}}$(2.0)	
				$2.43.10^{-3}$(3.3)	$2.47.10^{-3}$(3.5)	$2.35.10^{-3}$(0.3)	$2.24.10^{-3}$(0.3)		

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Sb (cont'd)		$^{124m_2}Sb$ → (I.T., F_2=1) $^{124m_1}Sb$ → (I.T., F_3=0.75) ^{124}Sb (VI)	602.7	$2.94.10^{-2}$(0.8)	$3.00.10^{-2}$(1.2)	$2.93.10^{-2}$(0.5)	$2.97.10^{-2}$(1.3)	$\underline{2.96.10^{-2}}$(0.6)	INW : internal compar.: ^{65}Zn
				$2.97.10^{-2}$(2.0)	$2.92.10^{-2}$(2.1)	$3.07.10^{-2}$(0.1)	$2.86.10^{-2}$(0.5)		
			645.9	-	-	$2.18.10^{-3}$(0.7)	$2.18.10^{-3}$(2.4)	$\underline{2.21.10^{-3}}$(0.7)	
				$2.22.10^{-3}$(2.6)	$2.20.10^{-3}$(3.2)	$2.31.10^{-3}$(0.2)	$2.17.10^{-3}$(0.4)		
			722.8	-	-	$3.00.10^{-3}$(2.8)	$3.29.10^{-3}$(0.6)	$\underline{3.19.10^{-3}}$(0.8)	
				$3.26.10^{-3}$(2.6)	$3.15.10^{-3}$(1.1)	$3.34.10^{-3}$(0.3)	$3.07.10^{-3}$(2.0)		
			1691.0	-	-	$1.40.10^{-2}$(0.3)	$1.42.10^{-2}$(0.8)	$\underline{1.41.10^{-2}}$(1.1)	
				$1.41.10^{-2}$(2.3)	$1.36.10^{-2}$(2.1)	$1.47.10^{-2}$(0.1)	$1.41.10^{-2}$(0.5)		
			2090.9	-	-	$1.64.10^{-3}$(0.3)	$1.66.10^{-3}$(2.5)	$\underline{1.58.10^{-3}}$(2.0)	
				$1.57.10^{-3}$(2.4)	$1.50.10^{-3}$(2.3)	$1.66.10^{-3}$(0.5)	$1.57.10^{-3}$(0.7)		
I	KFKI : 1) 43 µg $KH(IO_3)_2$ (in H_2O) on W 41; pellet 5 mm diam. x 3 mm 2) 18 µg KI (in H_2O) on W 41; pellet 5 mm diam. x 3 mm INW : 240 µg KIO_3 (in H_2O) on W 41; pellet 10 mm diam. x 4 mm	^{128}I (I)	442.9	$1.11.10^{-2}$(2.0)	$1.17.10^{-2}$(1.5)	$1.09.10^{-2}$(1.0)	$1.08.10^{-2}$(2.1)	$\underline{1.12.10^{-2}}$(1.7)	
				$1.17.10^{-2}$(1.0)					
			526.6	$1.03.10^{-3}$(1.1)	$1.12.10^{-3}$(1.8)	$1.06.10^{-3}$(0.5)	$1.08.10^{-3}$(0.8)	$\underline{1.07.10^{-3}}$(1.4)	
				$1.07.10^{-3}$(1.8)					
Cs (cont'd)	KFKI : 20 µg $CsNO_3$ (in H_2O) on Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : CsCl (in H_2O) on W 41; 0.7 mg (CH 3), 1.7 mg (CH 15); pellet 10 mm diam. x 4 mm	^{134m}Cs (I) → (I.T., F_2=1) ^{134}Cs (IV/b)	127.5	$5.47.10^{-3}$(1.3)	$5.54.10^{-3}$(1.3)	$5.69.10^{-3}$(0.6)	$5.23.10^{-3}$(1.0)	$\underline{5.48.10^{-3}}$(1.7)	INW : internal compar. ^{69m}Zn
			563.2	$4.22.10^{-2}$(2.6)	$4.09.10^{-2}$(3.2)	$4.26.10^{-2}$(0.6)	$3.99.10^{-2}$(1.3)	$\underline{4.14.10^{-2}}$(1.7)	
			569.3	$7.41.10^{-2}$(0.9)	$7.36.10^{-2}$(1.8)	$7.51.10^{-2}$(0.5)	$7.07.10^{-2}$(0.2)	$\underline{7.34.10^{-2}}$(1.5)	

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Cs (cont'd)			604.7	$4.81.10^{-1}$(1.0)	$4.75.10^{-1}$(2.1)	$4.93.10^{-1}$(0.3)	$4.53.10^{-1}$(0.2)	$\underline{4.76.10^{-1}}$(2.0)	
			795.8	$4.21.10^{-1}$(0.7)	$4.18.10^{-1}$(1.8)	$4.26.10^{-1}$(0.4)	$3.93.10^{-1}$(0.2)	$\underline{4.15.10^{-1}}$(2.0)	
			801.9	$4.16.10^{-2}$(2.0)	$4.10.10^{-2}$(2.7)	$4.27.10^{-2}$(1.9)	$3.91.10^{-2}$(0.6)	$\underline{4.11.10^{-2}}$(2.0)	
Ba	KFKI : ∿ 3.5 mg $Ba(NO_3)_2$ packed in Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : $BaCO_3$ (in HNO_3) on W 41; 6 mg (CH 3), 12 mg (CH 15); pellet 10 mm diam. x 4 mm	^{131m}Ba → I.T. F_2=1 → ^{131}Ba (IV/b)	123.8	$4.13.10^{-5}$(0.7)	$4.16.10^{-5}$(1.1)	$4.25.10^{-5}$(1.0)	$3.99.10^{-5}$(0.9)	$\underline{4.13.10^{-5}}$(1.3)	INW : internal compar.: ^{69m}Zn and ^{65}Zn
			133.6	$3.14.10^{-6}$(1.0)	$3.34.10^{-6}$(0.7)	-	-	($3.24.10^{-6}$)	
			216.1	$2.88.10^{-5}$(1.0)	$2.90.10^{-5}$(1.3)	$3.00.10^{-5}$(0.6)	$2.87.10^{-5}$(0.6)	$\underline{2.91.10^{-5}}$(1.0)	
			373.2	$2.04.10^{-5}$(0.7)	$2.07.10^{-5}$(1.3)	$2.07.10^{-5}$(0.8)	$1.94.10^{-5}$(1.4)	$\underline{2.03.10^{-5}}$(1.5)	
			486.5	$3.46.10^{-6}$(1.2)	$3.41.10^{-6}$(1.0)	-	-	($3.44.10^{-6}$)	
			496.3	$6.96.10^{-5}$(1.7)	$7.01.10^{-5}$(1.3)	$6.80.10^{-5}$(0.3)	$6.58.10^{-5}$(0.8)	$\underline{6.84.10^{-5}}$(1.4)	
			620.1	$2.26.10^{-6}$(2.2)	$2.41.10^{-6}$(2.6)	-	-	($2.34.10^{-6}$)	
		^{133m}Ba (I)	276.1	-	-	$2.28.10^{-6}$(0.8)	$2.27.10^{-6}$(1.0)	($2.27.10^{-6}$)	
	KFKI : 50 µg $Ba(NO_3)_2$ (in H_2O) on Al-foil; pellet 6.4 mm diam. x 0.4 mm INW : 4 mg $BaCO_3$ powder in polythene vial	^{139}Ba (I)	165.9	$1.04.10^{-3}$(1.6)	$1.06.10^{-3}$(1.5)	$1.04.10^{-3}$(1.1)	$1.07.10^{-3}$(1.2)	$\underline{1.05.10^{-3}}$(0.7)	
La	KFKI : Al-1% La wire, 0.2 mm diam. INW : 200 µg La (in HNO_3) on W 41; pellet 10 mm diam. x 4 mm	^{140}La (I)	328.8	$2.86.10^{-2}$(1.0)	$2.79.10^{-2}$(0.7)	$2.92.10^{-2}$(4.0)	$2.91.10^{-2}$(0.5)	$\underline{2.87.10^{-2}}$(1.0)	
			487.0	$6.32.10^{-2}$(0.6)	$6.39.10^{-2}$(0.7)	$6.24.10^{-2}$(1.9)	$6.52.10^{-2}$(1.6)	$\underline{6.37.10^{-2}}$(0.9)	
			815.8	$3.28.10^{-2}$(2.0)	$3.30.10^{-2}$(1.5)	$3.31.10^{-2}$(0.6)	$3.37.10^{-2}$(0.2)	$\underline{3.32.10^{-2}}$(0.6)	
			1596.5	$1.36.10^{-1}$(0.8)	$1.37.10^{-1}$(0.6)	$1.34.10^{-1}$(2.2)	$1.30.10^{-1}$(0.9)	$\underline{1.34.10^{-1}}$(1.1)	
Ce (cont'd)	KFKI : 1 mg CeO_2 (in HNO_3 + H_2O_2) on Al-foil; pellet 6.4 mm diam. x 0.2 mm	^{141}Ce (I)	145.4	$3.75.10^{-3}$(2.1)	$3.63.10^{-3}$(1.3)	$3.67.10^{-3}$(0.8)	$3.60.10^{-3}$(0.9)	$\underline{3.66.10^{-3}}$(0.9)	INW : internal compar. ^{69m}Zn

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, % KFKI "WWR-M"		Measured $k_{0,Au}$ and relative error, % INW "THETIS"		Recommended or (tentative) $k_{0;Au}$ (relat. err., %) [experimental]	NOTES
Ce (cont'd)	INW : $Ce(SO_4)_2.4H_2O$ (standardized) on W 41; 0.7 mg (CH 3), 1.5 mg (CH 15); pellet 10 mm diam. x 4 mm	^{143}Ce (I)	231.6	$3.43.10^{-5}$(2.8)	$3.46.10^{-5}$(0.9)	$3.31.10^{-5}$(0.5)	$3.26.10^{-5}$(3.2)	$\underline{3.37.10^{-5}}$(1.4)	INW : internal compar. ^{69m}Zn
			293.3	$6.99.10^{-4}$(2.2)	$6.83.10^{-4}$(0.8)	$6.84.10^{-4}$(1.3)	$6.88.10^{-4}$(2.1)	$\underline{6.89.10^{-4}}$(0.5)	
			350.6	$5.18.10^{-5}$(2.0)	$5.07.10^{-5}$(2.9)	$5.12.10^{-5}$(2.3)	$5.18.10^{-5}$(0.6)	$\underline{5.14.10^{-5}}$(0.5)	
			664.5	$9.52.10^{-5}$(2.2)	$9.18.10^{-5}$(2.1)	$9.15.10^{-5}$(0.6)	$8.86.10^{-5}$(3.7)	$\underline{9.18.10^{-5}}$(1.5)	
			722.0	$8.95.10^{-5}$(4.0)	$8.78.10^{-5}$(2.2)	$8.80.10^{-5}$(1.5)	$8.58.10^{-5}$(2.1)	$\underline{8.78.10^{-5}}$(0.9)	
Pr	KFKI : 1) Al-1.25% Pr wire; 1 mm diam. 2) Al-1.25% Pr wire; 0.5 mm diam. INW : Pr_6O_{11} (ignited at 900°C) (in HNO_3) on W 41; 1 mg (CH 3), 2.5 mg (CH 15); pellet 10 mm diam. x 4 mm	^{142m}Pr I.T. $F_2=1$ ^{142}Pr (IV/b)	1575.6	$6.23.10^{-3}$(1.3) $6.15.10^{-3}$(1.6)	$6.15.10^{-3}$(0.9) $6.23.10^{-3}$(1.6)	$6.04.10^{-3}$(0.3)	$6.07.10^{-3}$(0.7)	$\underline{6.12.10^{-3}}$(0.6)	INW : internal compar. ^{69m}Zn ≳ 0.4% error when applying reaction/decay type IV/b
Nd	KFKI : Nd_2O_3 (in HNO_3); 237 µg Nd on Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : 1) Nd_2O_3 (ignited at 900°C) (in HNO_3) on W 41; 6.5 mg Nd (CH 3), 16 mg Nd (CH 15); pellet 10 mm diam. x 4 mm 2) $^{146}Nd_2O_3$ (97.63% ^{146}Nd enrich.)(ign. at 900°C) (in HNO_3) on W 41; 0.9 mg Nd (CH 2 and CH 10); pellet 6 mm diam. x 2 mm	^{147}Nd (I)	91.1	$9.90.10^{-4}$(1.0)	$9.71.10^{-4}$(0.9)	$1.01.10^{-3}$(0.7)	$9.60.10^{-4}$(1.3)	$\underline{1.02.10^{-3}}$(2.5)	INW : internal compar. 1) ^{69m}Zn 2) ^{65}Zn * Cd subtraction method IN PRACTICE, MANY SPECTRAL INTERFERENCES WITH OTHER Nd-ISOTOPES AND DAUGHTERS OCCUR; IT IS POSSIBLE TO WAIT FOR THEIR DECAY, SINCE T (^{147}Nd) = 10.98d
						$1.10.10^{-3}$(1.7)*	$1.10.10^{-3}$(1.8)*		
			120.5	$1.30.10^{-5}$(1.2)	$1.26.10^{-5}$(2.0)	-	-	($1.28.10^{-5}$)	
			275.4	$3.00.10^{-5}$(1.5)	$3.07.10^{-5}$(2.7)	$2.81.10^{-5}$(0.4)	$2.76.10^{-5}$(0.5)	$\underline{2.86.10^{-5}}$(2.0)	
						$2.74.10^{-5}$(2.1)*	$2.77.10^{-5}$(2.9)*		
			319.4	$6.86.10^{-5}$(1.3)	$6.63.10^{-5}$(1.6)	$6.94.10^{-5}$(1.9)	$6.62.10^{-5}$(0.7)	$\underline{6.78.10^{-5}}$(0.9)	
						$6.72.10^{-5}$(1.0)*	$6.92.10^{-5}$(1.3)*		
			398.2	$2.89.10^{-5}$(1.4)	$2.91.10^{-5}$(2.2)	-	-	($2.90.10^{-5}$)	
			439.9	$4.10.10^{-5}$(1.1)	$4.09.10^{-5}$(2.9)	$4.34.10^{-5}$(1.9)	$4.30.10^{-5}$(1.8)	$\underline{4.22.10^{-5}}$(1.4)	
						$4.40.10^{-5}$(1.9)*	$4.08.10^{-5}$(2.7)*		
			531.0	$4.50.10^{-4}$(1.0)	$4.44.10^{-4}$(1.3)	$4.73.10^{-4}$(0.8)	$4.44.10^{-4}$(0.8)	$\underline{4.56.10^{-4}}$(1.1)	
						$4.60.10^{-4}$(0.1)*	$4.64.10^{-4}$(0.8)*		
			685.9	$2.75.10^{-5}$(0.8)	$2.60.10^{-5}$(3.4)	-	-	($2.68.10^{-5}$)	
(cont'd)	KFKI : as for ^{147}Nd	^{149}Nd (I)	97.0	-	-	-	-	($3.32.10^{-5}$)	E_{eff} of 96.9 & 97.0
						$3.23.10^{-5}$(2.2)*	$3.40.10^{-5}$(3.3)*		
			114.3	-	-	$4.16.10^{-4}$(1.7)	-	($4.05.10^{-4}$)	
						$3.97.10^{-4}$(1.3)*	$4.03.10^{-4}$(3.2)*		
		β^- $F_2=1$	155.9	-	-	$1.29.10^{-4}$(2.2)	$1.15.10^{-4}$(1.2)	($1.22.10^{-4}$)	E_{eff} of 155.1 & 155.9
						$1.19.10^{-4}$(0.6)*	$1.25.10^{-4}$(1.8)*		

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Nd (cont'd)	INW : 1) as for ^{147}Nd 2) Nd_2O_3 (87.90% ^{148}Nd enrichm.) (ign. at 900°C)(in HNO_3) on W 41; 90 µg Nd (CH 3), 550 µg Nd (CH 15); pellet 6 mm diam. x 2 mm	β^-, F_2=1	198.9	-	-	-	-	($2.98.10^{-5}$)	E_{eff} of 197.8 & 198.9
						$2.91.10^{-5}$(2.4)*	$3.04.10^{-5}$(1.7)*		
			208.1	-	-	-	-	($5.71.10^{-5}$)	INW : internal compar. 1) ^{69m}Zn; 2) ^{56}Mn
						$5.53.10^{-5}$(1.4)*	$5.88.10^{-5}$(3.7)*		
			211.3	-	-	-	-	($5.26.10^{-4}$)	* Cd subtraction method
						$5.18.10^{-4}$(0.8)*	$5.34.10^{-4}$(1.4)*		
			240.2	-	-	-	-	($7.72.10^{-5}$)	IN PRACTICE, MANY SPECTRAL INTERFERENCES OCCUR WITH OTHER Nd-ISOTOPES AND DAUGHTERS NOTABLY WITH ^{151}Nd, FOR WHICH IT IS POSSIBLE TO WAIT FOR DECAY
						$7.61.10^{-5}$(0.7)*	$7.82.10^{-5}$(0.4)*		
			267.7	-	-	-	-	($1.16.10^{-4}$)	
						$1.16.10^{-4}$(1.4)*	$1.17.10^{-4}$(1.6)*		
			270.2	-	-	-	-	($2.12.10^{-4}$)	
						$2.04.10^{-4}$(0.4)*	$2.20.10^{-4}$(0.9)*		
			326.6	-	-	-	$9.19.10^{-5}$(1.8)	($9.10.10^{-5}$)	
						$8.96.10^{-5}$(1.0)*	$9.14.10^{-5}$(0.9)*		
			349.1	-	-	-	-	($2.96.10^{-5}$)	E_{eff} of 347.8 & 349.2
						$3.09.10^{-5}$(1.4)*	$2.82.10^{-5}$(0.8)*		
			423.6	-	-	$1.68.10^{-4}$(2.0)	$1.58.10^{-4}$(0.7)	($1.60.10^{-4}$)	E_{eff} of 423.6 & 425.2
						$1.55.10^{-4}$(1.0)*	$1.60.10^{-4}$(3.4)*		
			540.5	-	-	-	$1.34.10^{-4}$(1.1)	($1.35.10^{-4}$)	
						$1.38.10^{-4}$(0.8)*	$1.33.10^{-4}$(0.6)*		
			654.8	-	-	-	$1.66.10^{-4}$(0.7)	($1.66.10^{-4}$)	
						$1.68.10^{-4}$(0.7)*	$1.63.10^{-4}$(1.2)*		
		^{149}Pm (II/a)	285.9	$6.25.10^{-5}$(1.4)	$6.04.10^{-5}$(2.3)	$6.32.10^{-5}$(1.3)	$6.00.10^{-5}$(0.4)	$\underline{6.10.10^{-5}}$(1.1)	
						$5.86.10^{-5}$(3.1)*	$6.11.10^{-5}$(1.7)*		
	INW : 1) Nd_2O_3 (ign. at 900°C)(in dil. HNO_3) on W 41; 5 µg Nd (CH 9); pellet 10 mm diam. x 4 mm 2) Nd_2O_3 (^{150}Nd enrichm. = 96.13%)(ign. at 900°C)(in dil. HNO_3) on W 41; 14 µg Nd (CH 17), 28 µg Nd (CH 9); pellet 10 mm diam. x 4 mm	^{151}Nd (I)	255.6	-	-	-	$1.33.10^{-4}$(0.1)	($1.31.10^{-4}$)	internal compar. : 1) ^{66}Cu 2) ^{52}V
						$1.32.10^{-4}$(0.5)	$1.29.10^{-4}$(0.3)		
						$1.34.10^{-4}$(1.8)*	$1.29.10^{-4}$(0.6)*		
		β^-, F_2=1	1180.6	-	-	-	$1.11.10^{-4}$(0.5)	($1.09.10^{-4}$)	* Cd-subtr.method
						$1.10.10^{-4}$(0.4)	$1.09.10^{-4}$(0.3)		
						$1.10.10^{-4}$(1.7)*	$1.07.10^{-4}$(1.2)*		
		^{151}Pm (II/a)	340.1	-	-	-	-	($1.73.10^{-4}$)	255.6 keV-LINE INTERFERED BY ^{149}Nd, ^{151}Pm AND ^{149}Pm; INTERFERENCE NEGLIGIBLE FOR SHORT t_d
						$1.75.10^{-4}$(0.9)	$1.71.10^{-4}$(0.4)		
						$1.76.10^{-4}$(2.1)*	$1.70.10^{-4}$(0.9)*		

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Sm	KFKI : 1) Al-561 ppm Sm wire; 1 mm diam. 2) Al-80 ppm Sm wire; 0.2 mm diam.	^{153}Sm (I)	69.7	$3.48.10^{-2}$(2.2) $3.64.10^{-2}$(1.8)	$3.60.10^{-2}$(2.1) $3.67.10^{-2}$(1.6)	-	-	$(3.60.10^{-2})$	INW : internal compar. 1) ^{69m}Zn 2) ^{66}Cu
			103.2	$2.32.10^{-1}$(1.5) $2.36.10^{-1}$(1.1)	$2.30.10^{-1}$(1.2) $2.33.10^{-1}$(0.7)	$2.29.10^{-1}$(1.5) $2.29.10^{-1}$(1.4)	$2.31.10^{-1}$(1.2) $2.31.10^{-1}$(2.3)	$\underline{2.31.10^{-1}}$(0.4)	
	INW : Sm_2O_3 (ignited at 900°C) (in HNO_3) on W 41; 75 µg (CH 3), 185 µg (CH 15); pellet 10 mm diam. x 4 mm	^{155}Sm (I)	141.2	$4.97.10^{-4}$(2.8)	$4.66.10^{-4}$(2.7)	$4.84.10^{-4}$(1.0)	$4.84.10^{-4}$(2.6)	$\underline{4.83.10^{-4}}$(1.3)	INW : internal compar. ^{66}Cu
			246.0	$9.23.10^{-4}$(3.2)	$9.23.10^{-4}$(5.1)	$8.71.10^{-4}$(3.8)	$9.04.10^{-4}$(1.7)	$\underline{9.05.10^{-4}}$(1.4)	
Eu	KFKI : Al-560 ppm Eu wire; 1 mm diam.	^{154m}Eu							INW : internal compar. 1) ^{65}Zn 2) ^{60}Co 3) ^{60}Co
	INW : 1) Eu_2O_3 (ignited at 900°C) (in HNO_3) on W 41; 0.1 mg (CH 3), 0.1 mg (CH 15); pellet 10 mm diam. x 4 mm	I.T. F_2=1 ^{154}Eu (IV/b)	248.0	$1.52.10^{-1}$(2.6)	$1.53.10^{-1}$(3.2)	$1.51.10^{-1}$(1.3) $1.74.10^{-1}$(6.1) $1.63.10^{-1}$(0.9)	$1.40.10^{-1}$(2.7)	$(1.55.10^{-1})$	All values are related to T (^{154}Eu) = 8.561 y
	2) Eu_2O_3 (ignited at 900°C) (in HNO_3) on W 41; 50 µg Eu (CH 3; CH 5; CH 11); pellet 10 mm diam. x 2 mm		591.8	$1.07.10^{-1}$(3.9)	$1.11.10^{-1}$(4.4)	$1.07.10^{-1}$(0.3) - $1.02.10^{-1}$(0.9)	$1.11.10^{-1}$(1.8)	$\underline{1.08.10^{-1}}$(1.5)	
	3) Eu_2O_3 (ignited at 900°C) (in HNO_3) on W 41; 500 µg Eu (CH 11); pellet 10 mm diam. x 4 mm		723.3	$4.51.10^{-1}$(2.4)	$4.51.10^{-1}$(3.1)	$4.68.10^{-1}$(1.5) $4.21.10^{-1}$(3.3) $4.34.10^{-1}$(0.6)	$4.48.10^{-1}$(0.8)	$\underline{4.46.10^{-1}}$(1.5)	
			756.9	-	-	$1.09.10^{-1}$(3.2) - $1.06.10^{-1}$(1.4)	$1.10.10^{-1}$(1.0)	$(1.08.10^{-1})$	
			873.2	$2.79.10^{-1}$(1.9)	$2.80.10^{-1}$(2.2)	$2.81.10^{-1}$(1.6) $2.58.10^{-1}$(2.0) $2.67.10^{-1}$(2.7)	$2.68.10^{-1}$(0.8)	$\underline{2.72.10^{-1}}$(1.4)	
			996.4	-	-	$2.38.10^{-1}$(2.7) $2.15.10^{-1}$(2.6) $2.26.10^{-1}$(0.9)	$2.41.10^{-1}$(2.8)	$(2.30.10^{-1})$	
			1274.4	$7.87.10^{-1}$(2.7)	$7.94.10^{-1}$(2.3)	$7.80.10^{-1}$(0.4) $7.42.10^{-1}$(1.6) $7.61.10^{-1}$(0.4)	$7.98.10^{-1}$(0.8)	$\underline{7.77.10^{-1}}$(1.1)	

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Gd	INW : $^{158}Gd_2O_3$ (81.00% ^{158}Gd enrichm.)(ign. at 900°C)(in dil. HNO_3) on W 41; 3 µg Gd (CH 3; CH 12); pellet 6 mm diam. x 2 mm	^{159}Gd (I)	363.6	-	-	$8.24.10^{-4}$(0.5) $8.03.10^{-4}$(2.5)*	$8.40.10^{-4}$(1.3) $8.46.10^{-4}$(3.0)*	($8.28.10^{-4}$)	internal compar. : ^{69m}Zn * Cd subtr.method
	INW : $^{160}Gd_2O_3$ (98.71% ^{160}Gd enrichm.)(ign. at 900°C)(in dil. HNO_3) on W 41; 11 µg Gd (CH 17), 21 µg Gd (CH 9); pellet 6 mm diam. x 2 mm	^{161}Gd (I)	102.3	-	-	$7.91.10^{-4}$(0.5) $8.16.10^{-4}$(1.3)*	$7.66.10^{-4}$(1.0) $7.79.10^{-4}$(1.3)*	($7.88.10^{-4}$)	internal compar. : ^{52}V
			165.2	-	-	$1.02.10^{-4}$(6.9) $1.05.10^{-4}$(9.3)*	$1.10.10^{-4}$(8.4) $1.09.10^{-4}$(10.4)*	($1.07.10^{-4}$)	* Cd subtr.method
			283.6	-	-	$2.72.10^{-4}$(2.1) $2.69.10^{-4}$(2.9)*	$2.97.10^{-4}$(1.2) $2.98.10^{-4}$(1.5)*	($2.84.10^{-4}$)	
			314.9	-	-	$1.02.10^{-3}$(0.3) $1.03.10^{-3}$(1.1)*	$1.03.10^{-3}$(1.0) $1.03.10^{-3}$(1.2)*	($1.03.10^{-3}$)	
			360.9	-	-	$2.70.10^{-3}$(0.6) $2.72.10^{-3}$(1.3)*	$2.72.10^{-3}$(0.1) $2.72.10^{-3}$(1.2)*	($2.72.10^{-3}$)	
			480.1	-	-	$1.05.10^{-4}$(3.3) $1.01.10^{-4}$(5.3)*	$1.06.10^{-4}$(8.2) $1.02.10^{-4}$(10.4)*	($1.04.10^{-4}$)	
Tb	KFKI : 1) 5 µg Tb_4O_7 (in HNO_3 + H_2O_2) on Al-foil; pellet 6.4 mm diam. x 0.2 mm 2) Al-0.2% Tb wire; 0.2 mm diam. INW : Tb_4O_7 (ign. at 900°C)(in HCl) on W 41; 6 mg (CH 3), 12 mg (CH 15); pellet 10 mm diam. x 4 mm	^{160}Tb (I)	86.8	$4.09.10^{-2}$(1.0) $4.21.10^{-2}$(0.8)	$4.16.10^{-2}$(0.9) $4.22.10^{-2}$(0.6)	$4.33.10^{-2}$(0.6)	$4.13.10^{-2}$(1.8)	$\underline{4.20.10^{-2}}$(1.1)	INW : internal compar. ^{51}Cr
			197.0	$1.54.10^{-2}$(0.7) $1.66.10^{-2}$(1.2)	$1.59.10^{-2}$(0.9) $1.67.10^{-2}$(1.1)	$1.62.10^{-2}$(0.3)	$1.64.10^{-2}$(1.8)	$\underline{1.62.10^{-2}}$(0.5)	
			215.6	$1.23.10^{-2}$(1.0) $1.29.10^{-2}$(1.2)	$1.24.10^{-2}$(1.4) $1.30.10^{-2}$(0.7)	$1.26.10^{-2}$(0.3)	$1.28.10^{-2}$(2.1)	$\underline{1.27.10^{-2}}$(0.4)	
			298.6	$7.78.10^{-2}$(1.1) $8.58.10^{-2}$(0.9)	$7.95.10^{-2}$(1.5) $8.68.10^{-2}$(0.9)	$8.02.10^{-2}$(0.6)	$8.49.10^{-2}$(2.1)	$\underline{8.25.10^{-2}}$(1.2)	
			879.4	$9.09.10^{-2}$(1.4) $9.65.10^{-2}$(1.1)	$9.21.10^{-2}$(1.4) $9.78.10^{-2}$(0.6)	$9.21.10^{-2}$(0.2)	$9.61.10^{-2}$(1.9)	$\underline{9.42.10^{-2}}$(0.9)	
			962.3	$2.95.10^{-2}$(2.0) $3.08.10^{-2}$(0.8)	$3.02.10^{-2}$(0.9) $3.14.10^{-2}$(0.6)	-	-	($3.05.10^{-2}$)	
			965.1	$1.05.10^{-1}$(2.0) $1.11.10^{-1}$(0.8)	$1.07.10^{-1}$(0.9) $1.13.10^{-1}$(0.7)	$1.04.10^{-1}$(0.2)	$1.11.10^{-1}$(2.0)	$\underline{1.08.10^{-1}}$(1.4)	E_{eff} : 962.3 & 966.2
			966.2	$7.56.10^{-2}$(1.4) $8.03.10^{-2}$(0.8)	$7.65.10^{-2}$(0.9) $8.13.10^{-2}$(0.7)	-	-	($7.84.10^{-2}$)	
			1178.0	$4.56.10^{-2}$(0.3) $4.86.10^{-2}$(1.2)	$4.68.10^{-2}$(1.4) $4.88.10^{-2}$(0.5)	$4.57.10^{-2}$(0.3)	$4.79.10^{-2}$(1.8)	$\underline{4.71.10^{-2}}$(1.1)	

(cont'd)

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Tb (cont'd)			1199.9	$7.34.10^{-3}$(1.8) $7.70.10^{-3}$(2.3)	$7.71.10^{-3}$(3.4) $7.81.10^{-3}$(2.0)	$7.27.10^{-3}$(0.2)	$7.56.10^{-3}$(1.8)	$\underline{7.53.10^{-3}}$(1.3)	
			1271.9	$2.25.10^{-2}$(1.1) $2.43.10^{-2}$(1.7)	$2.31.10^{-2}$(1.3) $2.39.10^{-2}$(1.6)	$2.30.10^{-2}$(0.4)	$2.39.10^{-2}$(2.1)	$\underline{2.35.10^{-2}}$(0.8)	
			1312.1	$8.48.10^{-3}$(1.6) $9.41.10^{-3}$(1.7)	$8.75.10^{-3}$(1.9) $9.47.10^{-3}$(1.6)	$8.78.10^{-3}$(0.4)	$9.10.10^{-3}$(1.8)	$\underline{8.98.10^{-3}}$(0.9)	
Dy	INW : Dy_2O_3 (ign. at 900°C)(in HNO_3) on W 41; 5 µg Dy (CH 9), 15 µg Dy (CH 8); pellet 10 mm diam. x 4 mm	^{165m}Dy (I)	108.2	-	-	$1.86.10^{-1}$(0.6)	$1.90.10^{-1}$(0.9)	($1.88.10^{-1}$)	INW : internal compar. ^{52}V
		L.T. F_2=0.9776	515.5	-	-	$9.17.10^{-2}$(0.6)	$9.33.10^{-2}$(1.2)	($9.25.10^{-2}$)	
	KFKI : Dy_2O_3 (in HNO_3) on Al-foil; 2.6 µg Dy; pellet 6.4 mm diam. x 0.2 mm	^{165}Dy (IV/b)	94.7	$3.72.10^{-1}$(1.2)	$3.73.10^{-1}$(1.5)	$3.47.10^{-1}$(2.3) $3.50.10^{-1}$(0.3)	$3.46.10^{-1}$(0.9) $3.55.10^{-1}$(0.1)	$\underline{3.57.10^{-1}}$(1.4)	INW : internal compar. 1) ^{88}Rb 2) ^{69m}Zn
	INW : 1) Dy_2O_3 (ign. at 900°C)(in HNO_3) on W 41; 20 µg Dy (CH 3 and CH 15); pellet 10 mm diam. x 4 mm		279.8	$4.94.10^{-2}$(1.4)	$5.00.10^{-2}$(1.8)	$4.71.10^{-2}$(1.7) $4.84.10^{-2}$(0.3)	$4.87.10^{-2}$(0.1) $4.89.10^{-2}$(0.3)	$\underline{4.88.10^{-2}}$(0.8)	
			361.7	$8.31.10^{-2}$(1.3)	$8.48.10^{-2}$(1.9)	$8.10.10^{-2}$(1.9) $8.35.10^{-2}$(0.5)	$8.47.10^{-2}$(1.2) $8.46.10^{-2}$(0.2)	$\underline{8.36.10^{-2}}$(0.7)	
			633.4	$5.74.10^{-2}$(2.4)	$5.95.10^{-2}$(1.0)	$5.46.10^{-2}$(2.2) $5.44.10^{-2}$(0.9)	$5.62.10^{-2}$(2.5) $5.49.10^{-2}$(0.5)	$\underline{5.62.10^{-2}}$(1.5)	
	2) as above : 1 µg Dy (CH 3), 3 µg Dy (CH 15)		715.3	$5.36.10^{-2}$(1.9)	$5.44.10^{-2}$(1.8)	$5.10.10^{-2}$(1.7) $5.07.10^{-2}$(0.6)	$5.26.10^{-2}$(2.8) $5.15.10^{-2}$(0.3)	$\underline{5.23.10^{-2}}$(1.2)	
Ho	KFKI : 100 µg Ho_2O_3 (in HNO_3) on Al-foil; pellet 6.4 mm diam. x 0.2 mm	^{166}Ho (I)	80.6	$5.59.10^{-2}$(2.1)	$5.60.10^{-2}$(0.4)	$5.17.10^{-2}$(1.8) $5.31.10^{-2}$(0.5)	$5.49.10^{-2}$(1.2) $5.25.10^{-2}$(1.0)	$\underline{5.45.10^{-2}}$(1.6)	INW : internal compar. ^{69m}Zn
			1379.4	$7.06.10^{-3}$(3.1)	$7.22.10^{-3}$(1.0)	$6.78.10^{-3}$(0.4) $6.64.10^{-3}$(0.5)	$6.84.10^{-3}$(1.1) $6.50.10^{-3}$(0.4)	$\underline{6.91.10^{-3}}$(1.9)	
	INW : Ho_2O_3 (ign. at 900°C)(in HNO_3) on W 41; pellet 10 mm diam. x 4 mm		1581.9	$1.45.10^{-3}$(4.0)	$1.44.10^{-3}$(0.8)	$1.34.10^{-3}$(1.3) $1.33.10^{-3}$(0.3)	$1.36.10^{-3}$(2.3) $1.29.10^{-3}$(0.4)	$\underline{1.39.10^{-3}}$(2.4)	
	1) 0.25 mg (CH 3), 0.6 mg (CH 15) 2) 0.2 mg (CH 3), 0.5 mg (CH 15)		1662.4	$8.88.10^{-4}$(4.0)	-	$8.70.10^{-4}$(2.9) $8.49.10^{-4}$(0.7)	$8.77.10^{-4}$(1.8) $8.38.10^{-4}$(0.4)	$\underline{8.68.10^{-4}}$(1.1)	

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Er	KFKI : $^{170}Er_2O_3$ (96.89% ^{170}Er enrichm.); 3.7 mg Er on Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : $^{170}Er_2O_3$ (96.89% ^{170}Er enrichm.)(ign. at 900°C)(d.in HNO_3) on W 41; 30 µg (CH 3), 90 µg (CH 15); pellet 6 mm diam. x 2 mm	^{171}Er (I)	111.6	$3.42.10^{-3}$(0.4)	$3.30.10^{-3}$(0.5)	$3.46.10^{-3}$(1.3) $3.48.10^{-3}$(1.5)*	$3.41.10^{-3}$(1.0) $3.41.10^{-3}$(1.0)*	$\underline{3.41.10^{-3}}$(0.8)	INW : internal compar. ^{69m}Zn
			116.7	$3.44.10^{-4}$(0.5)	$3.09.10^{-4}$(1.2)	$3.47.10^{-4}$(1.2) $3.48.10^{-4}$(1.4)*	$3.33.10^{-4}$(5.6) $3.32.10^{-4}$(5.9)*	$\underline{3.36.10^{-4}}$(1.8)	* Cd subtraction method
			124.0	$1.54.10^{-3}$(0.3)	$1.53.10^{-3}$(0.2)	$1.52.10^{-3}$(1.1) $1.53.10^{-3}$(1.3)*	$1.49.10^{-3}$(1.3) $1.49.10^{-3}$(1.4)*	$\underline{1.52.10^{-3}}$(0.6)	
			210.6	$1.10.10^{-4}$(2.0)	$1.07.10^{-4}$(5.0)	-	-	($1.09.10^{-4}$)	E_{eff} of 210.1 & 210.6
			237.1	$5.53.10^{-5}$(6.0)	$4.92.10^{-5}$(9.0)	-	-	($5.23.10^{-5}$)	
			295.9	$5.04.10^{-3}$(0.6)	$4.99.10^{-3}$(1.0)	$4.68.10^{-3}$(1.8) $4.69.10^{-3}$(2.0)*	$4.68.10^{-3}$(0.5) $4.66.10^{-3}$(0.5)*	$\underline{4.79.10^{-3}}$(1.5)	
			308.3	$1.09.10^{-2}$(0.4)	$1.08.10^{-2}$(0.8)	$1.02.10^{-2}$(1.0) $1.02.10^{-2}$(1.2)*	$1.01.10^{-2}$(0.9) $1.01.10^{-2}$(0.9)*	$\underline{1.04.10^{-2}}$(1.4)	
Tm	INW : Tm_2O_3 (ign. at 900°C)(in dil. HNO_3) on W 41; 86 µg Tm (CH 3), 215 µg Tm (CH 15); pellet 10 mm diam. x 4 mm	^{170}Tm (I)	84.3	-	-	$4.26.10^{-2}$(3.9)	$4.33.10^{-2}$(2.6)	($4.30.10^{-2}$)	internal compar. ^{65}Zn
Yb	KFKI : 1) 6.5 µg Yb_2O_3 (in HNO_3) on Al-foil; pellet 6.4 mm diam. x 0.2 mm 2) 5.7 µg Yb_2O_3 (in HNO_3) on Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : Yb_2O_3 (ign. at 900°C)(in HNO_3) on W 41; 0.4 mg (CH 3); 1.2 mg (CH 15); pellet 10 mm diam. x 4 mm	^{175}Yb (IV/b)	113.8	$9.67.10^{-3}$(0.7)	$9.59.10^{-3}$(0.8)	$9.16.10^{-3}$(0.5)	$9.25.10^{-3}$(0.7)	$\underline{9.42.10^{-3}}$(1.3)	INW : internal compar. ^{69m}Zn
			137.7	$5.77.10^{-4}$(2.9)	$5.67.10^{-4}$(3.0)	$5.69.10^{-4}$(0.7)	$5.61.10^{-4}$(4.3)	$\underline{5.69.10^{-4}}$(0.6)	
			144.9	$1.54.10^{-3}$(2.7) $1.58.10^{-3}$(1.2)	$1.53.10^{-3}$(1.8) $1.54.10^{-3}$(1.5)	$1.61.10^{-3}$(0.8)	$1.64.10^{-3}$(1.9)	$\underline{1.59.10^{-3}}$(1.5)	
			282.5	$1.43.10^{-2}$(2.1) $1.48.10^{-2}$(0.5)	$1.46.10^{-2}$(0.2) $1.45.10^{-2}$(0.6)	$1.45.10^{-2}$(0.6)	$1.47.10^{-2}$(0.6)	$\underline{1.46.10^{-2}}$(0.3)	
			396.3	$3.06.10^{-2}$(0.6) $3.11.10^{-2}$(0.4)	$3.13.10^{-2}$(0.3) $3.06.10^{-2}$(0.4)	$3.14.10^{-2}$(0.7)	$3.17.10^{-2}$(0.6)	$\underline{3.12.10^{-2}}$(0.6)	
(cont'd)	INW : 1) Yb_2O_3 (ign. at 900°C)(in dil. HNO_3) on W 41; 460 µg Yb (CH 3), 1.5 mg Yb (CH 15); pellet 10 mm diam. x 4 mm	^{117}Yb (IV/b)	121.6	-	-	$1.55.10^{-4}$(0.8) $1.67.10^{-4}$(0.7) $1.67.10^{-4}$(0.8)*	$1.60.10^{-4}$(1.5) $1.66.10^{-4}$(3.0) $1.67.10^{-4}$(3.1)*	($1.64.10^{-4}$)	internal compar. 1)2) ^{69m}Zn * Cd subtraction method

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Yb (cont'd)	INW : 2) $^{176}Yb_2O_3$ (96.68% ^{176}Yb enrichm.)(ign. at 900°C)(in dil. HNO_3) on W 41; 40 µg Yb (CH 3), 400 µg Yb (CH 15); pellet 6 mm diam. x 2 mm		138.6	-	-	-	-	$(6.48.10^{-5})$	* Cd-subtr.method
						$6.36.10^{-5}$(0.3)	$6.58.10^{-5}$(1.8)		
						$6.37.10^{-5}$(0.3)*	$6.60.10^{-5}$(1.8)*		
			150.4	-	-	$8.41.10^{-4}$(0.8)	$8.47.10^{-4}$(0.6)	$(8.94.10^{-4})$	
						$9.14.10^{-4}$(0.3)	$9.20.10^{-4}$(0.4)		
						$9.17.10^{-4}$(0.4)*	$9.23.10^{-4}$(0.5)*		
			899.2	-	-	-	-	$(3.12.10^{-5})$	
						$3.16.10^{-5}$(2.0)	$3.08.10^{-5}$(5.4)		
						$3.15.10^{-5}$(2.2)*	$3.09.10^{-5}$(5.5)*		
			941.7	-	-	-	-	$(4.87.10^{-5})$	
						$4.90.10^{-5}$(2.8)	$4.84.10^{-5}$(3.4)		
						$4.91.10^{-5}$(3.0)*	$4.85.10^{-5}$(3.5)*		
			1028.0	-	-	-	-	$(2.94.10^{-5})$	
						$2.95.10^{-5}$(3.9)	$2.93.10^{-5}$(3.7)		
						$2.96.10^{-5}$(4.2)*	$2.94.10^{-5}$(3.8)*		
			1080.1	-	-	$2.58.10^{-4}$(1.1)	$2.57.10^{-4}$(0.8)	$(2.68.10^{-4})$	
						$2.69.10^{-4}$(0.1)	$2.76.10^{-4}$(1.0)		
						$2.70.10^{-4}$(0.2)*	$2.76.10^{-4}$(1.1)*		
			1119.6	-	-	-	-	$(2.74.10^{-5})$	
						$2.72.10^{-5}$(5.0)	$2.78.10^{-5}$(3.1)		
						$2.70.10^{-5}$(5.5)*	$2.78.10^{-5}$(3.2)*		
			1149.7	-	-	-	-	$(2.96.10^{-5})$	
						$3.00.10^{-5}$(1.8)	$2.93.10^{-5}$(4.8)		
						$2.98.10^{-5}$(2.0)*	$2.94.10^{-5}$(4.9)*		
			1241.4	-	-	$1.57.10^{-4}$(0.6)	$1.55.10^{-4}$(0.6)	$(1.62.10^{-4})$	
						$1.63.10^{-4}$(0.7)	$1.66.10^{-4}$(2.0)		
						$1.63.10^{-4}$(0.9)*	$1.67.10^{-4}$(2.0)*		
Lu (cont'd)	KFKI : Al-0.103% Lu wire, 1 mm diam. INW : 1) Lu_2O_3 (ign. at 900°C)(in HNO_3) on W 41; 11 µg Lu (CH 3); 27 µg Lu (CH 15); pellet 10 mm diam. x 4 mm	^{176m}Lu (I)	88.4	$1.82.10^{-2}$(0.8)	$1.87.10^{-2}$(2.8)	$1.70.10^{-2}$(1.2)	$1.71.10^{-2}$(0.6)	$1.73.10^{-2}$(1.5)	INW : internal compar.: 1) ^{69m}Zn 2) ^{88}Rb
						$1.64.10^{-2}$(1.6)	$1.68.10^{-2}$(0.1)		
						$1.71.10^{-2}$(0.7)	$1.73.10^{-2}$(0.5)		

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Lu (cont'd)	INW : 2) Lu_2O_3 (ign. at 900°C)(in HNO_3) on W 41; 60 µg Lu (CH 3 and CH 15); pellet 10 mm diam. x 4 mm 3) Al- 0.103% Lu wire, 1mm diam.								
Hf	KFKI : 5.1 µg HfO_2 (in HF) on Al-foil, pellet 6.4 mm diam. x 0.2 mm INW : Hf (in HF + fuming HNO_3) on W 41; 1.4 mg (CH 3), 4 mg (CH 15); pellet 12.5 mm diam. x 2.5 mm	^{175}Hf (I)	343.6	$9.01.10^{-3}$(1.5) $9.35.10^{-3}$(1.1)	$9.23.10^{-3}$(1.1) $8.97.10^{-3}$(2.0)	$9.10.10^{-3}$(5.1)	$8.72.10^{-3}$(3.7)	$\underline{9.06.10^{-3}}$(1.0)	INW : internal compar.: ^{60}Co
	KFKI : 1) HfO_2 (dissolved in HF in teflon bomb); 6.9 µg Hf on Al-foil; pellet 6.4 mm diam. x 0.2 mm 2) Al- 0.0904% Hf wire, 1 mm diam. INW : Hf (in HF/HNO_3) on W 41; 1.4 mg Hf (CH 3); 4 mg Hf (CH 15); pellet 12.5 mm diam. x 3 mm	^{180m}Hf (I)	93.3 215.2 332.3 443.2 500.7	- $6.13.10^{-4}$(1.0) $6.12.10^{-4}$(0.9) $7.26.10^{-4}$(1.6) $6.55.10^{-4}$(5.5) $6.24.10^{-4}$(0.9) $5.55.10^{-4}$(2.5) -	- $1.24.10^{-4}$(5.1) - $5.74.10^{-4}$(1.2) - $6.48.10^{-4}$(0.6) - $5.88.10^{-4}$(1.9) - $1.04.10^{-4}$(2.0)	$1.25.10^{-4}$(0.4) $5.80.10^{-4}$(0.4) $6.71.10^{-4}$(0.1) $5.87.10^{-4}$(0.1) $1.02.10^{-4}$(0.3)	$1.23.10^{-4}$(1.4) $5.77.10^{-4}$(0.3) $6.69.10^{-4}$(0.4) $5.87.10^{-4}$(0.4) $1.01.10^{-4}$(0.7)	$\underline{1.24.10^{-4}}$(0.5) $\underline{5.91.10^{-4}}$(1.5) $\underline{6.74.10^{-4}}$(2.0) $\underline{5.88.10^{-4}}$(1.9) $\underline{1.02.10^{-4}}$(0.9)	KFKI : internal comparator : 2) ^{175}Hf and ^{181}Hf INW : internal comparator : ^{60}Co
	KFKI : 5.1 µg HfO_2 (in HF) on Al-foil, pellet 6.4 mm diam. x 0.2 mm INW : Hf (in HF + fuming HNO_3) on W 41; 1.4 mg (CH 3), 4 mg (CH 15); pellet 12.5 mm diam. x 2.5 mm	^{181}Hf (I)	133.0 133.4 136.3 345.9 482.2	$2.34.10^{-2}$(0.9) $2.37.10^{-2}$(0.9) $2.70.10^{-2}$(0.9) $2.74.10^{-2}$(0.9) $3.56.10^{-3}$(1.7) $3.68.10^{-3}$(1.3) $7.52.10^{-3}$(2.6) $8.36.10^{-3}$(0.9) $4.39.10^{-2}$(1.8) $4.58.10^{-2}$(0.9)	$2.35.10^{-2}$(1.0) $2.35.10^{-2}$(1.4) $2.72.10^{-2}$(1.0) $2.72.10^{-2}$(1.4) $3.65.10^{-3}$(1.0) $3.72.10^{-3}$(3.8) $7.58.10^{-3}$(1.0) $8.24.10^{-3}$(1.8) $4.55.10^{-2}$(0.9) $4.55.10^{-2}$(1.4)	$2.43.10^{-2}$(0.5) $2.86.10^{-2}$(0.2) - - $4.66.10^{-2}$(0.9)	$2.39.10^{-2}$(0.9) $2.82.10^{-2}$(1.1) - - $4.66.10^{-2}$(0.6)	$\underline{2.37.10^{-2}}$(0.6) $\underline{2.76.10^{-2}}$(1.0) ($3.65.10^{-3}$) ($7.93.10^{-3}$) $\underline{4.56.10^{-2}}$(0.9)	INW : internal compar.: ^{60}Co E_{eff} : 133.0 & 136.2 & 136.9 E_{eff} : 136.2 & 136.9

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, % KFKI "WWR-M"		Measured $k_{0,Au}$ and relative error, % INW "THETIS"		Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
Ta	KFKI : 11 µg Ta (in HF) on Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : Ta (in HF + fuming HNO_3) on W 41; pellet 10 mm diam. x 4 mm 1) 70 µg (CH 3), 180 µg (CH 15) 2) 70 µg (CH 3), 180 µg (CH 15)	^{182m}Ta I.T. F_2=1 ^{182}Ta (IV/b)	152.4	$1.63.10^{-2}$(1.0) $1.61.10^{-2}$(1.9)	$1.65.10^{-2}$(1.5) $1.58.10^{-2}$(2.0)	$1.62.10^{-2}$(0.6) $1.55.10^{-2}$(0.9)	$1.61.10^{-2}$(0.9) $1.64.10^{-2}$(0.6)	$\underline{1.61.10^{-2}}$(0.7)	INW : internal compar.: ^{95}Zr
			222.1	$1.80.10^{-2}$(1.3) $1.78.10^{-2}$(1.7)	$1.85.10^{-2}$(1.6) $1.76.10^{-2}$(2.6)	$1.80.10^{-2}$(1.1) $1.67.10^{-2}$(1.7)	$1.77.10^{-2}$(0.8) $1.82.10^{-2}$(1.2)	$\underline{1.78.10^{-2}}$(1.1)	
			1121.3	$8.53.10^{-2}$(0.9) $8.36.10^{-2}$(1.8)	$8.51.10^{-2}$(1.8) $8.23.10^{-2}$(1.8)	$8.12.10^{-2}$(1.0) $8.14.10^{-2}$(1.6)	$8.00.10^{-2}$(0.8) $8.24.10^{-2}$(1.0)	$\underline{8.27.10^{-2}}$(0.8)	
			1189.0	$3.96.10^{-2}$(1.4) $3.95.10^{-2}$(2.2)	$3.97.10^{-2}$(2.1) $3.91.10^{-2}$(2.2)	$3.82.10^{-2}$(1.2) $3.81.10^{-2}$(2.1)	$3.76.10^{-2}$(1.0) $3.87.10^{-2}$(1.2)	$\underline{3.88.10^{-2}}$(0.7)	
			1221.4	$6.70.10^{-2}$(1.1) $6.55.10^{-2}$(1.7)	$6.56.10^{-2}$(1.8) $6.49.10^{-2}$(1.6)	$6.35.10^{-2}$(1.2) $6.31.10^{-2}$(1.4)	$6.23.10^{-2}$(1.4) $6.44.10^{-2}$(1.2)	$\underline{6.45.10^{-2}}$(0.8)	
			1231.0	$2.74.10^{-2}$(1.1) $2.80.10^{-2}$(1.3)	$2.78.10^{-2}$(1.4) $2.73.10^{-2}$(1.2)	$2.69.10^{-2}$(1.0) $2.70.10^{-2}$(2.5)	$2.62.10^{-2}$(0.7) $2.72.10^{-2}$(1.0)	$\underline{2.72.10^{-2}}$(0.7)	
W	KFKI : 1) 0.5 µg W (in HF + HNO_3) on Al-foil; pellet 6.4 mm diam. x 0.2 mm 2) Al- 99 ppm W wire; 0.5 mm diam. INW : W (in HF + fuming HNO_3) on W 41; 2 mg (CH 3), 5 mg (CH 15); pellet 10 mm diam. x 4 mm	^{187}W (I)	134.2	$1.12.10^{-2}$(2.1) $1.16.10^{-2}$(2.3)	$1.11.10^{-2}$(1.4) $1.13.10^{-2}$(1.7)	$1.15.10^{-2}$(0.2)	$1.12.10^{-2}$(0.9)	$\underline{1.13.10^{-2}}$(0.7)	INW : internal compar.: ^{69m}Zn
			479.6	$2.93.10^{-2}$(1.8) $2.99.10^{-2}$(2.5)	$2.84.10^{-2}$(1.6) $2.95.10^{-2}$(1.2)	$2.98.10^{-2}$(0.3)	$3.04.10^{-2}$(1.0)	$\underline{2.97.10^{-2}}$(1.0)	
			551.5	$6.79.10^{-3}$(1.8) $7.08.10^{-3}$(2.1)	$6.65.10^{-3}$(1.9) $6.97.10^{-3}$(1.5)	$6.93.10^{-3}$(0.6)	$6.95.10^{-3}$(0.9)	$\underline{6.91.10^{-3}}$(0.5)	
			618.3	$8.43.10^{-3}$(2.6) $8.80.10^{-3}$(2.6)	$8.54.10^{-3}$(2.1) $8.56.10^{-3}$(2.1)	$8.74.10^{-3}$(0.4)	$8.71.10^{-3}$(0.7)	$\underline{8.65.10^{-3}}$(0.5)	
			685.7	$3.71.10^{-2}$(1.7) $3.81.10^{-2}$(2.1)	$3.64.10^{-2}$(2.3) $3.73.10^{-2}$(0.8)	$3.70.10^{-2}$(0.2)	$3.69.10^{-2}$(0.7)	$\underline{3.71.10^{-2}}$(0.5)	
			772.9	$5.51.10^{-3}$(1.5) $5.81.10^{-3}$(2.5)	$5.54.10^{-3}$(2.6) $5.85.10^{-3}$(1.5)	$5.53.10^{-3}$(0.6)	$5.55.10^{-3}$(0.8)	$\underline{5.61.10^{-3}}$(0.7)	
Re (cont'd)	KFKI : Al- 0.118% Re wire; 1 mm diam. INW : 1) NH_4ReO_4 (in H_2O) on W 41; 80 µg (CH 3); 200 µg (CH 15); pellet 10 mm diam. x 4 mm	^{186}Re (I)	122.3	$2.77.10^{-3}$(1.5)	$2.87.10^{-3}$(3.5)	$2.71.10^{-3}$(3.3) $2.75.10^{-3}$(2.3)	$2.70.10^{-3}$(1.4) $2.91.10^{-3}$(0.8)	$\underline{2.79.10^{-3}}$(1.1)	INW : internal compar.: ^{69m}Zn
			137.2	$4.34.10^{-2}$(2.5) $4.25.10^{-2}$(0.3)	$4.41.10^{-2}$(2.0) $4.31.10^{-2}$(0.8)	$4.47.10^{-2}$(0.3) $4.34.10^{-2}$(1.1)	$4.29.10^{-2}$(0.6) $4.23.10^{-2}$(0.7)	$\underline{4.33.10^{-2}}$(0.7)	

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Re (cont'd)	INW : 2) analogous with NH_4ReO_4 with certified Re-content (J & M)								
Re	KFKI : Al- 0.118% Re wire; 1 mm diam.	^{188m}Re (I)	92.5	-	$7.91.10^{-4}$(1.9)	-	$7.43.10^{-4}$(1.1)	$\underline{7.77.10^{-4}}$(1.5)	INW : internal compar.: ^{69m}Zn
	INW : 1) NH_4ReO_4 (in HNO_3) on W41; 65 µg Re (CH 3), 160 µg Re (CH 15); pellet : 10 mm diam. x 4 mm	I.T. F_2=1	106.0	$1.56.10^{-3}$(2.5)	$1.57.10^{-3}$(4.1)	$7.87.10^{-4}$(0.6) $1.42.10^{-3}$(1.4) $1.46.10^{-3}$(0.5)	$7.88.10^{-4}$(2.2) $1.48.10^{-3}$(1.3) $1.49.10^{-3}$(0.8)	$\underline{1.50.10^{-3}}$(1.6)	
	2) NH_4ReO_4, 69.4% Re certified (in HNO_3), on W41; 75 µg Re (CH 3 & CH 15); pellet : 10 mm diam. x 4 mm	^{188}Re (IV/a)	155.0	$7.72.10^{-2}$(0.7) $7.90.10^{-2}$(1.2)	$7.75.10^{-2}$(0.3) $8.00.10^{-2}$(1.7)	$7.87.10^{-2}$(0.3) $7.70.10^{-2}$(0.9)	$7.68.10^{-2}$(1.6) $7.56.10^{-2}$(0.3)	$\underline{7.77.10^{-2}}$(0.6)	
			478.0	$5.27.10^{-3}$(1.7) $5.23.10^{-3}$(1.6)	$5.29.10^{-3}$(0.5) $5.52.10^{-3}$(1.5)	$5.41.10^{-3}$(1.0) $5.22.10^{-3}$(1.1)	$5.28.10^{-3}$(0.4) $5.13.10^{-3}$(0.4)	$\underline{5.29.10^{-3}}$(0.8)	
			633.3	$7.76.10^{-3}$(0.8) $7.91.10^{-3}$(1.4)	$7.89.10^{-3}$(1.0) $7.85.10^{-3}$(3.4)	$7.74.10^{-3}$(1.0) $7.30.10^{-3}$(1.6)	$7.46.10^{-3}$(2.2) $7.17.10^{-3}$(0.8)	$\underline{7.64.10^{-3}}$(1.3)	E_{eff} of 633.1 & 635.0
			829.5	$2.17.10^{-3}$(2.1) $2.16.10^{-3}$(1.1)	$2.17.10^{-3}$(4.1) $2.27.10^{-3}$(6.4)	-	-	$(2.17.10^{-3})$	
			931.3	$2.87.10^{-3}$(2.0) $2.83.10^{-3}$(2.6)	$2.82.10^{-3}$(6.0) $2.88.10^{-3}$(4.9)	-	-	$(2.85.10^{-3})$	
Os (cont'd)	KFKI : $(NH_4)_2OsCl_6$ 43.6% Os certified; 8.86 µg Os on Al-foil; pellet : 6.4 mm diam. x 0.2 mm	^{185}Os (I)	646.1	$6.45.10^{-3}$(4.0)	$6.15.10^{-3}$(1.2)	$6.76.10^{-3}$(2.0) $6.39.10^{-3}$(1.3)	$6.42.10^{-3}$(0.7)	$\underline{6.43.10^{-3}}$(1.5)	INW : 1) internal compar.: ^{69m}Zn 2) internal compar.: ^{95}Zr and ^{97}Zr
	INW : 1) $(NH_4)_2OsCl_6$ (in HCl) on W41; 0.48 mg Os (CH 3), 1.3 mg Os (CH 15); pellet : 10 mm diam. x 4 mm	^{191m}Os I.T. F_2=1 ^{191}Os (IV/a)	129.4	$2.87.10^{-3}$(2.3)	$2.79.10^{-3}$(1.0)	$2.84.10^{-3}$(4.5) $3.03.10^{-3}$(0.8)	$3.00.10^{-3}$(1.6)	$\underline{2.91.10^{-3}}$(1.6)	
	2) $(NH_4)_2OsCl_6$ 43.6% Os certified (in HNO_3/HF) on W41; 0.3 mg Os (CH 3), 1.0 mg Os (CH 15); pellet : 10 mm diam. x 4 mm	^{193}Os (I)	139.0	$5.37.10^{-4}$(3.6)	$5.36.10^{-4}$(2.2)	$5.52.10^{-4}$(0.6) $5.68.10^{-4}$(0.7)	$5.25.10^{-4}$(1.5)	$\underline{5.44.10^{-4}}$(1.4)	E_{eff} of 138.9 & 142.1
			180.9	-	-	$4.77.10^{-5}$(3.0) $4.82.10^{-5}$(0.8)	$4.70.10^{-5}$(4.7)	$(4.76.10^{-5})$	E_{eff} of 180.0 & 181.8
			219.1	-	-	$3.78.10^{-5}$(2.7) $4.10.10^{-5}$(1.1)	$3.69.10^{-5}$(2.5)	$(3.86.10^{-5})$	E_{eff} of 218.8 & 219.1

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Os (cont'd)			251.6	$2.90.10^{-5}$(15.0)	-	$3.16.10^{-5}$(1.3) $3.09.10^{-5}$(2.7)	$3.01.10^{-5}$(2.2)	($3.04.10^{-5}$)	
			280.4	$1.79.10^{-4}$(5.5)	$1.78.10^{-4}$(3.3)	$1.79.10^{-4}$(0.2) $1.82.10^{-4}$(1.5)	$1.77.10^{-4}$(14.0)	$\underline{1.79.10^{-4}}$(0.5)	
			298.8	$2.99.10^{-5}$(5.0)	-	$2.92.10^{-5}$(3.8) $2.82.10^{-5}$(6.8)	$2.60.10^{-5}$(1.1)	($2.83.10^{-5}$)	
			321.6	$1.82.10^{-4}$(5.8)	$1.72.10^{-4}$(2.0)	$1.80.10^{-4}$(0.6) $1.78.10^{-4}$(0.8)	$1.78.10^{-4}$(1.0)	$\underline{1.78.10^{-4}}$(0.9)	
			361.8	-	$3.51.10^{-5}$(12.0)	$3.70.10^{-5}$(0.7) $4.00.10^{-5}$(0.9)	$4.01.10^{-5}$(2.1)	($3.81.10^{-5}$)	
			387.5	$1.69.10^{-4}$(3.2)	$1.65.10^{-4}$(1.3)	$1.76.10^{-4}$(1.4) $1.77.10^{-4}$(1.0)	$1.78.10^{-4}$(0.4)	$\underline{1.73.10^{-4}}$(1.5)	
			460.5	$5.58.10^{-4}$(3.3)	$5.26.10^{-4}$(2.3)	$5.64.10^{-4}$(0.1) $5.70.10^{-4}$(1.0)	$5.58.10^{-4}$(1.3)	$\underline{5.55.10^{-4}}$(1.4)	
			557.9	$2.45.10^{-4}$(5.5)	$2.47.10^{-4}$(4.9)	$2.69.10^{-4}$(0.3) $2.53.10^{-4}$(0.7)	$2.55.10^{-4}$(3.1)	$\underline{2.54.10^{-4}}$(1.7)	E_{eff} of 556.0, 557.4, 559.3 & 560.0
Ir	KFKI : Al- 0.107% Ir wire, 1 mm diam. INW : 1) Al- 0.107% Ir wire, 1 mm diam.	^{194}Ir (I)	293.5	$2.04.10^{-2}$(1.1)	$2.05.10^{-2}$(0.7)	- - - $1.95.10^{-2}$(0.2)	- - - $2.07.10^{-2}$(1.2)	$\underline{2.03.10^{-2}}$(1.3)	INW : internal compar.: 2) ^{66}Cu 3) ^{69m}Zn 4) ^{69m}Zn
	2) $(NH_4)_2IrCl_6$ (in HNO_3) on W 41; 33 µg Ir (CH 3), 65 µg Ir (CH 15); pellet 10 mm diam. x 4 mm		328.4	$1.07.10^{-1}$(0.6)	$1.06.10^{-1}$(0.4)	$9.60.10^{-2}$(0.7) $1.02.10^{-1}$(1.1) $1.03.10^{-1}$(0.4) $9.90.10^{-2}$(0.7)	$1.05.10^{-1}$(0.8) $1.02.10^{-1}$(0.7) $1.05.10^{-1}$(0.8) $1.02.10^{-1}$(0.1)	$\underline{1.03.10^{-1}}$(1.0)	
	3) $(NH_4)_2IrCl_6$ (in HNO_3) on W 41; 35 µg Ir (CH 3), 140 µg Ir (CH 15); pellet 10 mm diam. x 4 mm		645.1	$9.74.10^{-3}$(1.6)	$1.00.10^{-2}$(1.2)	$9.16.10^{-3}$(0.9) $9.68.10^{-3}$(0.6) $9.48.10^{-3}$(0.7) $8.68.10^{-3}$(0.8)	$9.52.10^{-3}$(0.3) $9.38.10^{-3}$(1.8) $9.23.10^{-3}$(1.1) $8.93.10^{-3}$(0.2)	($9.38.10^{-3}$)	
	4) $(NH_4)_2IrCl_6$, 34.38% Ir certified (in HNO_3) on W 41; 55 µg Ir (CH 3), 140 µg Ir (CH 15); pellet 10 mm diam. x 4 mm		938.7	$4.95.10^{-3}$(0.8)	$5.16.10^{-3}$(3.7)	- - - $4.38.10^{-3}$(0.4)	- - - $4.53.10^{-3}$(0.2)	($4.76.10^{-3}$)	

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Pt	KFKI : Al- 1.03% Pt wire, 1 mm diam. INW : 1) Pt (in A.R.) on W41; 2 mg (CH 3), 5 mg (CH 15); pellet 10 mm diam. x 4 mm 2) Al- 1.03% Pt wire, 1 mm diam.	^{199m}Pt → (I.T., F_2=1) ^{199}Pt → (β^-, F_3=1) ^{199}Au (V/b)	158.4	$1.06.10^{-3}$(2.2)	$1.05.10^{-3}$(1.3)	$1.02.10^{-3}$(0.4) $1.03.10^{-3}$(0.4)	$9.90.10^{-4}$(0.9) $1.00.10^{-3}$(0.9)	$\underline{1.03.10^{-3}}$(1.4)	INW : internal compar.: ^{69m}Zn
			208.2	$2.29.10^{-4}$(2.5)	$2.30.10^{-4}$(1.3)	$2.27.10^{-4}$(0.7) $2.25.10^{-4}$(0.7)	$2.21.10^{-4}$(0.4) $2.18.10^{-4}$(0.4)	$\underline{2.26.10^{-4}}$(1.0)	
Au	KFKI : Al- 0.1% Au wire, 0.2 mm diam.; Al- 0.5% Au wire, 0.5 mm diam.; Al- 0.1018% Au wire, 1 mm diam.; Al- 0.1011% Au wire, 1 mm diam.; 12 µg Au (in A.R.) on Al-foil; pellet 6.4 mm diam. x 2 mm INW : Al- 0.503% Au wire, 1 mm diam.; Al- 0.5% Au wire, 1 mm diam.; Al- 0.1018% Au wire, 1 mm diam.; Al- 0.1011% Au wire, 1 mm diam.; Al- 0.1005% Au wire, 1 mm diam.; Al- 0.097% Au wire, 1 mm diam. RISØ : Al- 0.1005% Au wire, 1 mm diam.	^{198}Au (I)	411.8					≡ 1	= COMPARATOR
Hg (cont'd)	KFKI : 15 µg HgO (in HNO_3) on Al-foil (pipetted under H_2S-atmosphere); pellet 6.4 mm diam. x 0.3 mm	^{197m}Hg (I)	134.0	$4.90.10^{-4}$(1.3)	$5.12.10^{-4}$(2.0)	$5.01.10^{-4}$(0.8)	$4.94.10^{-4}$(0.9)	$\underline{4.99.10^{-4}}$(1.0)	INW : internal compar.: ^{69m}Zn
		^{203}Hg (I)	279.2	$1.10.10^{-2}$(1.4)	$1.11.10^{-2}$(1.4)	$1.15.10^{-2}$(1.6)	$1.06.10^{-2}$(0.2)	$\underline{1.10.10^{-2}}$(1.7)	INW : internal compar.: ^{69m}Zn

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
Hg (cont'd)	INW : Hg (in HNO_3) on W 41 (dried at room temp.); 180 µg (CH 3), 450 µg (CH 15); pellet 10 mm diam. x 4 mm								
Th	KFKI, INW : Al- 0.819% Th wire, 1 mm diam.	^{233}Th $\xrightarrow{\beta^-,\ F_2=1}$ ^{233}Pa (II/b)	300.1	$4.33.10^{-3}$(1.2) $4.42.10^{-3}$(1.4)	$4.29.10^{-3}$(2.2) $4.44.10^{-3}$(1.5)	$4.41.10^{-3}$(0.8)	$4.34.10^{-3}$(1.1)	$\underline{4.37.10^{-3}}$(0.3)	
			312.0	$2.55.10^{-2}$(1.8) $2.46.10^{-2}$(1.8)	$2.50.10^{-2}$(1.7) $2.54.10^{-2}$(0.7)	$2.56.10^{-2}$(0.6)	$2.51.10^{-2}$(1.4)	$\underline{2.52.10^{-2}}$(0.5)	
			340.5	$2.91.10^{-3}$(2.5) $2.89.10^{-3}$(3.4)	$2.91.10^{-3}$(2.5) $2.98.10^{-3}$(1.6)	$2.99.10^{-3}$(1.2)	$2.97.10^{-3}$(1.2)	$\underline{2.95.10^{-3}}$(0.7)	
			375.4	$4.57.10^{-4}$(1.4) $4.30.10^{-4}$(10.0)	$4.48.10^{-4}$(1.0) $4.54.10^{-4}$(10.0)	$4.56.10^{-4}$(1.2)	$4.46.10^{-4}$(2.5)	$\underline{4.49.10^{-4}}$(0.6)	
			398.6	$9.36.10^{-4}$(2.2) $9.04.10^{-4}$(2.2)	$9.25.10^{-4}$(2.2) $9.07.10^{-4}$(6.5)	$9.31.10^{-4}$(0.5)	$9.36.10^{-4}$(0.6)	$\underline{9.26.10^{-4}}$(0.5)	
			415.8	$1.16.10^{-3}$(1.8) $1.11.10^{-3}$(8.9)	$1.15.10^{-3}$(3.3) $1.19.10^{-3}$(6.1)	$1.19.10^{-3}$(1.0)	$1.16.10^{-3}$(0.7)	$\underline{1.16.10^{-3}}$(1.0)	
U (cont'd)	KFKI, INW, RISØ : Al- 0.443% U wire, 1 mm diam. (depleted U : 99.962% ^{238}U 0.0375% ^{235}U)	^{239}U $\xrightarrow{\beta^-,\ F_2=1}$ ^{239}Np (II/b)	209.8	-	$7.87.10^{-4}$(1.9)		$7.87.10^{-4}$(1.4)	$\underline{7.80.10^{-4}}$(0.5)	* Cd subtr. method
						$7.77.10^{-4}$(0.8) (RISØ)	$7.71.10^{-4}$(0.8)* (RISØ)		
			228.1	-	$2.72/10^{-3}$(1.4)	$2.81.10^{-3}$(0.3)		$\underline{2.77.10^{-3}}$(0.7)	E_{eff} of 226.4 & 228.2
						$2.78.10^{-3}$(1.2) (RISØ)	$2.78.10^{-3}$(1.2)* (RISØ)		

TABLE VI.2-1 : continued

Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %				Recommended or (tentative) $k_{0,Au}$ (relat. err., %) [experimental]	NOTES
				KFKI "WWR-M"		INW "THETIS"			
U (cont'd)			277.6	-	$3.40.10^{-3}$(1.4)		$3.48.10^{-3}$(0.9)	$\underline{3.40.10^{-3}}$(0.8)	
						$3.38.10^{-3}$(0.8) (RISØ)	$3.36.10^{-3}$(0.8)* (RISØ)		
			285.5	-	-			$(1.83.10^{-4})$	
						$1.84.10^{-4}$(1.3) (RISØ)	$1.83.10^{-4}$(1.5)* (RISØ)		
			315.9	-	$3.66.10^{-4}$(2.7)	$3.79.10^{-4}$(0.2)		$\underline{3.68.10^{-4}}$(1.5)	
						$3.65.10^{-4}$(1.7) (RISØ)	$3.62.10^{-4}$(1.8)* (RISØ)		
			334.3	-	$4.93.10^{-4}$(2.5)		$4.86.10^{-4}$(0.7)	$\underline{4.81.10^{-4}}$(1.0)	
						$4.75.10^{-4}$(1.0) (RISØ)	$4.71.10^{-4}$(1.0)* (RISØ)		

2.2. k_0-values of $^{94}Zr(n,\gamma)^{95}Zr$ and $^{96}Zr(n,\gamma)^{97}Zr$

As a detailed example of experimental k_0-determination at the INW, the KFKI and at Risø, Table VI.2-2 shows the individual results for the 724.2 keV and 756.7 keV lines of ^{95}Zr, and for the 743.3 keV and 657.9 keV lines of ^{97m}Nb resp. ^{97}Nb (daughter isotopes of ^{97}Zr) [SIMONITS86]. All k_0-factors were obtained according to the Cd-subtraction method [Eq. (I.3-19)], with F_{Cd} (^{198}Au) = 0.991 and F_{Cd} (^{94}Zr, ^{96}Zr) = 1 (see V.3.2.2). The introduced half-lives are to be found in Table VIII.3-1 [for the redetermination of T (^{97}Zr), see VII.1.2]. The specific count rates for the daughter isotopes ^{97m}Nb (743.3 keV) and ^{97}Nb (657.9 keV) were calculated according to the relevant equations of reaction decay type II/a and III/a, respectively (see I.3.4.2). As Au-comparator, use was made of Al-Au alloyed wires of 1 mm thickness with various Au-content ($\sim$ 0.1%). The Zr-standard was a circular 125 μm thick Zr-foil (Goodfellow; Zr-content : 99.8+%). At the three institutes, countings were performed at reference distance (> 15 cm) to a large Ge-detector (see II.2).

The uncertainties quoted on the individual results were calculated from counting statistics on N_p and $(N_p)_{Cd}$ [for Au and Zr], to which an extra error of 1% (supposed to be random) was added in quadrature. For ^{97}Zr, the results of Table VI.2-2 show the superiority of determination in highly thermalized neutron fluxes [compare for instance the uncertainties on the results obtained in channels R4V4 (DR-3) and "MILA" (WWR-M)]. Evidently, this is due to the extremely high Q_0-value (= 248) for the reaction $^{96}Zr(n,\gamma)^{97}Zr$, which causes A_{sp} to be only slightly higher than $(A_{sp})_{Cd}$ in less-thermalized channels. In view of this phenomenon, it was decided to calculate weighted averages, and - although the situation is different for $^{94}Zr(n,\gamma)^{95}Zr$ [Q_0 = 5.05] - the same procedure was followed in this case as well. Finally, the uncertainty quoted on the weighted average is the larger of the internal and external errors, which were reasonably consistent (see I.3.4.4).

TABLE VI.2-2 : Experimental determination of $k_{0,Au}$-values for the reactions $^{94}Zr(n,\gamma)^{95}Zr$ and $^{96}Zr(n,\gamma)^{97}Zr/^{97m}Nb/^{97}Nb$

REACTOR Channel	Date	Measured $k_{0,Au}$ values with rel.error (%)				
		^{97m}Nb	^{97}Nb	^{95}Zr		
		743.3 keV	657.9 keV	724.2 keV	756.7 keV	724.2 + 756.7 keV
RISØ DR 3 Ch. R4V4 (f ≃ 320)	03-DEC-84	$1.289.10^{-5}$ (2.8)	$1.282.10^{-5}$ (2.8)	-	-	$2.145.10^{-4}$ (2.4)
	04-DEC-84	$1.301.10^{-5}$ (2.7)	$1.282.10^{-5}$ (2.7)	-	-	$2.097.10^{-4}$ (2.3)
	05-DEC-84	$1.317.10^{-5}$ (2.5)	$1.314.10^{-5}$ (2.5)	-	-	$2.197.10^{-4}$ (2.0)
	06-DEC-84	$1.323.10^{-5}$ (2.1)	$1.311.10^{-5}$ (2.3)	-	-	$2.155.10^{-4}$ (1.7)
	Weighted average :	$1.310.10^{-5}$ (1.2)	$1.299.10^{-5}$ (1.3)	-	-	$2.152.10^{-4}$ (1.0)
INW THETIS Ch. 7 (f ≃ 110)	05-FEB-85	$1.235.10^{-5}$ (3.8)	$1.263.10^{-5}$ (3.8)	$9.290.10^{-5}$ (1.7)	$1.135.10^{-4}$ (1.7)	$2.064.10^{-4}$ (1.2)
	12-FEB-85	$1.395.10^{-5}$ (3.7)	$1.369.10^{-5}$ (3.7)	$9.167.10^{-5}$ (1.7)	$1.144.10^{-4}$ (1.7)	$2.061.10^{-4}$ (1.2)
	26-FEB-85	$1.338.10^{-5}$ (3.8)	$1.354.10^{-5}$ (3.8)	$9.473.10^{-5}$ (1.8)	$1.151.10^{-4}$ (1.7)	$2.098.10^{-4}$ (1.2)
	04-JUL-85	$1.330.10^{-5}$ (5.0)	$1.355.10^{-5}$ (4.7)	-	-	$2.101.10^{-4}$ (1.9)
	04-JUL-85	$1.211.10^{-5}$ (4.9)	$1.253.10^{-5}$ (5.6)	$9.514.10^{-5}$ (1.7)	$1.151.10^{-4}$ (1.7)	$2.102.10^{-4}$ (1.2)
	10-DEC-85	$1.334.10^{-5}$ (4.1)	$1.419.10^{-5}$ (4.7)	-	-	-
	Weighted average :	$1.307.10^{-5}$ (2.2)	$1.333.10^{-5}$ (1.9)	$9.354.10^{-5}$ (0.9)	$1.145.10^{-4}$ (0.9)	$2.083.10^{-4}$ (0.6)
INW THETIS Ch. 16 (f ≃ 110)	29-MAY-85	$1.225.10^{-5}$ (3.8)	$1.276.10^{-5}$ (3.8)	-	-	$2.067.10^{-4}$ (1.7)
	29-MAY-85	$1.215.10^{-5}$ (4.3)	$1.252.10^{-5}$ (4.8)	$9.054.10^{-5}$ (1.7)	$1.137.10^{-4}$ (1.6)	$2.043.10^{-4}$ (1.2)
	02-JUL-85	$1.259.10^{-5}$ (4.1)	$1.304.10^{-5}$ (4.0)	-	-	-
	02-JUL-85	$1.246.10^{-5}$ (7.1)	$1.266.10^{-5}$ (6.1)	$9.317.10^{-5}$ (1.9)	$1.175.10^{-4}$ (1.7)	$2.107.10^{-4}$ (1.3)
	12-DEC-85	$1.333.10^{-5}$ (4.2)	$1.357.10^{-5}$ (4.2)	-	-	-
	Weighted average :	$1.253.10^{-5}$ (2.0)	$1.294.10^{-5}$ (2.0)	$9.167.10^{-5}$ (1.4)	$1.154.10^{-4}$ (1.6)	$2.071.10^{-4}$ (1.0)
INW THETIS Ch. 14 (f ≃ 39)	19-NOV-85	$1.383.10^{-5}$ (10.7)	$1.305.10^{-5}$ (10.7)	-	-	$2.094.10^{-4}$ (1.9)
	19-NOV-85	$1.494.10^{-5}$ (10.1)	$1.322.10^{-5}$ (10.4)	$9.271.10^{-5}$ (1.9)	$1.157.10^{-4}$ (1.7)	$2.084.10^{-4}$ (1.3)
	08-JAN-86	$1.133.10^{-5}$ (11.5)	$1.198.10^{-5}$ (11.1)	-	-	-
	08-JAN-86	$1.209.10^{-5}$ (11.1)	$1.169.10^{-5}$ (10.5)	-	-	$2.170.10^{-4}$ (1.6)
	Weighted average :	$1.287.10^{-5}$ (6.3)	$1.243.10^{-5}$ (5.3)	$9.271.10^{-5}$ (1.9)	$1.157.10^{-4}$ (1.7)	$2.112.10^{-4}$ (1.3)
KFKI WWR-M Ch. "MILA" (f ≃ 38)	27-FEB-85	$1.208.10^{-5}$ (14.1)	$1.246.10^{-5}$ (15.3)	$9.370.10^{-5}$ (2.1)	$1.154.10^{-4}$ (2.7)	$2.091.10^{-4}$ (1.8)
	11-APR-85	-	-	$9.239.10^{-5}$ (1.7)	$1.140.10^{-4}$ (1.6)	$2.064.10^{-4}$ (1.2)
	06-DEC-85	$1.480.10^{-5}$ (13.9)	$1.390.10^{-5}$ (13.5)	$9.578.10^{-5}$ (1.8)	$1.160.10^{-4}$ (2.0)	$2.122.10^{-4}$ (1.4)
	Weighted average :	$1.318.10^{-5}$ (10.1)	$1.319.10^{-5}$ (10.1)	$9.387.10^{-5}$ (1.1)	$1.150.10^{-4}$ (1.1)	$2.088.10^{-4}$ (0.9)
GRAND MEAN (weighted):		$1.296.10^{-5}$ (0.9)	$1.304.10^{-5}$ (0.9)	$9.321.10^{-5}$ (0.6)	$1.149.10^{-4}$ (0.6)	$2.094.10^{-4}$ (0.6)

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CHAPTER VII

SPECIAL PROBLEMS

1. UNCERTAINTIES INDUCED BY HALF-LIVES

1.1. Error propagation

A_{sp} being defined as :

$$A_{sp} = \frac{N_p / t_m}{SDC\ w} \qquad \text{(VII.1-1)}$$

the propagation of the error on T towards A_{sp} (and thus towards k_0 and ρ) can be calculated from :

$$Z_{A_{sp}}(T) = \left| -\frac{\ln 2}{T}\left(t_d + t_m - \frac{1-S}{S} t_{irr}\right) + \frac{1-C}{C} \right| \qquad \text{(VII.1-2)}$$

Eq. (VII.1-2) shows that, with respect to t_{irr}, t_d and t_m, a compensation of errors is to be expected.

In case of irradiation and counting of short-lived radionuclides, with $t_{irr} \simeq t_m \simeq 2T$ and $t_d \simeq T$, one obtains $Z_{A_{sp}}(T) \simeq 0.8$.

If in actual analysis a short-lived radionuclide is measured during $t_m >> T$, after $t_{irr} >> T$ (i.e. irradiation as for the longer-lived radionuclides), one obtains, again for $t_d \simeq T$, $Z_{A_{sp}}(T) \simeq 1 + \ln 2 \simeq 1.7$.

If for medium-lived radionuclides t_{irr} and t_m are kept relatively short (t_{irr} and t_m << T), and if $t_d \simeq T/\ln 2$ is chosen, one obtains $t_m << t_d$, $C \simeq 1$, $1-S \simeq 1$, $S \simeq (t_{irr} \ln 2)/T$ and thus $Z_{A_{sp}}(T) \simeq 0$. Although these conditions could be realized more or less in case of k_0-determination this is not so in actual analysis, but even in rather extreme - but still practical - circumstances, $Z_{A_{sp}}(T)$ remains lower than unity.

In case of very long-lived isotopes (t_{irr}, t_d and t_m << T), one obtains $Z_{A_{sp}}(T) \simeq 1$. This follows also immediately from Eq. (VII.1-1); since $S \simeq (t_{irr} \ln 2)/T$, D = 1 and C = 1, one has $A_{sp} \sim T$.

In view of the above, it can be concluded that half-lives should be known with an accuracy better than 1%. One has to keep in mind, however, that in the practice of k_0-based NAA or ENAA the uncertainties on the analytical results originating from T will be smaller than expected from Eq. (VII.1-2) on condition that the analyst introduces the same T as introduced for k_0-determination. Indeed, there exists a definite (but not generally descriptable) correlation between $s_{k_0}(T)$ and $s_\rho(T)$, although not as favourable as in case of relative standardization. The correlation is obvious in case of very long-lived isotopes; $A_{sp} \sim T$ (see above) leads to $k_0 \sim T$ and $\rho \sim T$, but since $\rho \sim 1/k_0$, introduction of the same half-life in both operations (k_0-determination and analysis) actually makes $Z_\rho(T) \simeq 0$. Thus, just like with the Q_0-values (V.3.4), the analyst is strongly advised to stick to the half-life data adopted in the present work (see Table VIII.3-1), even if other or new values are estimated to be more accurate.

The half-life values adopted in the present work are compiled in Table VIII.3-1. They were selected as "best choices" from various sources, notably (in descending order of selection frequency) :

- the most recent Nuclear Data Sheets ;
- the report of KOCHER81
- recent reports of ICRM, the International Committee for Radionuclide Metrology [YOSHIZAWA85, NBS82];
- the 7th edition of the Table of Isotopes [LEDERER78] ;
- the recent editions of the Table de Radionucléides [LMRI80/85] ;
- recent experimental results, including those of the present work (see VII.1.2 and VII.1.3).

Fig. VII.1-1 gives an impression of the uncertainty assignments on the thus collected "best choices", considering only radionuclides which are relevant from analytical standpoint (thus excluding short-lived components in mother-daughter decay, for which in practice $t_d \gg T$, i.e. $D \cong 0$; e.g. ^{97m}Nb, ^{113m}Sn). The expansion shows the cases for which $s_T \geq 1\%$ (and for which in fact accurate redetermination of T is desirable : see Table VIII.3-1). Although the situation with respect to accuracy looks reassuring ($\sim$ 90% of the radionuclides having $s_T < 1\%$), attentiveness is dictated. For instance,

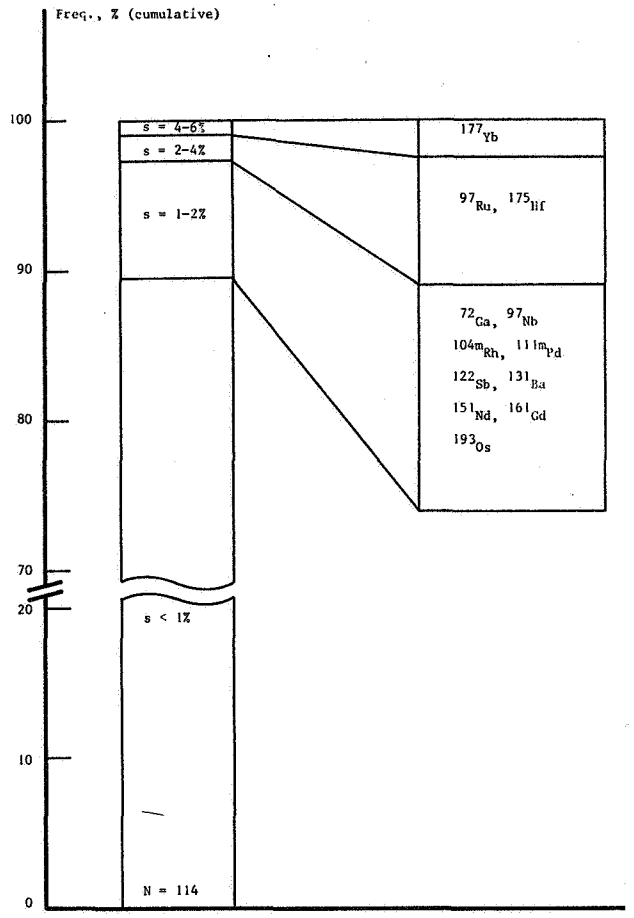


Fig. VII.1-1 : Frequency (Freq.,%; cumulative) of the uncertainty on T (s,%; "best choice" T's adopted in the present work) falling in a specified interval (s < 1%, s = 1-2%, etc.)

whereas for ^{116m}In BLACHOT81 quotes a half-life of 54.15 min with 0.1% uncertainty, recent remeasurements yield conflicting values of 54.29 min (± 0.2%) [GOPYCH84] and 55.77 min (± 0.2%) [NEMETH86]. Such problems are mentioned in the "COMMENTS" of Table VIII.3-1.

1.2. Experimental determination of the ^{97}Zr half-life

In the present work, special attention was paid to the half-life value of ^{97}Zr. As mentioned in V.2.2, the double counting procedure for determining α and f imposes a decay time of 3-4 days (depending on the value of f) to obtain approximately equal peak areas for the ^{97}Zr 743.2 keV and ^{95}Zr 724.2 and 756.7 keV gamma-energies. Since this represents 4-6 half-lives of ^{97}Zr, the propagation of the error on T (^{97}Zr) towards A_{sp} (^{97}Zr) is expected to be high. In a practical example taking t_{irr} = 5 min, t_d = 100 h and t_m = 1000 s as input data, a 1% error on the half-life generates a 3.1% error on A_{sp}, and this is further multiplied in the f- and α-results. The available data from recent compilation works are shown in Table VII.1-1. Note that the reported 16.9 and 16.90 ± 0.05 h values are in fact adopted from the 1973-result of Santry and Werner (16.90 ± 0.05 h; SANTRY73). The half-life of ^{97}Zr has been remeasured in 1979-1980 at the KFKI (Budapest, Hungary) and the IRI (Delft, The Netherlands) using different measuring setups [SIMONITS86]. The results are shown in

TABLE VII.1-1 : Survey of recently compiled data for the ^{97}Zr half-life
(* adopted from experimental result of SANTRY73)

Source	T(^{97}Zr), hours
LEDERER78	16.9*
REUS79	17.0
ERDTMANN79	16.8
NUKLIDK.81	16.8
KOCHER81	16.90 ± 0.05*
REUS83	17.0
CH.NUCL.84	16.8
NNDC COMPUT.CH.85	16.90 ± 0.05*
HAESNER85	16.90 ± 0.05*
THIS WORK (experim.)	16.744±0.011

Table VII.1-2. The resulting T (^{97}Zr) = 16.744 ± 0.011 h value is significantly lower than any of the data from Table VII.1-1. It must also be concluded that, in spite of the low 0.3% uncertainty reported on the 16.90 h-value, the latter is in error with ∿ +1%.

1.3. Experimental determination of the ^{125m}Sn half-life

A last case to be mentioned is the half-life of the short-lived ^{125m}Sn isotope, for which the experimental literature data are collected in Table VII.1-3, together with the recent compilation values. In spite of the fact that conflicting experimental results were reported, the most recent compilations adopted the (9.52 ± 0.05) h value of ERDAL68. Although this may be justified by evaluating (as objectively as possible) the quality of the underlying experiment, it was decided in the present work to perform a remeasurement. Therefore, the ^{125m}Sn 331.9 keV γ-line, emitted by a neutron-irradiated Sn-foil, was measured repeatedly on a Ge(Li) detector (1.9 keV FWHM) [t_m=80 s], using a dead-time stabilizer and a Canberra 2020 amplifier/pulse pile-up re-

TABLE VII.1-2 : Half-life measurements for ^{97}Zr at the KFKI (Budapest) and the IRI (Delft)

Run	Instrumentation	Meas. points	Total decay time, h (half-lives)	Isotope and energy used	Half-life (h) with abs. and rel. error (%)
1	Canb.Ge(Li) No.1 ICA-70 (KFKI) analyzer t_m = 500 s	57	78 (∿4.66T)	^{97}Nb,658 keV ^{97m}Nb,743 keV	16.75 ± 0.03 (0.2) 16.75 ± 0.02 (0.13)
2	Canb.Ge(Li) No.2 ICA-70 (KFKI) analyzer t_m = 500 s	40	78 (∿4.66T)	^{97}Nb,658 keV ^{97m}Nb,743 keV	16.75 ± 0.03 (0.2) 16.72 ± 0.02 (0.11)
3	Philips Ge(Li) IRI TN 1212 ADC t_m = 1 h	96	96 (∿5.73T)	^{97}Nb,658 keV ^{97m}Nb,743 keV	16.765±0.033 (0.2) 16.773±0.034 (0.2)
Mean (weighted average) : $T(^{97}Zr)$ = 16.744 ± 0.011 h (± 0.06%; 1 s)					

TABLE VII.1-3 : Survey of literature data for the ^{125m}Sn half-life

T (^{125m}Sn), min			
Experimental		Recently compiled	
Source	Value	Source	Value
LIVINGOOD39	9		
SULLIVAN47	10		
LEE49	9.8 ± 0.2		
NELSON50	9.5 ± 0.1		
MAJUMDAR63	9.7		
ERDAL68	9.52 ± 0.05		
LEYSIN70	7.78 ± 0.07		
		LEDERER78	9.5
		REUS79	9.52
		ERDTMANN79	9.7
		NUKLIDK.81	9.5
		TAMURA81	9.52 ± 0.05
		REUS83	9.52
		CH.NUCL.84	9.52
		NNDC COMP.CH.85	9.52 ± 0.05
THIS WORK	9.525 ± 0.013		

jector. The experiment was done in twofold :

1. t_m = 80 s ; counting intervals = 3 min; measured points = 14; total decay time = 39 min (∿ 4.1 T). Obtained result : 9.539 ± 0.022 min ;
2. t_m = 80 s ; counting intervals = 2 min; measured points = 26; total decay time = 50 min (∿ 5.2 T). Obtained result : 9.517 ± 0.016 min.

The weighted average comes to T = 9.525 ± 0.013 min (± 0.14% ; 1 s). The accuracy of this result was checked by determination of the ^{27}Mg half-life, which is close to the one of ^{125m}Sn. The value compiled by KOCHER81, 9.458 ± 0.012 min, is originating from the evaluation by ENDT78, who calculated it as the weighted mean of five determinations with uncertainties below 0.05 min [DANIEL53 (9.51 ± 0.03 min); LOCKETT53 (9.39 ± 0.03 min);

SARGENT53 (9.45 ± 0.04 min); POULORIKAS59 (9.46 ± 0.02 min); REPACE70 (9.462 ± 0.012 min)]. Other experimental data, not included by ENDT78, are : GORODETZKY68 (9.52 ± 0.07 min), HANSEN70 (9.43 ± 0.08 min) and BODE75 (9.350 ± 0.013 min). The results of the 2 runs of the present work, performed as for ^{125m}Sn, were 9.516 ± 0.030 min and 9.454 ± 0.043 min, leading to a weighted average of T (^{27}Mg) = 9.495 ± 0.029 min (± 0.3%; 1 s). This is consistent with the evaluated ENDT78-value. It can thus finally be concluded that the obtained T (^{125m}Sn) value = 9.525 ± 0.013 min is also reliable; it fully confirms the finding of ERDAL68, adopted by recent compilations.

2. PARAMETERS RELATED TO COMPLEX ACTIVATION AND DECAY

2.1. Q_0 and $\bar{E}_r$ for m- and g-formation

For some types of activation/decay (types IV/a, IV/d, V/a, VII/a, VII/b and VIII; see Table I.3-1), both parameters $[f + Q_0^g(\alpha)]$ and $[f + Q_0^m(\alpha)]$ have to be introduced in the relevant formulae.

It is not always possible to find literature data for both Q_0^m and Q_0^g. This is for instance the case for ^{124}Sn(n,γ)$^{125(m)}$Sn : whereas several experimental Q_0^m-values are available (see Table V.3-3), not one single Q_0^g-value has been reported.

A comparison of reliable Q_0^m and Q_0^g-values reveals that both quantities are equal to a good approximation. This is shown in Table VII.2-1 for the values evaluated in the present work (see Table V.3-3).

TABLE VII.2-1 : Comparison of Q_0^m and Q_0^g-values (F_2 = fractional decay from m- to g-state)

Reaction	Q_0^g	Q_0^m	Q_0 F_{2m+g}
^{79}Br(n,γ)$^{80(m)}$Br	11.0	13.2	-
^{103}Rh(n,γ)$^{104(m)}$Rh	7.6	7.5	-
^{130}Te(n,γ)$^{131(m)}$Te	1.7	2.5	-
^{133}Cs(n,γ)$^{134(m)}$Cs	-	11.8	12.7
^{164}Dy(n,γ)$^{165(m)}$Dy	-	0.25	0.19
^{187}Re(n,γ)$^{188(m)}$Re	4.34	4.57	-

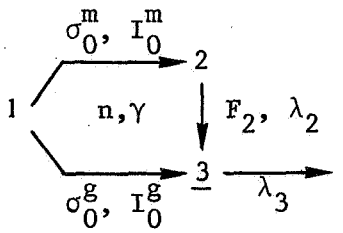
An analogous situation can be observed for the $g(T_n)$-factors of $^{151}Eu(n,\gamma)^{152m}Eu$ and $^{151}Eu(n,\gamma)^{152}Eu$ [KIM75], e.g. with values of resp. 0.894 and 0.902 at 20°C. This can be explained by the parallel $\sigma(E)$ versus E functions for the (n,γ) reactions leading to the m- and g-states. On the same ground, it is reasonable to expect that also $\bar{E}_r^m \simeq \bar{E}_r^g$ (and even $F_{Cd}^m \simeq F_{Cd}^g$).

Thus, if no experimental data for either Q_0^m or Q_0^g are available, it seems justified to assume that $Q_0^m(\alpha) = Q_0^g(\alpha)$. This assumption leads to the fact that one can safely put $[f + Q_0^m(\alpha)]/[f + Q_0^g(\alpha)] = 1$ in the expressions for "$\frac{N_p/t_m}{SDC}$" [see Table I.3-1].

2.2. Experimental determination of k_0^m/k_0^g; the cases $^{80(m)}Br$ and $^{104(m)}Rh$

For the types of activation/decay mentioned in VII.2.1, the ratio σ_0^m/σ_0^g has to be introduced in the equations for calculation of "$\frac{N_p/t_m}{SDC}$" (see Table I.3-1).

Analytically speaking, activation/decay type IV/a is the most important one. The ratio $F_2\sigma_0^m/\sigma_0^g$ (see Table I.3-1) can be interpreted as :



$$F_2\sigma_0^m/\sigma_0^g = k_0^m/k_0^g \qquad \text{(VII.2-1)}$$

$$\text{with } k_0^m = [\theta F_2 \sigma_0^m \gamma_3/M]/[\theta_c \sigma_{0,c} \gamma_c/M_c]$$

$$k_0^g = [\theta \sigma_0^g \gamma_3/M]/[\theta_c \sigma_{0,c} \gamma_c/M_c]$$

Experimental determination of the k_0^m/k_0^g ratio is possible according to the double measurement technique [SIMONITS80]. If a gamma-line emitted by nuclide 3 is counted after short and long decay time (superscripts I and II, respectively), it is easy to prove that :

$$k_0^m/k_0^g = \frac{f + Q_0^g(\alpha)}{f + Q_0^m(\alpha)} [S_3 D_3^I C_3^I (N_{p,3}/t_m)^{II} - S_3 D_3^{II} C_3^{II} (N_{p,3}/t_m)^I] \times$$

$$\times \left[\frac{\lambda_3}{\lambda_3-\lambda_2}(S_2 D_2^{II} C_2^{II} - \frac{\lambda_2}{\lambda_3} S_3 D_3^{II} C_3^{II})(N_{p,3}/t_m)^I - \frac{\lambda_3}{\lambda_3-\lambda_2}(S_2 D_2^I C_2^I - \frac{\lambda_2}{\lambda_3} S_3 D_3^I C_3^I)(N_{p,3}/t_m)^{II}\right]^{-1}$$

(VII.2-2)

In the present work, k_0^m/k_0^g-ratios were determined for $^{79}Br(n,\gamma)^{80(m)}Br$ [measuring the 616.3 and 665.8 keV lines of ^{80}Br] and for $^{103}Rh(n,\gamma)^{104(m)}Rh$ [measuring the 555.8 line of ^{104}Rh]. The resulting values were :

k_0^m/k_0^g [$^{80(m)}Br$] = 0.26 (uncertainty estimated at 10%)

k_0^m/k_0^g [$^{104(m)}Rh$] = 0.082 ($\pm$ 1%)

Comparison with other literature data is made in Table VIII.3-1.

2.3. Counting of gamma-rays emitted by both the mother and daughter isotope ; the case $^{99}Mo/^{99m}Tc$

In some cases a special problem arises because the measured gamma-ray is emitted by both the mother and the daughter isotope. Thus, the formulae for expressing " $\frac{N_p/t_m}{SDC}$ " will inevitably contain the relevant absolute gamma-intensities for the two isotopes (see activation/decay types II/d and IV/d in Table I.3-1).

From analytical standpoint, the most important (but frequently overlooked) case concerns the measurement of the 140.5 keV line emitted by ^{99}Mo and ^{99m}Tc; this is by far the most prominent line in the $^{99}Mo/^{99m}Tc$ gamma-spectrum. From Table I.3-1 (type II/d) it appears that knowledge of the factor $\gamma_2/F_2\gamma_3$ is required [$\gamma_2 = \gamma_{140.5,^{99}Mo}$; $\gamma_3 = \gamma_{140.5,^{99m}Tc}$; F_2 = fractional decay of ^{99}Mo to ^{99m}Tc]. Table VII.2-2 gives a survey of the data available in evaluation works. Note that, in addition to REUS83, data for γ_2 are also not given by PAGDEN71, FILBY70, ERDTMANN74, BOWMAN74 and ERDTMANN79. Table VII.2-2 reveals that the factor $\gamma_2/F_2\gamma_3$ shows a significant scatter in literature, which is almost entirely due to the reported γ_2-value.

It is possible to determine the factor $\gamma_2/F_2\gamma_3$ experimentally [SIMONITS 81]. When considering in the $^{99}Mo/^{99m}Tc$ gamma-spectrum any ^{99}Mo-line (other than 140.5 keV) as a reference, one can write :

$$R = \frac{N_{p,140.5}}{N_{p,ref}} = \frac{\varepsilon_{p,140.5}}{\varepsilon_{p,ref}} \left(\frac{\gamma_2}{\gamma_{ref}} + \frac{F_2\gamma_3}{\gamma_{ref}} \cdot \frac{\lambda_3-\lambda_2}{\lambda_3-\lambda_2} \frac{S_3\ D_3\ C_3}{S_2\ D_2\ C_2} \right) \qquad \text{(VII.2-3)}$$

which can be substituted as a simple linear function :

$$R = c(a + bx) = A + Bx \qquad \text{(VII.2-4)}$$

where $a = \frac{\gamma_2}{\gamma_{ref}}$

$b = \frac{F_2\gamma_3}{\gamma_{ref}}$

TABLE VII.2-2 : Status of evaluated data for ^{99}Mo and ^{99m}Tc (* calculated from published decay scheme and $\alpha_t = 0.110$; ** recent experimental measurement; *** adopted from DICKENS80; **** indicative only)

Evaluation work	$\gamma_{140.5}$, %		F_2	$\frac{\gamma_2}{F_2\gamma_3}$
	^{99}Mo (γ_2)	^{99m}Tc (γ_3)		
MEDSKER74	4.09 *	88.5	0.8766	0.0527
LMRI75	4.98±0.75 *	89.3±0.3	0.874±0.009	0.0638
MARTIN76	5.7±0.5	88.9±0.3	0.868±0.009	0.0739
KOCHER77	5.7±0.5	88.9±0.3	0.868±0.009	0.0739
LEDERER78	1.44 *	89.0±0.2	0.87±0.01	0.0186
ZIJP79	4.95±0.09	88.97±0.24	0.8752±0.0018	0.0636
DICKENS80 **	5.02±0.26	87.2±0.5	0.8805±0.0031	0.0654
KOCHER81	3.8±0.5	89.07±0.24	0.886±0.009	0.0482
REUS83	-	87.7	0.876	-
THIS WORK	5.10±0.39	85.8±2.3****	(0.8805±0.0031)***	0.0675±0.0055

$c = \frac{\varepsilon_{p,140.5}}{\varepsilon_{p,ref}}$

$x = \frac{\lambda_3-\lambda_2 \frac{S_3 D_3 C_3}{S_2 D_2 C_2}}{\lambda_3-\lambda_2}$

$A = ca$

$B = cb$

Thus, when after irradiation of a Mo-foil with reactor neutrons, the 140.5 keV and "ref" peak areas, measured on a calibrated Ge-detector, are

followed as a function of time, R versus x is a straight line from which the parameters A and B can be determined. Then, by introducing a reliable value for γ_{ref}, one gets γ_2 and $F_2\gamma_3$ (and γ_3, upon introduction of an adopted F_2-value), leading finally to $\gamma_2/F_2\gamma_3$.

Obviously, the determination of A will be more accurate as more points are measured at low x-values. According to the definition of x, it is more advantageous to perform a short irradiation (S_3/S_2 large) followed by immediate counting (D_3/D_2 maximum). Regarding the latter condition, however, the shortest applicable waiting time is limited to 2-3 hours, due to the induced 14.6 min ^{101}Mo activity. This unwanted interference can be suppressed to some extent by applying Cd-covered irradiations since the Q_0-value is about 53 for ^{98}Mo in contrast with 19 for ^{100}Mo. Therefore, some measurements were also performed in this way.

The longest applicable waiting time, on the other hand, is limited by the fact that both x and R tend to a constant value with increasing t_d (D3 $\rightarrow$ 0). It is therefore not worthwile to continue measurements after cooling times of 50-60 h, i.e. when the transient equilibrium is reached.

The measurements were performed at the INW (Thetis reactor) and the KFKI (WWR-M reactor). Different irradiation and measuring conditions as well as evaluation procedures were used to reduce systematic errors.

The detailed results from the different runs are listed in SIMONITS81. The here presented "final" results are slightly diverging from the original ones, due to the introduction of newly evaluated absolute gamma-intensity data for the ^{99}Mo 181.1 and 739.5 keV reference lines [$\gamma_{181.1}$ = 6.08 $\pm$ 0.16% (DICKENS80) versus formerly 6.0 $\pm$ 0.2% (LMRI75); γ_{739} = 12.14 $\pm$ 0.22% (DICKENS80) versus formerly 12.3 $\pm$ 0.3% (LMRI75)]. This leads to :

$$\gamma_2 = 5.10 \pm 0.39\%,$$

and, after introduction of F_2 = 0.8805 $\pm$ 0.0031 [DICKENS80; cf. formerly 0.874] :

$$\gamma_3 = 85.8 \pm 2.3\%.$$

The result for γ_2 is in good agreement with the data of LMRI75, ZIJP79 and DICKENS80 (see Table VII.2-2), and this is true as well for the factor $\gamma_2/F_2\gamma_3$ = 0.0675 $\pm$ 0.0055. It should be mentioned also that the here obtained γ_3-value (to be considered as indicative only) is reasonably consistent with the recent data of DICKENS80 and REUS83, within its (rather large) uncertainty.

The rather large uncertainty on the present result is obviously caused by the indirect measurement relative to $\gamma_{181.1}$ and $\gamma_{739.5}$.

It is worthwile to calculate the error to be expected when deriving the ^{99}Mo-activity (which is proportional to k_0 and ρ) from the measured 140.5 keV line but not correcting for direct formation (i.e. considering only the pure mother-daughter relation). This situation is not at all unrealistic in view of the fact that some compilations do not even mention the existence of this direct formation (see above). The error can be calculated as

$$\Delta,\% = \frac{\gamma_2/F_2\gamma_3}{\dfrac{\lambda_3-\lambda_2 \cdot \dfrac{S_3\ D_3\ C_3}{S_2\ D_2\ C_2}}{\lambda_3-\lambda_2}} \cdot 100 \qquad \text{(VII.2-5)}$$

and amounts for instance to 22.5% for t_{irr} = 5 min, t_d = 2.5 h (after decay of ^{101}Mo/^{101}Tc) and t_m = 1 h, and to 20.1% for t_{irr} = 7 h, t_d = 2.9 h and t_m = 1 h. After a cooling time of about 20 hours the expected error approximates a minimum value of about 6% as derived from :

$$\Delta_{min},\% = \frac{\gamma_2}{F_2\gamma_3} \cdot \frac{\lambda_3-\lambda_2}{\lambda_3} \cdot 100 \qquad \text{(VII.2-6)}$$

3. PRIMARY INTERFERENCES

3.1. Survey of interfering (n,n') and (n,2n) reactions

A problem inherent to comparator-type activation analysis (to which the k_0-method belongs) is the occurrence of primary interfering reactions of the type (n,n') and (n,2n), causing a positive error if not corrected for. Some cases of practical importance are listed in Table VII.3-1, together with the relevant data for the isotopic abundances and cross-sections. Note that $\bar{\sigma}$ represents the fission-neutron averaged cross-section (see e.g. IAEA70).
Table VII.3-2 shows the contribution from (n,γ), (n,n') and (n,2n) to the observed activity, for irradiation in three channels of reactor THETIS with low, medium and high thermalization. It is clear that the formation by (n,2n) is negligible, except for ^{137m}Ba and for ^{117m}Sn in a very hard neutron spectrum. On the other hand, the (n,n') interference is indeed serious, except for ^{77m}Se and ^{87m}Sr.

TABLE VII.3-1 : Some important primary interferences in comparator-type and absolute NAA; cross-section data from MUGHABGHAB81 (σ_0, I_0) and CALAMAND74 ($\bar{\sigma}$; + estimated); * - result from present work; ** - from DECORTE83; *** - based on Q_0 from VANDERLINDEN73

Produced isotope	formed by							
	(n,γ)				(n,n')		(n,2n)	
	θ, %	σ_0, barn	I_0, barn	$\bar{E}_r$, eV	θ, %	$\bar{\sigma}$, barn	θ, %	$\bar{\sigma}$, barn
^{77m}Se	9.0	22	17	577	7.6	0.733	23.6	0.00018+
^{87m}Sr	9.86	0.77*	3.17*	795	7.00	0.112	82.58	0.00011+
^{111m}Cd	12.49	0.14	3	125	12.80	0.228	24.13	0.00042
^{117m}Sn	14.53	0.00596*	0.336*	128	7.68	0.095**	24.22	0.00080+
^{135m}Ba	2.417	0.053*	2.96*	115	6.592	0.30*	7.854	0.0011+
^{137m}Ba	7.854	0.010	0.68***	545	11.23	0.225	71.70	0.0024

3.2. The cases $^{117}Sn(n,n')^{117m}Sn$ and $^{135}Ba(n,n')^{135m}Ba$

The (n,n') interferences for ^{117m}Sn [DECORTE83] and ^{135m}Ba were for the first time fully recognized and elaborated in the course of the present work. Evidence for serious interferences was obtained from Q_0 and k_0-determination [according to Eq. (I.3-18)], which yielded largely inconsistent results in irradiation channels with low and high neutron flux thermalization. In order to estimate the importance of the interference, the following procedure was applied.

a. The k_0-factor was experimentally determined according to the Cd-subtraction method [Eq. (I.3-19)]. Since primary interferences are automatically corrected for, this k_0-factor can be denoted as $(k_0)_{true}$;

b. Q_0-values were determined from Cd-ratio measurements in irradiation positions with highly thermalized neutron fluxes (reactor Thetis : channels 8, 7 and 16). Since appreciable (n,n') interferences are still to be feared, the thus obtained average Q_0-value was considered as a first approximation (Q_0^I) ;

TABLE VII.3-2 : Contribution of (n,γ), (n,n') and (n,2n) to the formation of ^{77m}Se, ^{87m}Sr, ^{111m}Cd, ^{117m}Sn, ^{135m}Ba and ^{137m}Ba in three channels of reactor THETIS [ϕ_f = fission neutron flux]

Produced isotope	Formed by	THETIS Channel 17	5	8
		ϕ_s/ϕ_e = 15 ϕ_s/ϕ_f = 1.6 α = -0.028	ϕ_s/ϕ_e = 42 ϕ_s/ϕ_f = 21 α = 0.052	ϕ_s/ϕ_e = 158 ϕ_s/ϕ_f = 118 α = 0.11
^{77m}Se	(n,γ) (n,n') (n,2n)	98.4% 1.6% ∿0.001%	99.87% 0.13% -	99.98% 0.02% -
^{87m}Sr	(n,γ) (n,n') (n,2n)	95.3% 4.7% ∿0.0005%	99.5% 0.5% -	99.91% 0.09% -
^{111m}Cd	(n,γ) (n,n') (n,2n)	71.6% 28.3% 0.1%	94.6% 5.4% -	98.7% 1.3% -
^{117m}Sn	(n,γ) (n,n') (n,2n)	49.5% 49.2% ∿1.3%	83.2% 16.3% ∿0.5%	94.3% 5.6% ∿0.1%
^{135m}Ba	(n,γ) (n,n') (n,2n)	35.1% 64.6% ∿0.3%	73.4% 26.5% ∿0.1%	90.2% 9.8% -
^{137m}Ba	(n,γ) (n,n') (n,2n)	23.0% 72.1% 4.9%	57.0% 40.3% 2.7%	80.7% 18.1% 1.2%

c. From determination of k_0'-factors [according to Eq. (I.3-18)] in channels with poorly thermalized fluxes (reactor Thetis : channels 3 and 9), and with introduction of ϕ_s/ϕ_f, a first approximation of $(\bar{\sigma}_{n,n'})$ is obtained as :

$$(\bar{\sigma}_{n,n'})_I = \left[\frac{k_0'}{(k_0)_{true}} - 1\right] \cdot \frac{\theta(^{116}Sn)}{\theta(^{117}Sn)} \cdot \sigma_0(^{116}Sn) \cdot \frac{\phi_s}{\phi_f} \cdot \left[1 + \frac{Q_{0,}^{I\,116}Sn(\alpha)}{f}\right] \qquad \text{(VII.3-1)}$$

d. The experimental Q_0-values (sub b.) can now be corrected for (n,n') interference, yielding a second approximation Q_0^{II}, thus enabling calculation of $(\bar{\sigma}_{n,n'})_{II}$, and so on. This iterative procedure leads to quickly converging Q_0 and $\bar{\sigma}_{n,n'}$ values.

The $\bar{\sigma}_{n,n'}$-values finally obtained were :

$^{117}Sn(n,n')^{117m}Sn$; $\bar{\sigma}_{n,n'} = 0.095$ b (cf. $\sigma_0[^{116}Sn(n,\gamma)^{117m}Sn] = 0.00596$ b)

$^{135}Ba(n,n')^{135m}Ba$; $\bar{\sigma}_{n,n'} = 0.30$ b (cf. $\sigma_0[^{134}Ba(n,\gamma)^{135m}Ba] = 0.053$ b)

It should be kept in mind that these results are still approximative, since the threshold energies for the reactions $^{117}Sn(n,n')^{117m}Sn$ and $^{135}Ba(n,n')^{135m}Ba$ are not high enough to assume interaction in a pure fission neutron spectrum, even in the poorly thermalized fluxes mentioned sub c.

3.3. Precautions and corrections

The following considerations can be made with respect to the problem of primary interferences :

- irradiation in very well thermalized neutron spectra leads to negligible errors; this is for instance the case in channel R4V4 of the DR-3 reactor, with ϕ_s/ϕ_f of the order of 600 ;
- other alternatives exist for the determination of Se, Sr, Cd, Sn and Ba, e.g. via ^{75}Se, ^{85}Sr, $^{115}Cd/^{115m}In$, $^{117m}Cd/^{117}Cd/^{117m}In/^{117}In$, $^{113(m)}Sn/^{113m}In$, ^{123m}Sn, ^{125m}Sn, ^{131}Ba, ^{133m}Ba, ^{139}Ba ;
- corrections can be applied on condition that the fast flux component is known or is experimentally determined. This cannot be considered as a serious drawback, since ϕ_f monitoring is often necessary in neutron activation analysis - whatsoever the standardization procedure - so as to account for interfering (n,p) or (n,α) reactions.

3.4. Corrections based on the $^{90}Zr(n,2n)^{89}Zr$ monitor

Zr, the monitor used for α and f determination, offers an interesting possibility for evaluating the fission neutron flux ϕ_f, at least in cases of high flux and low thermalization. Recently, the ^{235}U spectrum averaged

cross-section for the reaction $^{90}Zr(n,2n)^{89}Zr$ has been accurately determined by two research groups, namely SEKINE81 [(0.104 ± 0.005)mbarn] and MANNHART85 [(0.103 ± 0.004)mbarn]. The weighted average, (0.1034 ± 0.0031)mbarn, was adopted in the present work. Other relevant nuclear data are : M_{Zr} = 91.22 ; $\theta(^{90}Zr)$ = (51.45 ± 0.02)% [DEBIEVRE85]; $T(^{89}Zr)$ = (78.43 ± 0.08) h [KOCHER81] ; γ(909.1 keV) = (99.04 ± 0.03)% [KOCHER81]. The observed 909.1 keV peak area should be corrected for a spectral interference from the 911.1 keV ^{228}Ac background line. Thus, from measurement of the ^{89}Zr 909.1 keV line on an efficiency-calibrated detector, ϕ_f can be obtained as :

$$\phi_f = \frac{A_{sp}}{N_A.\theta.\gamma.\bar{\sigma}_{n,n'}.\varepsilon_p/M} \qquad \text{(VII.3-2)}$$

Table VII.3-3 shows for 4 irradiation channels a comparison of results obtained from $^{90}Zr(n,2n)^{89}Zr$ on one hand, and from the frequently used $^{115}In(n,n')^{115m}In$, $^{28}Al(n,\alpha)^{24}Na$, $^{54}Fe(n,p)^{54}Mn$ and $^{58}Ni(n,p)^{58}Co$ monitors on the other hand. Reasonable consistency is obtained, even when comparing the results from ^{115m}In and ^{89}Zr, with very low (340 keV) and very high (12 MeV) threshold energy, respectively. It should be noted that a similar comparison in channel R4V4 of the DR-3 reactor ($\phi_s/\phi_f \simeq 600$) revealed significant discrepancies, It is indeed to be expected that, in view of the relatively low threshold energy for (n,n') reactions, distortion of the fission spectrum at the low-energy side, in case of high thermalization, will lead to considerable errors. Thus, the accuracy will, fortunately, be better for hard neutron spectra - where the correction is the highest.

TABLE VII.3-3 : Comparison of ϕ_f obtained from various monitors, including $^{90}Zr(n,2n)^{89}Zr$

Reactor channel (ϕ_s/ϕ_f)	ϕ_f (n cm^{-2} s^{-1}), obtained from				
	$^{90}Zr(n,2n)^{89}Zr$ $\bar{\sigma}_{n,2n}$=0.1034mb	$^{115}In(n,n')^{115m}In$ $\bar{\sigma}_{n,n'}$=189mb	$^{28}Al(n,\alpha)^{24}Na$ $\bar{\sigma}_{n,\alpha}$=0.705mb	$^{54}Fe(n,p)^{54}Mn$ $\bar{\sigma}_{n,p}$=79.7mb	$^{58}Ni(n,p)^{58}Co$ $\bar{\sigma}_{n,p}$=108.5mb
BR2 Ch.H323 ($\phi_s/\phi_f \simeq 4$)	$2.39.10^{13}$	-	-	-	$2.34.10^{13}$
THETIS Ch.3 ($\phi_s/\phi_f \simeq 7$)	$2.28.10^{11}$	$2.59.10^{11}$	$1.91.10^{11}$	$1.99.10^{11}$	$1.97.10^{11}$
THETIS Ch.5 ($\phi_s/\phi_f \simeq 20$)	$5.76.10^{10}$	$6.06.10^{10}$	$4.70.10^{10}$	$5.32.10^{10}$	$4.77.10^{10}$
THETIS Ch.8 ($\phi_s/\phi_f \simeq 120$)	$1.25.10^{9}$	$1.52.10^{9}$	$1.53.10^{9}$	$1.28.10^{9}$	$1.37.10^{9}$

4. (n,γ) REACTIONS WITH WESCOTT - $g(T_n) \neq 1$

4.1. The $^{197}Au(n,\gamma)^{198}Au$ comparator

Since the k_0-methodology is written in the Høgdahl convention, inclusion of (n,γ) reactions which do not exactly obey the $\sigma(v) \sim 1/v$ law up to 1-2 eV will lead to inaccuracies, the importance of which is related to the deviation of the Westcott g-factor from unity. More precisely, the estimation of the error introduced should be based on the variation of g with neutron temperature, rather than on the g-value itself, and it is interesting to demonstrate this statement in a simplified way with the example of $^{197}Au(n,\gamma)^{198}Au$, the ultimate comparator. In general, a recommended $k_{0,Au}$-factor is the average of determinations in several channels of the THETIS and WWR-M reactors, with neutron temperatures from e.g. 20 to 100°C. Thus, according to GRYNTAKIS 75B, g_{Au} is ranging from 1.0038 to 1.0068. This variation of 0.3% (well within the experimental uncertainty) is - roughly speaking - transferred to the $k_{0,Au}(exp)$ values. Hence, the average recommended $k_{0,Au}$-factor is approximately corresponding to an average neutron temperature of 60°C, with $g_{Au} = 1.0053$. If this $k_{0,Au}$-factor is now used in an actual analysis at a neutron temperature between 20 and 100°C, the committed error on the resulting concentration turns out to be maximum 0.15%, which is negligible.

4.2. Problematic cases : estimation of errors

Cases similar to those mentioned above are for instance $^{109}Ag(n,\gamma)^{110m}Ag$, $^{133}Cs(n,\gamma)^{134}Cs$, $^{138}Ba(n,\gamma)^{139}Ba$, $^{181}Ta(n,\gamma)^{182}Ta$, $^{186}W(n,\gamma)^{187}W$, $^{185}Re(n,\gamma)^{186}Re$, $^{232}Th(n,\gamma)^{233}Th$ and $^{238}U(n,\gamma)^{239}U$.

A somewhat more serious situation occurs for reactions like $^{103}Rh(n,\gamma)$ [see Table VII.4-1] with g-factors deviating a few percent from unity. Here, errors of the order of 1-2% are to be expected, which is still acceptable.

From analytical standpoint there are two cases where the g-factor is drastically deviating from unity, and thus significant errors will be committed : $^{151}Eu(n,\gamma)$ and especially $^{176}Lu(n,\gamma)$ [see Table VII.4-1]. In principle, determination of Eu and Lu can also be performed via the $^{153}Eu(n,\gamma)^{154}Eu$ and $^{175}Lu(n,\gamma)^{176m}Lu$ reactions (for which recommended k_0-factors are available).

However, for instance in non-destructive NAA of geological material, measurement of ^{154}Eu and ^{176m}Lu gives rise to poorer precision or even to a complete loss of quantitative information (inherent poorer sensitivity for ^{154}Eu; short half-life and low gamma-energy for ^{176m}Lu), and this is - especially for the rare earths - a regrettable situation.

Although up to now no experimental work related to the above problem has been performed, the solution is straightforward : one should change over to the Westcott-convention, including a neutron temperature monitoring. The latter can be accomplished by the well-known technique of Lu-irradiation in two irradiation positions : the one under investigation and a reference position with known temperature (see e.g. IAEA70). Note that this relative measurement was formerly recommended because of the uncertainty of the knowledge regarding the cross-section for $^{176}Lu(n,\gamma)^{177}Lu$ and the ^{177}Lu decay scheme. In view of the recently re-evaluated data of interest (σ_0 = (2100 $\pm$ 50)barn[NNDC COMP.CH. 85] ; I_0 = (1100 $\pm$ 70)barn[NNDC COMP.CH.85]; γ(208 keV) = (11.0 $\pm$ 0.4)% [KOCHER81]), it might be interesting to explore the possibility of an absolute T_n-monitoring with acceptable accuracy.

Finally, it is worthwile to dwell on the situation arising when a neutron temperature monitoring would be performed. Since Lu would be coirradiated, it can serve as a relative standard for Lu-determination, and the complication of T_n-monitoring and changeover to the Westcott-convention is then only necessary for the $^{151}Eu(n,\gamma)$reactions. However, if recommended k_0-factors would

TABLE VII.4-1 : Isotopes for which application of the k_0-method gives rise to small or significant errors (see text); (a) = WESTCOTT62, (b) = GRYNTAKIS75, (c) = ENDF/B-V82, (d) = MOENS81, (e) = assumed to show a limited deviation from g (20°C)

Isotope measured	g	
	20°C	100°C
Subject to 1-2% errors		
$^{104(m)}Rh$	1.023 (a)	1.041 (a)
^{116m}In	1.0175 (b)	1.0321 (b)
^{154}Eu	1.0290 (b)	1.0074 (b)
$^{165(m)}Dy$	0.9876 (c)	- (e)
^{169}Yb	1.050 (d)	1.092 (d)
^{176m}Lu	0.9766 (c)	- (e)
^{186}Re	1.0049 (c)	- (e)
$^{188(m)}Re$	0.9819 (c)	- (e)
^{192}Ir	1.0326 (b)	1.0425 (b)
^{194}Ir	1.0218 (b)	1.0400 (b)
subject to significant errors		
^{152m}Eu	0.8936 (b)	0.8183 (b)
^{152}Eu	0.9022 (b)	0.8336 (b)
^{177}Lu	1.6914 (b)	2.2421 (b)

be available for ^{152m}Eu and ^{152}Eu (again, as above for Au, for $T_n \simeq 60°C$ and g = 0.8532), it appears from the g-factors of Table VII.4-1 - and following the same reasoning as outlined above for Au - that the maximum committed error on the Eu-concentration would be $\sim$ 4.5%, which is in most cases acceptable for chondrite normalization. Thus, it seems justified to determine the ^{152m}Eu and ^{152}Eu k_0-factors, which - although physically not very meaningful - will lead to reasonably accurate analytical results.

5. VARIABILITY OF THE NEUTRON FLUX DURING IRRADIATION

5.1. Treatment of the problem

When variations occur in the neutron flux during irradiation (and supposing that f and α remain constant), one should replace for instance Eq. (I.3-20) by :

$$\rho_{a,ppm} = \frac{\left(\frac{N_p/t_m}{S'DCW}\right)_a}{\left(\frac{N_p/t_m}{S'DCW}\right)_m} \cdot \frac{k_{0,c}(m)}{k_{0,c}(a)} \cdot \frac{G_{th,m} f + G_{e,m} Q_{0,m}(\alpha)}{G_{th,a} f + G_{e,a} Q_{0,a}(\alpha)} \cdot \frac{\varepsilon_{p,m}}{\varepsilon_{p,a}} \cdot 10^6 \qquad \text{(VII.5-1)}$$

with, in general :

$$S' = \int_0^{t_{irr}} F(t) \lambda \, e^{\lambda(t - t_{irr})} \, dt \qquad \text{(VII.5-2)}$$

where F(t) is the time-dependent neutron flux function, e.g. normalized to unity at an arbitrarily chosen t_{ref}. Eqs (I.3-18), (I.3-19) and (I.3-21) should be modified in a similar way.

5.2. Estimation of errors

If F(t) = 1, or if $T_a = T_m$, Eq. (VII.5-1) reduces to Eq. (I.3-20).

If $T \gg t_{irr}$, one can write $e^{\lambda t} \simeq 1 + \lambda t \simeq 1$. With $e^{-\lambda t_{irr}} \simeq 1 - \lambda t_{irr} \simeq 1$, Eq. (VII.5-2) becomes :

$$S' = \lambda \int_0^{t_{irr}} F(t) \, dt$$

and since $\lambda t_{irr} \simeq S$:

$$S' = S \int_0^{t_{irr}} F(t)\, dt/t_{irr} \qquad \text{(VII.5-3)}$$

Thus, if both T_a and $T_m \gg t_{irr}$, the ratio S'_a/S'_m in Eq. (VII.5-1) can be replaced by the ratio S_a/S_m, hence leading to the usual Eq. (I.3-20). Consequently, the resulting error on ρ_a is negligible.

If $T \ll t_{irr}$, only the flux at the end of the irradiation is "sensed". On condition that the flux variation from $\sim (t_{irr} - 7T)$ to t_{irr} is negligible, one can put $F_{end} \simeq$ constant, and Eq. (VII.5-2) becomes (with $S \simeq 1$) :

$$S' = F_{end} \qquad \text{(VII.5-4)}$$

Thus, if the above holds for both monitor and analyte, Eq. (VII.5-1) leads again to the usual Eq. (I.3-20), and the resulting error on ρ_a is negligible.

It is interesting to consider for instance the example of a β% linear flux change during t_{irr}, i.e. $F(t) = 1 + 0.01\ \beta t/t_{irr}$. Then, Eq. (VII.5-2) becomes :

$$S' = S \left[1 + 0.01\ \beta \left(\frac{1}{S} - \frac{1}{\lambda t_{irr}} \right)\right] \qquad \text{(VII.5-5)}$$

The % error on ρ, induced by not taking into account (say : by ignoring) the flux change, is given by :

$$\%E = \left(\frac{S_m\ S'_a}{S_a\ S'_m} - 1 \right) . \ 100 \qquad \text{(VII.5-6)}$$

The following conclusion can be drawn :

- $\beta = 0$, i.e. $F(t) = 1$, leads to $S = S'$ and $\%E = 0$, as expected ;
- $T_m \simeq T_a$ leads to $S_m \simeq S_a$, $S'_m \simeq S'_a$ and $\%E \simeq 0$, as expected ;
- $T \ll t_{irr}$ leads to $S \simeq 1$, $\lambda t_{irr} \gg 1$, and thus $S' \simeq 1 + 0.01\ \beta$. This means that only the flux at the end of the irradiation is "sensed" [cf. Eq. (VII.5-4)]. If this condition holds for both monitor and analyte, one obtains $\%E \simeq 0$;
- $T \gg t_{irr}$ leads to [from Eq. (VII.5-3)] :

$$S' \simeq S\ (1 + 0.01\ \beta/2) \qquad \text{(VII.5-7)}$$

This means that one observes a response to the average of the flux. If this condition holds for both monitor and analyte, one obtains $\%E \simeq 0$;

- if $T_a \ll t_{irr}$ and $T_m \gg t_{irr}$, Eq. (VII.5-6) leads to :

$$\%E \simeq \frac{\beta/2}{1 + 0.01\ \beta/2}$$

and for β small :

$$\%E \simeq \beta/2 \qquad \text{(VII.5-8)}$$

In the reverse case ($T_m \ll t_{irr}$ and $T_a \gg t_{irr}$) one obtains :

$$\%E \simeq -\beta/2 \qquad \text{(VII.5-9)}$$

In a practical example, the % uncertainty induced on the k_0-factors or the analytical results for some elements, induced by not taking into account a 5% linear flux change during a 10 min or 7 h irradiation period [with Au (^{198}Au; T = 2.695 d) as the comparator or monitor] is as follows :

a. t_{irr} = 10 min

Determination of Al (^{28}Al; T = 2.240 min) → %E = ± 1.1%
Mo (^{101}Mo; T = 14.6 min) → %E = ± 0.19%
Cl (^{38}Cl; T = 37.21 min) → %E = ± $7.5.10^{-2}$%
Mn (^{56}Mn; T = 2.5785 h) → %E = ± $1.8.10^{-2}$%

b. t_{irr} = 7 h

Determination of Mn (^{56}Mn; T = 2.5785 h) → %E = ± 0.7%
Sb (^{122}Sb; T = 2.70 d) → %E = ± 5.10^{-5}%
Sb (^{124}Sb; T = 60.20 d) → %E = ± $2.9.10^{-2}$%
Co (^{60}Co; T = 5.271 y) → %E = ± $3.0.10^{-2}$%

Thus, the maximum uncertainty is of the order of ∿ 1%. Note that in practice the uncertainties will be lower (and randomized), since a final result (k_0 or ρ) is originating from several irradiations.

The following example illustrates the practical correction procedure to be applied when the flux variation [F(t)] during irradiation is known. For one of the irradiations in channel H323 of the BR-2 reactor, the information sheet revealed the reactor power variations as listed in Table VII.5-1. The situation is visualized in Fig. VII.5-1.

TABLE VII.5-1 : Irradiation in channel H323 of the BR-2 reactor at Mol/Belgium : power data as specified on the information sheet

DATE/TIME	REACTOR POWER, MW	NOTES
----	----	START OF CYCLE
28.04.86/15.48	71.25	
30.04.86/08.35	71.25	SAMPLE IN
03.05.86/03.11	71.25	
03.05.86/03.14	0.57	POWER DROP
03.05.86/03.28	34.2	POWER INCREASE
03.05.86/03.50	57.0	POWER INCREASE
03.05.86/04.18	68.4	POWER INCREASE
03.05.86/04.37	71.2	
10.05.86/04.00	71.2	SAMPLE OUT
10.05.86/04.14	0.57	POWER DROP END OF CYCLE

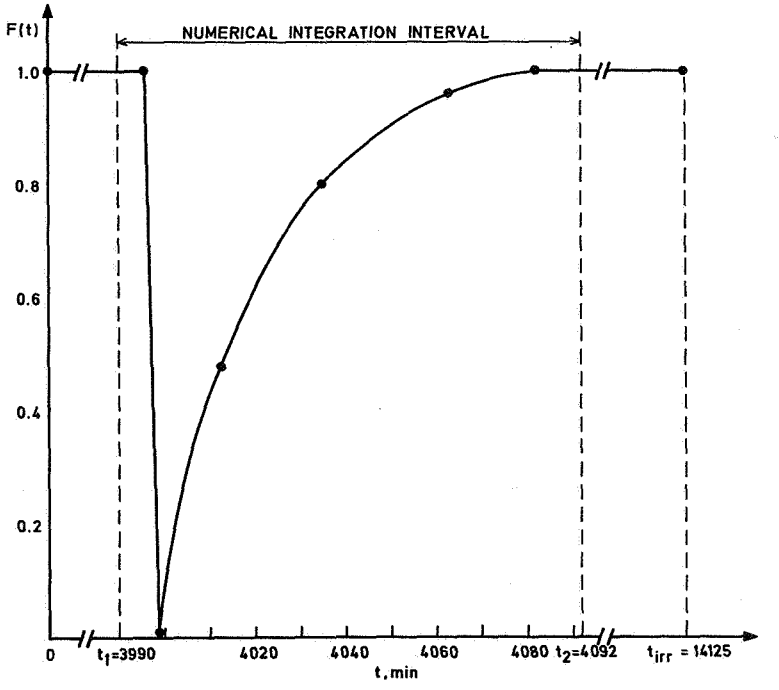


Fig. VII.5-1 : Flux variation (normalized) during an irradiation in channel H323 of the BR-2 reactor (see Table VII.5-1)

Although it can be foreseen that in this case (with a power decrease during a $\sim$ 1.5 h period as compared to a 235.4 h irradiation period) S' will not differ significantly from S, it might be interesting to give the general solution for the calculation of S'.

a. For the periods ($t_A \rightarrow t_B$) with constant power (flux), the partial $S_{t_A}^{t_B}$-factors are calculated as :

$$S_{t_A}^{t_B} = e^{-\lambda t_{irr}} (e^{\lambda t_B} - e^{\lambda t_A}) \qquad \text{(VII.5-10)}$$

In the above case this yields (see Fig. VII.5-1) :

$$S_0^{t_1} = e^{-\lambda t_{irr}} (e^{\lambda t_1} - 1) \qquad \text{(VII.5-11)}$$

and

$$S_{t_2}^{t_{irr}} = 1 - e^{\lambda (t_2 - t_{irr})} \qquad \text{(VII.5-12)}$$

b. For the periods ($t_C \rightarrow t_D$) with varying power (flux), the partial $S_{t_C}^{t_D}$-factors can be calculated by numerical integration of Eq. (VII.5-2).
In the above case this means :

$$S_{t_1}^{t_2} = \int_{t_1}^{t_2} F(t)\, \lambda\, e^{\lambda (t - t_{irr})}\, dt \qquad \text{(VII.5-13)}$$

This numerical integration may be performed according to the trapezoidal rule or Simpson's rule, using a programmable HP-calculator [HPMATHPAC76].

c. The saturation factor for use is finally :

$$S' = \Sigma\, S_{t_A}^{t_B} \text{ (constant } \phi) + \Sigma\, S_{t_C}^{t_D} \text{ (non constant } \phi) \qquad \text{(VII.5-14)}$$

In the above case this leads to :

$$S' = S_0^{t_1} + S_{t_2}^{t_{irr}} + S_{t_1}^{t_2} \qquad \text{(VII.5-15)}$$

Table VII.5-2 shows the detailed results for the flux monitors ^{198}Au, ^{97}Zr and ^{95}Zr. As expected in this particular case, the correct S' is not differing significantly from S, calculated by not taking into account (say: ignoring) the flux variation. Evidently, the maximum discrepancy (0.16%) is ob-

served for the long-lived ^{95}Zr-isotope. The discrepancies would of course become more serious for larger $(t_2 - t_1)/t_{irr}$.

TABLE VII.5-2 : Calculation of saturation factors for a non-constant flux [see Table VII.5-1 and Fig. VII.5-1]. S' is the correct saturation factor. S is the saturation factor obtained by not taking into account the flux variation

Factor	^{198}Au T = 2.695 d	^{97}Zr T = 16.74 h	^{95}Zr T = 64.03 d
$S_0^{t_1}$ [Eq. (VII.5-11)]	$8.339.10^{-2}$	$8.587.10^{-4}$	$2.738.10^{-2}$
$S_{t_2}^{t_{irr}}$ [Eq. (VII.5-12)]	$8.334.10^{-1}$	$9.9902.10^{-1}$	$7.265.10^{-2}$
$S_{t_1}^{t_2}$ [Eq. (VII.5-13)]	$2.346^5.10^{-3}$	$5.230^5.10^{-5}$	$5.530.10^{-4}$
S' [Eq. (VII.5-15)]	$9.191.10^{-1}$	$9.9993.10^{-1}$	$1.0058.10^{-1}$
S	$9.198.10^{-1}$	$9.9994.10^{-1}$	$1.0074.10^{-1}$

Special cases of the above occur when the samples are in the irradiation position during the start-up and/or the close-down of the reactor. The latter situation should by all means be avoided for short-lived isotopes. As outlined, the problem can be solved by numerical integration over the non-constant flux period, on condition that the change of the flux(power) with time is recorded. If this is not the case [F(t) not known, although a serious flux variation is presumed], the variability of the neutron flux during irradiation is to be considered as the very limiting condition for applicability of the k_0-standardization method.

From the above considerations, and taking into account the proper stability of the flux in the irradiation facilities of reactor Thetis (see Fig. II.1-2) [and also of reactors WWR-M and DR-3 ; see II.1.2.1 and II.1.2.2], it can be concluded that the uncertainties induced on k_0 [$s_{k_0}(F(t))$] are much lower than 1%. The same holds for [$s_\rho(F(t))$] if several irradiations are involved.

Nothing has been said so far about the effects caused by a variability of f and α during irradiation. However, in view of the moderate variations observed (Fig. II.1-3) and the large error reduction factors to be expected [$Z_{k_{0,\rho}}(F(f,\alpha))$ very small], one can safely assume that these effects are negligible.

6. INTERMITTENT IRRADIATION

6.1. Relevant equations

When performing N subsequent irradiations (1, 2,...i,...N), the simple equation for concentration calculation is no longer valid. For instance, Eq. (I.3-20) should be extended as (with $G_{th} = G_e = 1$) :

$$\rho_a,\text{ppm} = \left(\frac{N_p/t_m}{CW}\right)_a \cdot \frac{k_{0,c}^{(m)}}{k_{0,c}^{(a)}} \cdot \frac{1}{\varepsilon_{p,a}} \left[\sum_{i=1}^{N} \left\{\left(\frac{A_{sp,m}\, S_a\, D_a}{\varepsilon_{p,m}}\right)_i \cdot \frac{f_i + Q_{0,a}(\alpha_i)}{f_i + Q_{0,m}(\alpha_i)}\right\}\right]^{-1} \cdot 10^6 \qquad \text{(VII.6-1)}$$

where D_i is related to a decay time $t_{d,i}$ from the end of irradiation i. In Eq. (VII.6-1) it is assumed that during each irradiation the flux parameters are constant, but that they vary from irradiation to irradiation. It is evident that this requires each time the coirradiation of new monitors (also for f and α), which should be measured individually. Note that it is even not necessary to measure the monitor every time in the same counting position; if it is done, then of course $\varepsilon_{p,m}$ is not a function of i.

In many practical situations (e.g. when irradiating N times in the same channel of the Thetis reactor), it is justified to assume that f and α do not change significantly from irradiation to irradiation (see Fig. II.1-3). Then, Eq. (VII.6-1) becomes :

$$\rho_a,\text{ppm} = \left(\frac{N_p/t_m}{CW}\right)_a \cdot \frac{k_{0,c}(m)}{k_{0,c}(a)} \cdot \frac{f + Q_{0,m}(\alpha)}{f + Q_{0,a}(\alpha)} \cdot \frac{1}{\varepsilon_{p,a}} \left[\sum_{i=1}^{N} \left(\frac{A_{sp,m}\, S_a\, D_a}{\varepsilon_{p,m}}\right)_i\right]^{-1} . 10^6 \qquad \text{(VII.6-2)}$$

where f and α can be determined a priori.

In the extreme, when also the flux itself remains constant from irradiation to irradiation, it is sufficient to keep the same monitor with the sample during the N irradiations, and to perform one measurement of the accumulated activity. One obtains :

$$\rho_a,\text{ppm} = \frac{\left\{\dfrac{N_p/t_m}{CW \sum_{i=1}^{N} S_i\, D_i}\right\}_a}{\left\{\dfrac{N_p/t_m}{Cw \sum_{i=1}^{N} S_i\, D_i}\right\}_m} \cdot \frac{k_{0,c}(m)}{k_{0,c}(a)} \cdot \frac{f + Q_{0,m}(\alpha)}{f + Q_{0,a}(\alpha)} \cdot \frac{\varepsilon_{p,m}}{\varepsilon_{p,a}} . 10^6 \qquad \text{(VII.6-3)}$$

Note that an intermittent irradiation can be considered as a special case of flux variability during irradiation (see VII.5), namely with F(t) = 0 during certain time intervals. Following this reasoning, Eq. (VII.6-3) can be easily derived from Eq. (VII.5-1).

6.2. Estimation of errors

No significant loss of accuracy is induced on condition that proper care is taken with respect to the experimental work. This is illustrated by the following example, dealing with the determination of Ta in Nb-wire (k_0-method with ^{95}Zr as the flux monitor) :

a. one irradiation in channel 3/reactor Thetis ; t_{irr} = 7 h.
   Result : (20.5 $\pm$ 0.5) ppm Ta [only random error given] ;

b. six irradiations of 7 h each in channel 3/reactor Thetis.
   Result : (21.0 $\pm$ 0.4) ppm Ta [only random error given].

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CHAPTER VIII

ACCURACY, TRACEABILITY AND APPLICABILITY

1. ACCURACY

1.1. Evaluation of the accuracy

It is difficult to give in general a final account of the accuracy of the k_0-standardization. The accuracy depends indeed on a number of parameters such as the magnitude of Q_0, f and α, the counting geometry and the seriousness of true-coincidence effects. However, it might be instructive to estimate some grand mean of the accuracy, based on considerations with respect to uncertainties induced by the relevant steps and parameters. This is shown for NAA in Table VIII.1-1, for not too extreme conditions of irradiation and counting, and for (n,γ) reactions with medium Q_0-values and with no special difficulties [(n,n') interferences, $g(T_n) \neq 1$, etc.] . Following the recommendations of the BIPM Working Group on the Statement of Uncertainties [KAARLS80, MULLER84], quadratic summation leads to an overall uncertainty of less than 4%.

When comparing this to relative standardization, it must be remarked that, whereas usually all other uncertainties can be dropped, the uncertainty induced by k_0 should be replaced by the uncertainty on the standard preparation. According to the experience gained in the present work, systematic errors due to non-stoichiometry of compounds or caused by pipetting of small volumes are no exception and can easily amount to a few percents. In fact, such errors were detected and eliminated during the cooperative but independent k_0-determinations.

As to absolute standardization, it will be shown in the APPENDIX that inaccurate knowledge of absolute nuclear data (σ_0, γ and θ) often leads to systematic errors of tens of percents.

TABLE VIII.1-1 : Final account of the accuracy of k_0-standardization in NAA; the overall uncertainty is obtained by quadratic summation of the individual contributions

Uncertainty on analysis result (NAA)		
induced by	contribution	remarks
k_0	∿ 1%	< 2% for "recommended" k_0-factors (see VI.2.1)
Q_0	∿ 1%	actually lower, because of correlation (see V.3.4)
α	∿ 1.5%	average of all data in Table V.1-15
f	∿ 1%	f from bare Zr-monitoring; $s_f(\alpha)$ not included (see V.2.2 and V.2.5)
ε_p-measurement and conversion	∿ 2%	see Chapter III
coinc. correction	∿ 1.5%	see IV.3
Overall	∿ 3.5%	quadratic summation

1.2. Analysis of reference materials

In addition to the above considerations, the accuracy of the k_0-standardization was controlled by analysing a number of reference materials. The analyses were usually performed at both the INW and the KFKI, and implied different sample preparation (geometry, blanks, etc.), irradiation (f, α, interferences from ^{235}U-fission and threshold reactions, etc.), counting (dead time, pulse pile-up, detection efficiency, coincidence, etc.) and gamma spectrum interpretation (peak area evaluation, spectral interferences, etc.). As a matter of course, the INW and KFKI results are correlated by the introduction of identical k_0-factors and other nuclear data (Q_0, $\bar{E}_r$, T, etc.). The following reference materials were analysed :

a. SSB, a 7-element synthetic standard for biological materials, the preparation and properties of which have been described by Kolomi'tsev et al. [KOLOMI'TSEV74/74B] and Moshulishvili et al. [MOSHULISHVILI75]. The results of analysis at the INW and the KFKI (for the seven elements Sc, Co, Zn, Se, Ag, In and Sb) were found to lie always within the ± 6% maximal uncertainty specified on the given concentrations [MOENS81, LIN84] ;

b. geological reference materials USGS BCR-1 (basalt), USGS G-2 (granite) and USGS PCC-1 (peridotite) [LIN81/84, DECORTE84]. Although some 30 elements were determined, conclusions with respect to consistency could not always be drawn in a straightforward way. Only in case of low uncertainties (good counting statistics) on the INW/KFKI results, and in case of well-established specified concentrations could the accuracy of the k_0-standardization be investigated. Table VIII.1-2 shows for USGS G-2 a comparison of such INW and KFKI results with so-called "consensus" values given by Gladney et al. [GLADNEY83]. It should be remarked that the counting conditions at the INW (samples close to the detector) and the KFKI (samples at "ref" distance to the detector) were largely different, thus proving the accuracy of ε_p-conversion and coincidence correction. The results of Table VIII.1-2 confirm the adequate accuracy of the k_0-standardization method.

TABLE VIII.1-2 : Comparison of INW/KFKI results and "consensus" values, for some "low uncertainty" elements in USGS G-2 (* uncorrelated uncertainties ; ** estimated total uncertainty)

Element	Concentration in USGS G-2				
	"consensus" value [GLADNEY83]	INW	KFKI	INW/KFKI weighted mean	Ratio (INW/KFKI)/"consensus"
Ce, ppm	159 ± 11	149 ± 6*	152 ± 1*	152 ± 3**	0.96 ± 0.07
Co, ppm	4.6 ± 0.4	4.54 ± 0.02	4.64 ± 0.07	4.55 ± 0.09	0.99 ± 0.09
Fe, %	1.87 ± 0.07	1.82 ± 0.01	1.82 ± 0.02	1.82 ± 0.04	0.97 ± 0.04
Hf, ppm	7.9 ± 0.7	8.13 ± 0.06	8.12 ± 0.15	8.13 ± 0.17	1.03 ± 0.09
La, ppm	86 ± 5	85.8 ± 0.2	85.0 ± 0.7	85.6 ± 1.7	1.00 ± 0.06
Na, %	3.02 ± 0.09	3.04 ± 0.01	2.97 ± 0.06	3.04 ± 0.06	1.01 ± 0.04
Sc, ppm	3.5 ± 0.4	3.40 ± 0.01	3.47 ± 0.05	3.40 ± 0.07	0.97 ± 0.11
Tb, ppm	0.48 ± 0.07	0.46 ± 0.01	0.44 ± 0.01	0.45 ± 0.01	0.94 ± 0.14
Th, ppm	24.6 ± 1.5	24.2 ± 0.1	24.7 ± 0.1	24.4 ± 0.5	0.99 ± 0.06

c. spectrographic steel standards NBS 408a and NBS 442 [MOENS84B, DEMETER86]. These materials are interesting because they give upon irradiation rise to relatively simple gamma-spectra. The analyses were only performed at the KFKI. The results for the major and minor elements Cr, Cu, Fe, Mn and Mo were to within 2% consistent with the certified NBS-values [except for Cu in NBS 442 (ratio KFKI/NBS = 0.89), where the uncertainty on the KFKI-results is 12%].

d. Fired clay of Ghent (FCG), a candidate multi-element NAA standard for pottery [DECORTE84]. For 33 elements comparison was possible with results from relative standardization [GHYSELS]. Consistency to within $\sim$ 10% was obtained for 28 elements, and to within $\sim$ 5% for 21 elements. For Ag, Cl, Sb, Tb and W discrepancies of 23-86% were found. This is surprising, since in some of the other analysed materials acceptable correspondence was observed. This is shown in Fig. VIII.1-1, where the ratios of the INW/KFKI results to the specified values for Sb in 6 materials are given. It must be concluded that the outlying value for FCG is due to a gross error in the relative standardization, and this is possibly the case for other elements as well.

e. NBS SRM 1633a coal fly ash [LIN84, DECORTE84, DEMETER86]. A comparison between the INW/KFKI results and the specified values (certified or tentative) is made in Fig. VIII.1-2. As seen, the consistency is for most of the certified elements better than 3%, and for all of them better than 6%, except for Mg where the INW/KFKI result (showing, however, a high uncertainty) is 14% higher than the NBS-certification.

It can be concluded that the analysis results fully confirm the predicted standardization uncertainty of < 4%, as evaluated in VIII.1.1.

2. TRACEABILITY

2.1. Definitions and basic considerations

Traceability is defined by the U.S.National Bureau of Standards [NBS85] as the ability to trace the uncertainty of a measurement or a measured value;

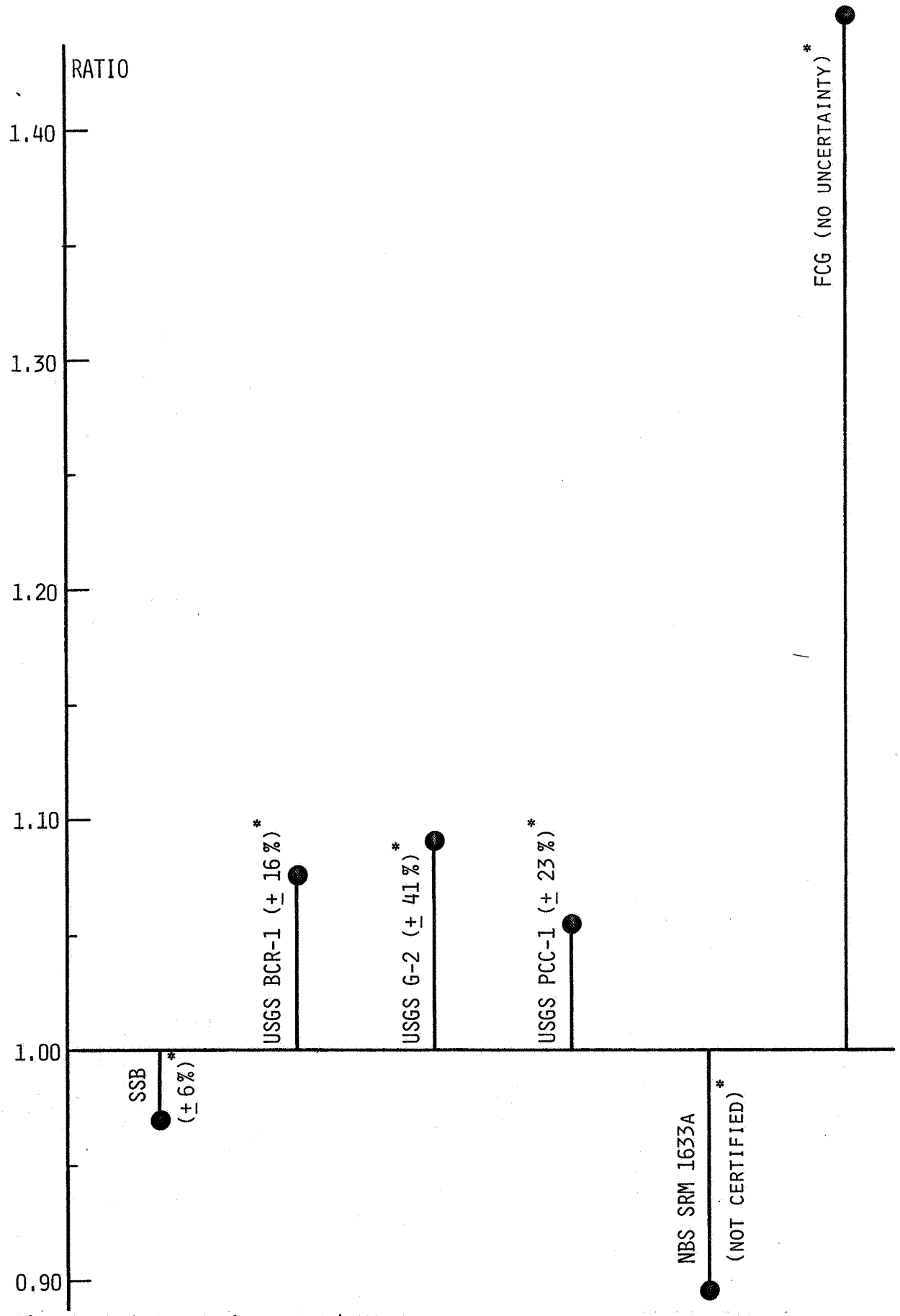

Fig. VIII.1-1 : Ratio of INW/KFKI k_0-based NAA results to specified values (with * = quoted uncertainty) for Sb in 6 materials, suggesting a gross error in the relative standardization of FCG

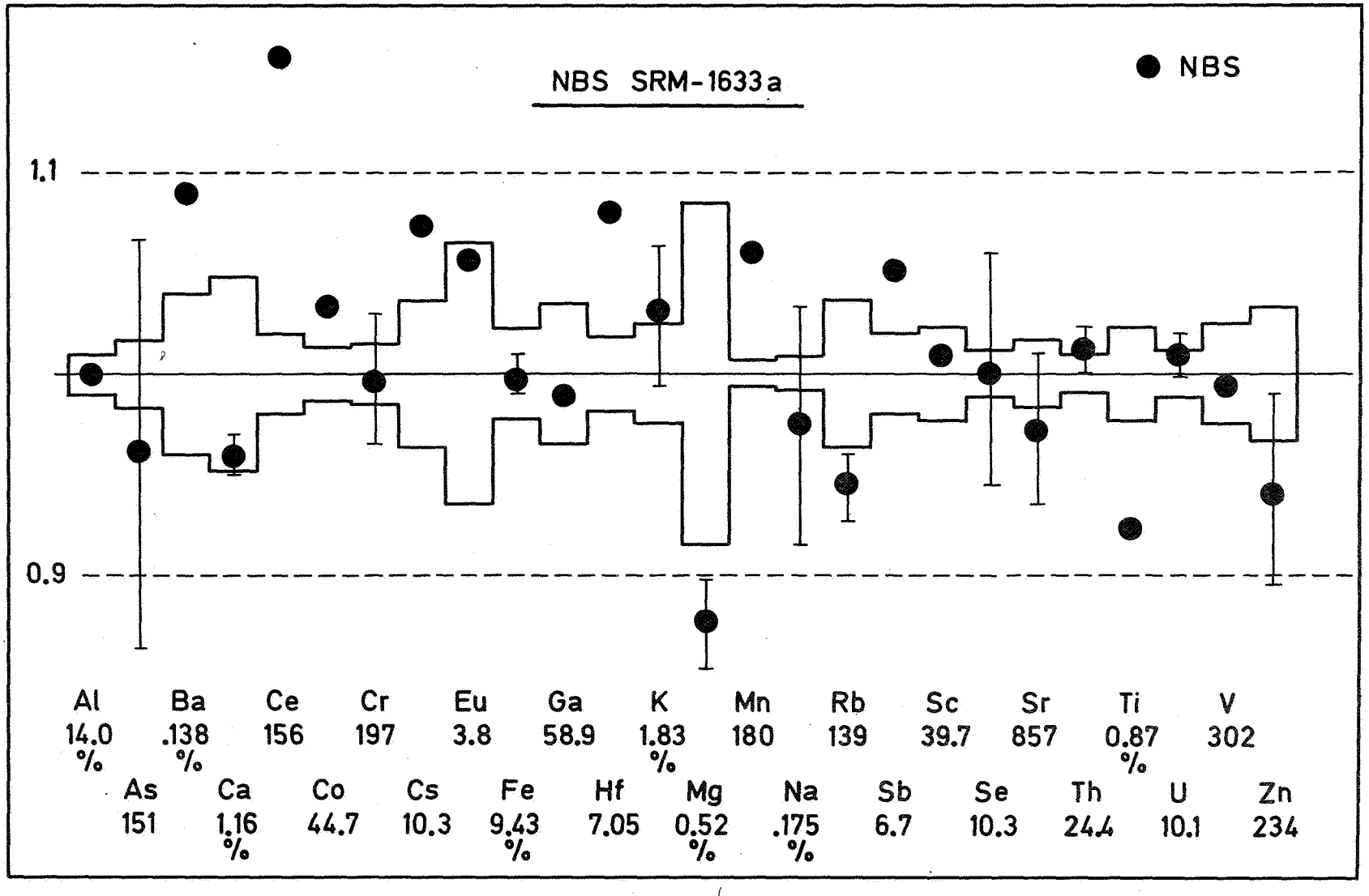

Fig. VIII.1-2 : Ratio of NBS-concentration data (NBS-certified : with ± 3s error bars) to overall KFKI/INW results (± 1s uncertainty). KFKI/INW results in ppm, unless otherwise stated

"uncertainty" should be understood as the best estimate of possible inaccuracy due to both random and systematic error.

No definition is formally approved by the Community Bureau of Reference (BCR), but occasionally the thoughts turn [GRIEPINK87] to the terminology of the ISO (International Organisation for Standardization). There [ISO86], traceability is defined in general as the ability to trace the history, application or location of an item or activity, or similar items or activities, by means of recorded identification; more specifically it is noted that, in a calibration sense, traceability relates measuring equipment to national or international standards, primary standards or basic physical constants or properties. In neutron activation analysis - like in all other analytical techniques - this "calibration traceability" is not the only concept to be considered, since calibration of the measuring equipment is but one part (sometimes even of minor importance) of the various steps and parameters involved. In general, these analysis steps are sample preparation, sample treatment and final measurement (including calibration), and in each of them several parameters play a role [MARCHANDISE].

It might be argued that the NBS-definition cannot be accepted for certification-work, since it allows of systematic error. However, one cannot escape from the fact that in every step of an analytical procedure an uncertainty is generated - of random or systematic nature; if soundly estimated and honestly reported by the analyst, the systematic error turns out frequently to surpass the random error [for instance, whereas in Ge gamma-spectrometry the random error from counting statistics may be as low as 0.1%, the error from peak-area evaluation is inevitably one order of magnitude larger ; for a given analytical problem, the latter is of systematic nature, since in every repetition the same spectral situation is encountered.]. The absence of systematic error can only be aimed at and supposed for the uncertainty, quoted on the finalized certified value (being an average of results from several analytical methods and laboratories), since most uncertainties which are of a systematic nature from one single laboratory become of a random character when several laboratories are considered [MARCHANDISE].

Since in the NBS-definition the "ability to trace the uncertainty" implies the knowledge of the steps and parameters which are relating the mass of the analyte to the primary standard, and since in the ISO-definition the

"history ..." (of steps and parameters, including calibration) relating the mass of the analyte to the primary standard should be associated with the knowledge of inevitable uncertainties (random and systematic), both definitions are not conflicting and are, on the contrary, elucidating each other.

Referring to the term "ability" in the definitions, it is clear that the human factor plays a role in the appraisal of an analytical method with respect to traceability. Any analytical method is depending on a number of parameters, which are determining the uncertainty of the analysis result. In the context of traceability, the quintessence is not whether these parameters are numerous, important or complex, but whether the analyst is aware of their existence and of their contribution to the uncertainty. Thus, whereas inherently an analytical method may be highly traceable, the actual traceability of a result depends on the degree of skill on the part of the analyst.

In view of the validation of the NAA k_0-standardization method, notably for certification work, it is of interest to dwell upon the proof of its traceability, especially in comparison with relative and absolute standardization.

2.2. Considerations with respect to the k_0-factors

The classical way of performing NAA is by applying the comparative method (relative standardization), which is based on the intercomparison of the sample - wherein the analyte is investigated - with a chemical standard. In absolute standardization, characterization of the analyte is essentially based on physically (absolute) defined standards - i.e. nuclear constants -, albeit that some irradiation and counting parameters have to be monitored experimentally. This type of monitoring is also required in the k_0-standardization method, but the individual nuclear constants are replaced by one single composite nuclear constant - the k_0-factor - which is experimentally determined. This determination, a priori performed in specialized laboratories, is based on irradiation and counting of a standard in experimental conditions evidently different from those chosen for the sample - thus necessitating the introduction of extra and more serious conversions (as compared to relative standardization) to arrive at the intercomparison of sample and standard (in relative standardization conversions are also required, e.g. with respect to decay time, neutron self-shielding, flux gradients, counting geometry,

gamma-attenuation; see I.3.1). The k_0-factor being an intermediate link between standard and analyte, as well k_0-determination as mass calculation of the analyte demand the introduction of conversion factors, which are in both operations different concerning magnitude and uncertainty. This is illustrated in Fig. VIII.2-1, where the schematic representation of the procedures followed in relative, absolute and k_0-standardization is given in order to facilitate understanding of the reasoning.

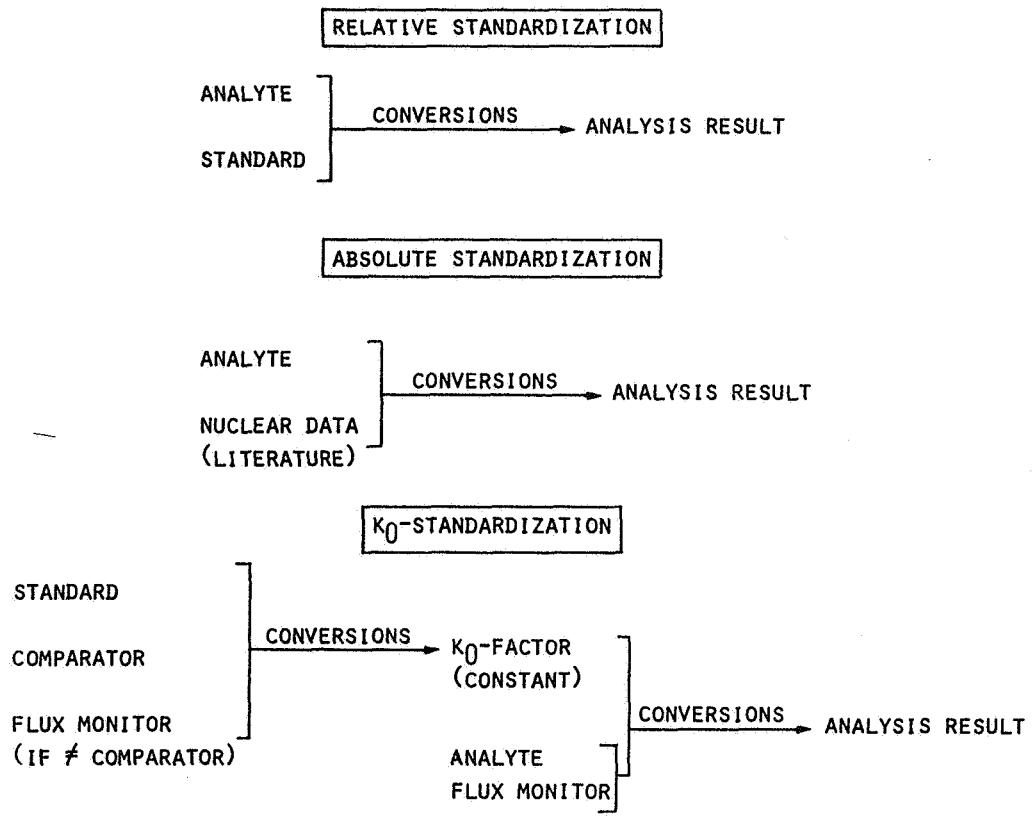

Fig. VIII.2-1 : Schematic representation of the procedures followed in relative, absolute and k_0-standardization

Essentially, from coirradiation of a standard (index s) and a comparator (index c), a $k_{0,c}(s)$-factor is obtained as :

$$k_{0,c}(s) = [(S'_s/w_s)/(S'_c/w_c)] \times \text{CONVERSION FACTORS} \qquad \text{(VIII.2-1)}$$

In Eq. (VIII.2-1), w represents the mass and S' is the normalized signal (count rate), which is similar to the quantity for use in relative standardi-

zation. Whereas the traceability as related to w_s does not differ from the situation in relative standardization, this is not so for w_c, especially not since Au - as a dilute Au-Al alloyed wire - was chosen as the comparator. However, based on NAA in optimized circumstances, each lot of Au-Al wire used was checked with respect to the gold homogeneity (found to be better than 1%), and its gold content was controlled (and, if necessary, redetermined with $\sim$ 1% uncertainty) versus a home-prepared gold standard. The latter was a dried aliquant of a freshly prepared solution of high-purity metallic gold, spotted with a calibrated micropipette (see IV.1).

The term CONVERSION FACTORS in Eq. (VIII.2-1) refers to conversions for both irradiation and counting, viz. for the contribution of epithermal activation and for the detection efficiency, respectively. Due to the selection of optimum experimental conditions for k_0-determination (quasi-point sources counted at large distance to the detector), some conversions are negligible (e.g. for true coincidence), while others have minor importance (e.g. for gamma-attenuation) or are readily performed with high accuracy (e.g. for detection efficiency) [see VI.2.1]. The role of the stability of neutron flux and detection efficiency will be discussed in VIII.2.3.4.

With regard to traceability, it is essential to remark that a published k_0-factor is the average of many results obtained with different experimental setups : chemical and physical characteristics of standard and comparator, reactors and irradiation positions, detectors, peak area evaluation methods, etc., not to forget the different experimenters involved (in Gent and Budapest) [see VI.2.1]. Consequently, the uncertainties resulting from all the aforementioned parameters, which play a role in the k_0-determination, are largely randomized and are in fact absorbed in the uncertainty quoted on the k_0-factor. This known uncertainty (better than 2%) is directly transferred - now as a systematic error - to the analysis result. Hence, in this context the k_0-method is quite traceable. Moreover, as far as the uncertainty associated with the standard preparation is concerned, a k_0-factor (being based on at least two different basic chemical materials and preparations in Gent and Budapest) is to be considered as of superior quality when compared to a standard as usually prepared for relative standardization; this is true not only with respect to accuracy, but also in the context of traceability - since the uncertainty on the standard preparation is represented in the uncertainty quoted on the k_0-factor.

It might be argued that the analyst who relies on k_0-factors simply does not make a comparison between the analyte and a primary standard through an unbroken chain of comparisons, as required according to the definition of traceability in metrology [ISO84] :

"Traceability is the property of a result of a measurement whereby it can be related to appropriate standards, generally international or national standards, through an unbroken chain of comparisons".

Although in its narrowest interpretation this statement could possibly be maintained, two comments of practical nature can be made :

- in analytical chemistry, international or national standards are not available. In fact, the trust in the quality of a chemical standard actually selected for relative standardization differs in nothing from the trust in the quality of a k_0-factor (based on chemical standards not selected by the analyst himself). In this context, a similar problem arises with respect to the half-lives of the radionuclides. No international or national standards being available, one has to trust the evaluated data encountered in literature (see VII.1) ;
- the feature to rely on a proportionality constant (like the k_0-factor) between standard and analyte is similar to the common practice of standardization in charged particle activation analysis or in NAA via short-lived isotopes.

The situation in absolute standardization, as compared to the k_0-method, is shown in Fig. VIII.2-2. As mentioned above, absolute standardization is based on absolute nuclear constants of the analyte (index a) : M_a - atomic mass, θ_a - isotopic abundance, $\sigma_{0,a}$ - 2200 $m.s^{-1}$ (n,γ) cross-section and γ_a - absolute gamma-intensity. In fact, these constants are figuring in the definition of a k_0-factor (with a = s)

$$k_{0,c}(s) = M_c\ \theta_s\ \sigma_{0,s}\ \gamma_s / M_s\ \theta_c\ \sigma_{0,c}\ \gamma_c \qquad \text{(VIII.2-2)}$$

but - it should be stressed - their knowledge is irrelevant in case of the k_0-method, since k_0 as such is experimentally determined.

In this reasoning, one difficulty might be the phenomenon of natural isotopic variability, possibly making $\theta_s \neq \theta_a$, but the resulting effects of inaccuracy and untraceability are essentially identical in relative, absolute

and k_0-standardization ; this is an inherent feature of NAA, where primarily isotopes are characterized - and not elements. The determination of Se via the $^{74}Se(n,\gamma)^{75}Se$ reaction is one of the examples ; the natural isotopic variability of ^{74}Se is $\pm$ 1.3% (see APP.2), and this uncertainty is of systematic nature.

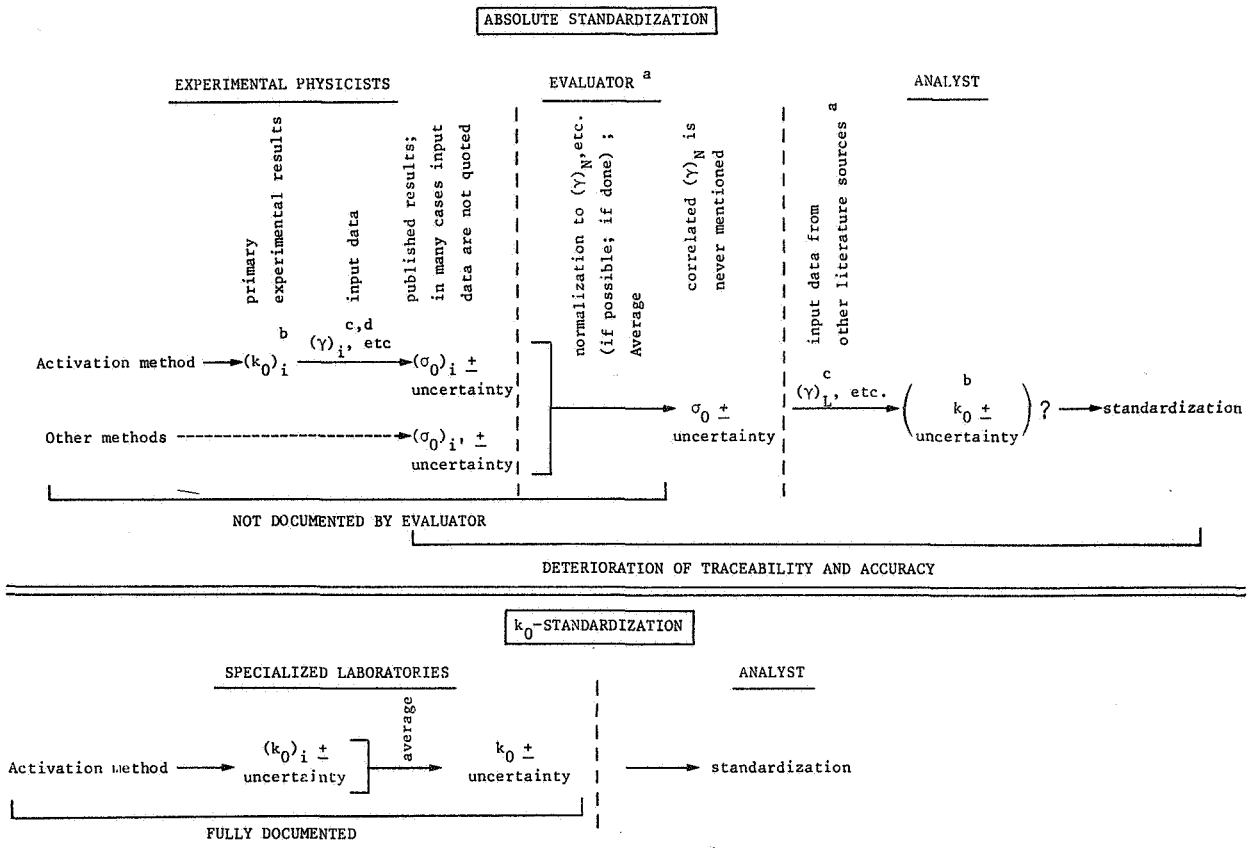

Fig. VIII.2-2 : Comparison of absolute and k_0-standardization (a. the situation is even more complex, since different evaluation centers publish different evaluated data which are sometimes conflicting ; b. in the terminology of the present work ; c. also the nuclear data of the comparator, as used by the experimental physicists, and of the monitor, as used by the analyst, play an important role ; d. activation methods based on β-measurements do not require the knowledge of gamma-intensity data)

Thus, the analyst applying the absolute method has to select for instance a $\sigma_{0,a}$ - value from literature, preferably from a recent evaluation where mention is made of the associated uncertainty (in view of the traceability). However, unlike an experimentally determined k_0-factor, an evaluated σ_0-value is strongly correlated with M, θ and γ, since in the "activation method" (see APP.1) a σ_0-value is obtained from combination of Eqs (VIII.2-1) and (VIII.2-2). In the best case these correlations are known to the evaluator, on condition that the underlying nuclear data were specified by the experimental physicists ; but it is inevitably a black box for the analyst, who is nevertheless obliged to combine M, θ, σ_0 and γ (from different sources) in the equation for mass calculation of the analyte. This "untransparency" of evaluated σ_0's, demonstrated in detail in APP.4 (e.g. see also DECORTE85), is deteriorating the traceability of absolute standardization, according to any of the definitions given above (and it is, in fact, a nice example of a broken chain of comparisons).

2.3. Analysis conversion factors

Considering now the conversions required for mass calculation of the analyte, the situation is essentially as given in Eq. (VIII.2-3) :

$$w_a = [S'_a/(S'_m/w_m)].[k_{0,c}(m)/k_{0,c}(s)] \times \text{CONVERSION FACTORS} \qquad \text{(VIII.2-3)}$$

where m refers to a coirradiated flux monitor, for which the k_0-factor and its associated uncertainty are known. The flux monitor should be positioned versus the sample so as to account optimally for flux gradients; with foils, and especially with wires (see below), this goal is easy to achieve. Evidently, one can choose m = c (= Au), leading to $k_{0,c}(m) \equiv 1$ with zero uncertainty. The choice of m plays also a role in the uncertainty of w_m ; dilute Au-Al wire and high-purity Zr-foil being coirradiated with the sample (see below), one can select either Au or Zr (preferably ^{95}Zr, in view of the lower conversion factor for epithermal activation as compared to ^{97}Zr). As far as the effort needed to guarantee traceability (with respect to w_m) is concerned, the choice of m = Zr is to be preferred.

In Eq. (VIII.2-3) the term CONVERSION FACTORS usually relates to more serious conversions than in Eq. (VIII.2-1). For instance, in many applications an extended sample has to be counted at small detector separation, necessitating now conversions for true-coincidence and larger conversions for

detection efficiency including gamma-attenuation. In order to be accurate and traceable, all these conversions, as elaborated in Chapters III and IV, impose counting of cylindrically symmetrical samples having a rotation axis coincident with the axis of a cylindric detector (concentric with its housing) with known geometric parameters. It goes without saying that the validity of these conditions with respect to the detector should be checked a priori. As a matter of course, traceability is lost if this protocol is not followed.

2.3.1. Contribution of epithermal activation

Among the CONVERSION FACTORS in Eq. (VIII.2-3), it is possible - or actually necessary (in view of the traceability) - to perform an in-situ determination of two of them, both related to the contribution of epithermal activation : f - the thermal to epithermal neutron flux ratio, and α - a measure for the non-ideal epithermal neutron flux distribution. As outlined in Chapter V, the parameters f and α can be obtained from "bare monitor"-methods, by co-irradiation of dilute Au-Al wire and high purity Zr-foil, followed by counting the induced ^{198}Au, ^{95}Zr and ^{97}Zr activities on an efficiency-calibrated detector. It has been shown in great detail (see Chapter V) that, by applying the usual laws of error propagation, the uncertainties on f and α - and the residual uncertainties on the analysis result (usually lower than 1-2%) - can be evaluated, thus fulfilling the condition of traceability. The same reasoning holds for the traceability as related to the Q_0- and $\bar{E}_r$-values ($Q_0 = I_0/\sigma_0$, with I_0 = resonance integral ; $\bar{E}_r$ = effective resonance energy), also parameters to be introduced in the correction for epithermal activation. Q_0 and $\bar{E}_r$-values, together with their associated uncertainties, are compiled in Table VIII.3-1; it should be remarked that for low-Q_0 isotopes the effort of evaluating the relevant uncertainties is not worthwhile, since the residual uncertainty on the analysis result is negligible.

2.3.2. True-coincidence

No true-coincidence effects occur for the main gamma-lines of ^{198}Au (411.8 keV) and ^{95}Zr (724.2 and 756.7 keV), which can be chosen as flux monitor ; the same holds for the 743.3 keV line of $^{97}Zr/^{97m}Nb$, which plays a role in the f- and α-monitoring. As to the analyte, the parameters needed for true-

coincidence correction (see Chapter IV) - if the effect occurs at all - are the peak and total detection efficiency (for the latter the peak-to-total ratio is needed) and a set of nuclear data. These parameters are subject to a considerable error reduction towards the analysis result. The magnitude of the true-coincidence correction and of the associated uncertainty is mainly depending on the source-detector separation and the complexity of the decay scheme. This is clear from experiments [MOENS81, LIN81] with sources of ^{60}Co, ^{110m}Ag and ^{72}Ga, with simple, complex and very complex decay schemes, respectively. The residual uncertainties (directly transferred to the analysis result) from true-coincidence correction for their analytically important gamma-lines were found to be on the average :

^{60}Co : $\sim$ 0.1%, $\sim$ 0.9%, $\sim$ 1.2%
^{110m}Ag : $\sim$ 0.4%, $\sim$ 0.9%, $\sim$ 1.5%
^{72}Ga : $\sim$ 0.6%, $\sim$ 1.1%, $\sim$ 2.5%,

for measurements at $\sim$ 10 cm, $\sim$ 5 cm and $\sim$ 1.3 cm (i.e. on top of the housing) distance to a $\sim$ 85 cm^3 Ge-detector, respectively. On the basis of these data, which show a quite logical sequence, a sound estimation of residual uncertainties from true-coincidence correction is possible for all analytes and sample-detector separations. Hence, on condition that the detection efficiency determination is accurate - as it was in the above experiments -, adequate traceability is provided as to true-coincidence correction.

2.3.3. Detection efficiency/gamma-attenuation

The conversion for detection efficiency, including gamma-attenuation, has been elaborated in Chapter III, and the inseparatibility of geometry, efficiency and attenuation calculations has been demonstrated [MOENS81B, MOENS83]. In general, correction for gamma-attenuation, based on the assumption that the gammas pass the source and enter the absorbers in a direction normal to the detector face, turns out to fail to more or less extent especially for low gamma-energies and close-in geometries. It should not be denied that - for gamma-attenuation correction - the major element composition of the source should be known, and this might invite thoughts with respect to the traceability. However, this requirement is on no account an extra burdening when compared to relative standardization. Although it sounds nice to

state that in the latter the problem is solved by matching the standard to the sample, this is by no means feasible (except when applying standard addition) unless the major element composition of the sample is known as well. Fortunately, many samples - biological, environmental, geological, etc. - are composed of low-Z elements, and the exact knowledge of the major element composition is thus far from critical; in other cases, e.g. trace element determination in high-purity metals, no problem exists at all.

Apart from the above problems it should be well understood that the proposed conversion for detection efficiency (Chapter III) is based on the transformation of an experimentally determined reference efficiency curve (superscript ref), valid for point sources at large detector distance, to the geometrical configuration on hand (superscript geo). The quantities needed are :

$$\varepsilon_{p,a}^{geo} = \varepsilon_{p,a}^{ref} \cdot \bar{\Omega}_a^{geo}/\bar{\Omega}_a^{ref} \qquad \text{(VIII.2-4)}$$

for true-coincidence correction, and

$$\varepsilon_{p,m}^{geo}/\varepsilon_{p,a}^{geo} = (\varepsilon_{p,m}^{ref}/\varepsilon_{p,a}^{ref}).(\bar{\Omega}_m^{geo}/\bar{\Omega}_m^{ref})/(\bar{\Omega}_a^{geo}/\bar{\Omega}_a^{ref}) \qquad \text{(VIII.2-5)}$$

for final mass calculation. $\bar{\Omega}$ is the calculated effective solid angle.

With proper calibration of the detector in the reference conditions by using a set of absolutely calibrated point sources (^{152}Eu, ^{226}Ra, ^{241}Am, ^{133}Ba, ^{57}Co, etc.), the uncertainty on an absolute $\varepsilon_{p,a}^{ref}$-value [Eq. (VIII.2-4)] is of the order of 1.5% (including the accuracy of the gamma emission rate), except in the energy regions < 100 keV and > 2500 keV of the ε_p vs E_γ efficiency curve, where it can go up to 3-4% (see III.1.2). Furthermore, still referring to Eq. (VIII.2-4), it has been shown in III.2.4 that the uncertainty of the $\bar{\Omega}_a^{geo}/\bar{\Omega}_a^{ref}$-calculation is better than 2%, even for close-in geometries of extended sources. Finally, the uncertainty of $\varepsilon_{p,a}^{geo}$ [Eq. (VIII.2-4)] is reduced with at least a factor three towards the analysis result (see III.2.4).

As to Eq. (VIII.2-5), the uncertainty on $\varepsilon_{p,m}^{geo}/\varepsilon_{p,a}^{geo}$ is directly transferred to the analysis result. The uncertainty on a $\varepsilon_{p,m}^{ref}/\varepsilon_{p,a}^{ref}$-ratio is of the order of 0-2%, depending on the difference in gamma-energies of analyte and flux monitor (see III.1.2). If the flux monitor is counted as a quasi-point

source at the reference position, $\bar{\Omega}_m^{geo}/\bar{\Omega}_m^{ref} \simeq 1$ with negligible uncertainty, and only the uncertainty on $\bar{\Omega}_a^{geo}/\bar{\Omega}_a^{ref}$ should be added (see above). If the flux monitor is counted at the same distance to the detector as the sample (a procedure to be recommended), the uncertainty on the $(\bar{\Omega}_m^{geo}/\bar{\Omega}_m^{ref})/(\bar{\Omega}_a^{geo}/\bar{\Omega}_a^{ref})$-value is reduced with at least a factor 4 as compared to the uncertainty on $\bar{\Omega}_a^{geo}/\bar{\Omega}_a^{ref}$, again depending on the difference in gamma-energies (see III.2.4). The reductions mentioned here and above make, in fact, that the requirements with respect to the detector (cylindric, etc.) are far from critical (see also MOENS81B).

In view of the above uncertainty discussions, adequate traceability is provided with respect to the conversions for detection efficiency and gamma-attenuation as well.

2.3.4. Stability of equipment

Eventually, the only parameters which could - at first sight - deteriorate the traceability are those which, although checked a priori as to their accuracy and their residual uncertainty on the analysis result, rely on the stability of the irradiation and counting equipment. Fundamentally, there are two such parameters :

a. the stability of the neutron flux during irradiation, the effects of which are discussed in VII.5. In steady state operated reactors (like in THETIS/Gent) the validity of this condition can be controlled a priori. Inspection (or, if necessary, introduction) of the reactor flux variation during irradiation, as routinely recorded in the reactor logbook, provides further evidence of adequate traceability (see II.1.1) ;
b. the stability of the detection efficiency from the moment of detector calibration to the moment of counting the standard and the comparator or the sample and the flux monitors. Evidently, traceability is lost if a priori calibration is considered to be valid once and for all. On the contrary, as recommended in III.1.2 the efficiency curve should be checked regularly, e.g. by measuring some calibrated point sources with low, medium and high gamma-energy. If an analyst, applying the k_0-method and following this protocol, observes no significant change between the a priori calibration and an a posteriori calibration check, the standardization should be considered as quite traceable with respect to the stability of

the detection efficiency. Note that also in relative standardization a similar stability check is in principle necessary to provide adequate traceability, for instance by counting the standard before and after counting the sample.

2.4. Conclusions

The traceability of the NAA k_0-standardization seems to be somewhat more difficult to get to the bottom than for relative standardization. If the k_0-procedure is followed correctly (a prerequisite for all standardizations), adequate traceability is provided in every respect, as well for certification work as for routine analysis. On the other hand, the traceability of the absolute NAA-standardization is deteriorated due to the "untransparency" of the required nuclear data.

All things considered, traceability of an analytical method is not very vulnerable or most difficult to establish for the standardization procedure - or for the final measurement in general - (except e.g. in case of the absolute NAA-method), but rather for the sample preparation and sample treatment steps [MARCHANDISE], even when applying a nondestructive method [LAMOTTE84, REVEL84].

Finally, it should be remarked that traceability and accuracy are related to each other in the following way. The uncertainty quoted on an analysis result (and the result itself) can only be accepted in case of adequate traceability (especially for certification work), but adequate traceability does not necessarily lead to an acceptable uncertainty (which might be too high for a particular purpose).

3. APPLICABILITY

3.1. Compilation of k_0-factors and related nuclear data

The nuclear data for use in the k_0-standardization method are compiled in Table VIII.3-1 for 112 radionuclides of interest in (n,γ) activation analysis. Throughout the table, the notation ( ) following a value stands for the % uncertainty. The following information is included :

- 1st column : element and absorption cross-sections (σ_{abs} at 2200 ms^{-1}, I_{abs} ; from CH.NUCL.84); the value of σ_{abs} allows to estimate or to calculate the thermal neutron self-shielding effect (see I.2.4) ;
- 2nd column : target isotope ;
- 6th column, 2nd line : evaluated Q_0-value (see Table V.3-3), either of high accuracy (full underlining), reasonable accuracy (dashed underlining) or unknown accuracy (no underlining; mostly for low Q_0's), as outlined in V.3.3 ; for comparison only, Q_0- as calculated from I_0 and σ_0 given in Ref. MUGHABGHAB81/84 - is shown as well (6th column, 1st line) ;
- 7th column : effective resonance energy $\bar{E}_r$;
- 8th column : analytically interesting isotope(s) formed by (n,γ) ; mention is made of the activation-decay type (see Table I.3-1) and of recent literature data for F_2, F_3, F_{24}, etc.; other relevant data (such as σ_0^m/σ_0^g ; see e.g. ^{104}Rh) are given in the "COMMENTS" ;
- 9th column : half-life T ; the values were selected from recent literaure; inconsistencies and other problems are mentioned in the "COMMENTS" ;
- 10th column : main gamma-energies E_γ ; effective gamma-energies are indicated and the components are given in the "COMMENTS"; for data related to true-coincidence correction, reference is made to Table IV.2-4 ;
- 13th column, 1st line : experimentally determined $k_{0,Au}$-factors (see Table VI.2-1); as outlined in VI.2.1, the accuracy on recommended k_0-factors (full underlining) is better than 2%, and on tentative k_0-factors (between brackets) it is probably better than 5%; in a few cases (e.g. for the 398.6 and 415.8 keV lines of ^{233}Pa), a dashed underlining indicates that a k_0-factor - although in principle recommendable - might have an accuracy which is somewhat worse than 2% (as it follows from σ_0-determination; see APP.4.1 and "COMMENTS" of Table VIII.3-1) ;
- in the "COMMENTS" mention is made of possible sources of error, e.g. $g_{WESTCOTT} \neq 1$, $F_{Cd} \neq 1$, (n,n') primary interferences, burn-up, natural isotopic variability, etc.

For comparison only, Table VIII.3-1 includes theoretical $k_{0,Au}$-factors, (12th column), calculated according to Eq. (I.3-14) [with modifications for complex activation-decay as indicated in Table I.3-1] and with introduction of nuclear data from well-known and frequently consulted evaluation works :

- Ref. CH.NUCL.84 for M (1st column, 2nd line) ;
- Ref. MUGHABGHAB81/84 for θ (3rd column, 1st line) and σ_0 (4th column, 1st line) ;
- Ref. ERDTMANN79 for γ (11th column, 1st line).

A comparison between $(k_0)_{calc.}$ and $(k_0)_{exp.}$ is shown in Fig. VIII.3-1 for a total of 245 gamma-lines with recommended k_0's and 126 gamma-lines with tentative k_0's. The worse situation in the latter case is mainly caused by the fact that the "tentative" group contains a larger number of :

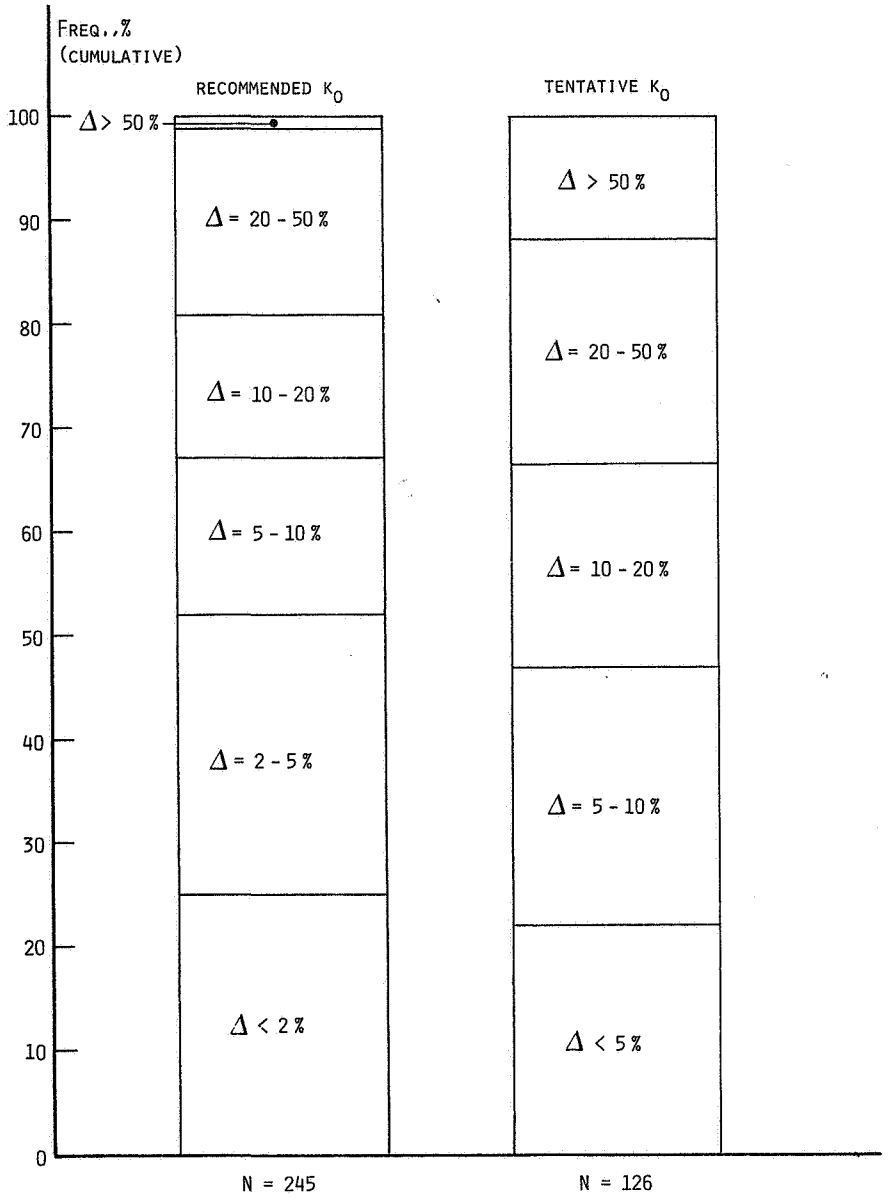

Fig. VIII.3-1 : Frequency (Freq.,%; cumulative) of the discrepancy (Δ,%) between $(k_0)_{calc.}$ and $(k_0)_{exp.}$ falling in a specified interval

TABLE VIII.3-1 : Compilation of k_0-factors and related nuclear data

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Na 22.99 0.530 ; 0.32	^{23}Na	100 100(0.) (DEBIEVRE85)	0.530(0.9)* 0.513(0.8)* (THIS WORK)	0.311(3.2)* 0.303(-)* ($Q_0 \times \sigma_0$)	0.587(-)* 0.59(-)* (Table V.3-3)	3380(11.)	^{24}Na (IV/b)	14.959h(0.02) (YOSHIZAWA85)	1368.6 2754.0	100 99.994(0.003)** 99.85 99.881(0.008)**	$4.82.10^{-2}$ $4.81.10^{-2}$	$4.68.10^{-2}$(0.6) (↔ σ_0=0.515b(0.6)) $4.62.10^{-2}$(0.9) (↔ σ_0=0.509b(0.9))

COMMENTS

σ_0 - other compil.: 0.530b(0.9)(NNDC COMPUT.CH.85)
0.53b(CH.NUCL.84; NUKLIDK.81)

* - for g+m (20.2 ms)

γ - ** from YOSHIZAWA85

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\tilde{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇐ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Mg 24.30[5] 0.063 ; 0.038	^{26}Mg	11.01 11.01(0.2) (DEBIEVRE85)	0.0382(2.1) 0.0372(0.9) (THIS WORK)	0.026(7.7) 0.024(–) ($Q_0 \times \sigma_0$)	0.68(-) 0.64(–) (Table V.3-3)	257000(13.)	^{27}Mg (I)	9.458min(0.1) (KOCHER81)	170.7 843.8 1014.4	0.70 0.84(3.6)* 71.4 71.8(0.6)* 28.6 28.0(1.4)*	$2.53.10^{-6}$ $2.58.10^{-4}$ $1.03.10^{-4}$	$3.02.10^{-6}$(1.0) (⇐ σ_0=0.0380b(3.7)) $2.53.10^{-4}$(0.5) (⇐ σ_0=0.0372b(0.8)) $9.80.10^{-5}$(0.2) (⇐ σ_0=0.0370b(1.4))

COMMENTS

σ_0 - other compil.: 0.0382b(2.1)(NNDC COMPUT.CH.85)
0.036b(CH.NUCL.84)
0.0382b(NUKLIDK.81)

T - cf. BODE75 : 9.350min(0.14)
THIS WORK : 9.495min(0.3)

γ - * from KOCHER81
- Note large discrepancy with ERDTMANN79 for γ_{171}; cf. REUS83 : 0.84%

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\tilde{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Al 26.98 0.233 ; 0.17	^{27}Al	100 100(0.) (DEBIEVRE85)	0.231(1.3) 0.226(1.) (THIS WORK)	0.17(41.) 0.16(–) ($Q_0 \times \sigma_0$)	0.74(-) 0.71(–) (Table V.3-3)	11800(5.9)	^{28}Al (I)	2.240min(0.045) (KOCHER81)	1778.9 TRUE-COINCIDENCE see Table IV.2-4	100 100(0.) (KOCHER81)	$1.79.10^{-2}$	$\frac{1.75.10^{-2}}{}$(0.8) (↔σ_0=0.226b(0.8))

COMMENTS

σ_0 - other compil. : 0.231b(1.3)(NNDC COMPUT.CH.85)
0.233b(CH.NUCL.84)
0.230b(NUKLIDK.81)

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
S 32.07 0.52 ; 0.25	^{36}S	0.02(50.)* 0.02(50.) (DEBIEVRE85)	0.15(20.) 0.16(50.) (THIS WORK)	0.17(24.) 0.18(-) ($Q_0 \times \sigma_0$)	1.1(-) 1.12(-) (Table V.3-3)	-	^{37}S (I)	5.05min(0.4) (ENDT78)	3103.8	90.0 94.1(0.6) (ENDT78)	$1.76.10^{-6}$	$1.96.10^{-6}$(1.8) (↔ σ_0=0.16b(1.9))

COMMENTS (see also DEBIEVRE83)

θ - note large uncertainty on θ; natural variations in normal terrestrial material (DEBIEVRE85), range ± 29% (FLEMING83); more accurate value desired
- * from NNDC COMPUT.CH.85

σ_0 - other compil.: 0.15b(20.)(NNDC COMPUT.CH.85)
0.23b(CH.NUCL.84)
0.15b(NUKLIDK.81)
(all give θ = 0.02%)
- experim.: HUGHES46; 0.137b
JURNEY81; 0.152b(7.), from thermal neutron capture studies
RAMAN84; 0.230b(9.), activ.meth. with γ_{3104} = 94.0% and 81.1% ^{36}S enrichm.

γ - note discrepancy with ERDTMANN79 for γ_{3104}; cf. LEDERER78 : 94.2%(0.6), REUS83 : 94.1%

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Cl 35.45 33.5 ; 12	^{37}Cl	24.23 24.23(0.2) (DEBIEVRE85)	0.433(1.4)* 0.423(1.5)* (THIS WORK)	0.30(13.)* 0.29(-)* ($Q_0 \times \sigma_0$)	0.69(-)* 0.69(-)* (Table V.3-3)	13700(14.)	^{38}Cl (IV/b)	37.21min(0.1) (KOCHER81)	1642.4 2167.5	32.8 32.5(1.8)** 44.0 44.0(1.1)**	$2.03.10^{-3}$ $2.72.10^{-3}$	$1.97.10^{-3}$(1.4) (↔ σ_0=0.424b(2.3)) $2.66.10^{-3}$(1.3) (↔ σ_0=0.423b(1.7))

COMMENTS

* - for g+m (0.7 s)

σ_0 - other compil.: 0.433b(1.4)(NNDC COMPUT.CH.85)
0.43b(CH.NUCL.84)
0.428b(NUKLIDK.81)

Y - ** from KOCHER81

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇐ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
K 39.10 2.1 ; 1.0	^{41}K	6.730 6.7302(0.04) (DEBIEVRE85)	1.46(2.1) 1.45(2.5) (THIS WORK)	1.42(4.2) 1.41(-) ($Q_0 \times \sigma_0$)	0.97(-) 0.97(-) (Table V.3-3)	2960(7.1)	^{42}K (I)	12.36h(0.08) (KOCHER81)	312.7 1524.7	0.3 0.319(5.3)* 17.9 17.9(2.8)*	$1.58.10^{-5}$ $9.40.10^{-4}$	$1.59.10^{-5}$(1.1) (⇐ σ_0=1.39b(5.4)) $9.46.10^{-4}$(0.6) (⇐ σ_0=1.47b(2.9))

COMMENTS

σ_0 - other compil.: 1.46b(2.1)(NNDC COMPUT.CH.85)
1.46b(CH.NUCL.84; NUKLIDK.81)

γ - * from KOCHER81
- cf. LMRI80 : γ_{313} = 0.32%(6.3); γ_{1525} = 17.9%(2.8);
cf. REUS83 : γ_{313} = 0.35%, γ_{1525} = 18.3%

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} ($\rightarrow\sigma_0$ from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ca 40.08 0.43 ; 2.4	^{46}Ca	0.0035 0.004(75.)* (DEBIEVRE85)	0.74(9.5) 0.62(76.)** (THIS WORK)	0.96(10.4) 0.81(–) ($Q_0 \times \sigma_0$)	1.30(-) 1.3(–) (Table V.3-3)	-	^{47}Ca (I) β^- F_2=1 ^{47}Sc (II/a)	4.536d(0.04) (BURROWS86) 3.345d(0.09) (BURROWS86)	489.2 807.9 1297.1 159.4	6.7 6.7(4.5)*** 6.9 6.9(4.3)*** 75.0 74.9(2.4)*** 68.0 68(4.4)***	$9.05.10^{-8}$ $9.32.10^{-8}$ $1.01.10^{-6}$ $9.18.10^{-7}$	$9.14.10^{-8}$(1.8) (σ_0=0.65b(4.8)) $9.20.10^{-8}$(0.2) (σ_0=0.64b(4.3)) $9.54.10^{-7}$(1.7) (σ_0=0.61b(2.9)) $8.57.10^{-7}$(1.6) (σ_0=0.60b(4.7))

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

θ - * note large uncertainty on θ; natural variations in normal terrestrial material (DEBIEVRE85), range unknown; more accurate value desired

σ_0 - ** with θ = 0.0035%, σ_0 = 0.71b (THIS WORK) is obtained
- other compil.: 0.74b(9.5)(NNDC COMPUT.CH.85),θ=0.004%
0.7b(CH.NUCL.84; NUKLIDK.81),θ=0.004%
- experim.: COOK53; 0.25b(40.)(no θ given)
CRANSTON71; 0.70b(16.), from thermal neutron capture studies
HEFT79; 0.72b(4.)(with θ = 0.0033%); normal. 0.59b

T - note inconsistency with previously reported value of 3.422d(0.1) for ^{47}Sc (KOCHER81); cf. REUS83 : T = 3.34 d

γ - *** from KOCHER81
- cf. BURROWS86 :
γ_{489} = 6.60%(7.), γ_{808} = 6.38%(7.), γ_{1297} = 75.0%(4.), γ_{159} = 67.9%(2.2)

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ca 40.08 0.43 ; 0.24	^{48}Ca	0.187 0.187(1.6) (DEBIEVRE85)	1.09(13.) 1.12(2.1) (THIS WORK)	0.89(20.) 0.50(-) ($Q_0 \times \sigma_0$)	0.82(-) 0.45(-) (Table V.3-3)	1330000(-)	^{49}Ca (I)	8.719min(0.15) (KOCHER81)	3084.4	91.7 92.1(0.8) (KOCHER81)	$9.74.10^{-5}$	$1.01.10^{-4}$(0.9) (↔ σ_0=1.12b(1.2))

COMMENTS

θ - natural variations in normal terrestrial material possible (see DEBIEVRE85), range small

σ_0 - other compil.: 1.09b(13.)(NNDC COMPUT.CH.85)
1.1b(CH.NUCL.84; NUKLIDK.81)

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Sc 44.96 27.2 ; 12	^{45}Sc	100 100(0.) (DEBIEVRE85)	27.2(0.7)* 26.3(0.7)* (THIS WORK)	12.0(4.2)* 11.3(-)* ($Q_0 \times \sigma_0$)	0.44(-)* 0.43(-)* (Table V.3-3)	5130(17.)	^{46}Sc (IV/b)	83.82d(0.02) (YOSHIZAWA85)	889.3 1120.5	99.98 99.9836(0.002)** 99.99 99.9871(0.001)**	1.26 1.26	1.22(0.4) (σ_0=26.3b(0.4)) 1.22(1.1) (σ_0=26.3b(1.1))

COMMENTS

σ_0 - other compil.: 27.2b(0.7)(NNDC COMPUT.CH.85)
27b(CH.NUCL.84)
26.5b(NUKLIDK.81)

* - for g+m (18.7 s)

γ - ** from YOSHIZAWA85

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇐ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ti 47.88 6.1 ; 2.9	^{50}Ti	5.2 5.4(1.9) (DEBIEVRE85)	0.179(1.7) 0.171(2.2) (THIS WORK)	0.118(9.3) 0.115(-) ($Q_0 \times \sigma_0$)	0.66(-) 0.67(-) (Table V.3-3)	63200(4.)	^{51}Ti (I)	5.752min(0.12) (KOCHER81)	320.1 928.6	95.0 92.9(0.3)* 5.0 6.9(5.8)*	$3.86.10^{-4}$ $2.03.10^{-5}$	$3.74.10^{-4}$(1.0) (⇐ σ_0=0.171b(1.)) $2.65.10^{-5}$(1.3) (⇐ σ_0=0.163b(6.))

COMMENTS

σ_0 - other compil.: 0.179b(1.7)(NNDC COMPUT.CH.85), with θ = 5.4%
0.177b(CH.NUCL.84), with θ = 5.4%
0.179b(NUKLIDK.81), with θ = 5.2%

γ - * from KOCHER81
- note large discrepancy with ERDTMANN79 for γ_{929}; cf. REUS83 : 6.88%

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
V 50.94 ∿ 5.06 ; 2.8	^{51}V	99.75 99.750(0.002) (DEBIEVRE85)	4.9(2.0) 4.79(1.7) (THIS WORK)	2.7(3.7) 2.63(-) ($Q_0 \times \sigma_0$)	0.55(-) 0.55(-) (Table V.3-3)	7230(4.)	^{52}V (I)	3.75min(0.3) (KOCHER81)	1434.0	100 100.0(1.0) (KOCHER81)	$2.00.10^{-1}$	$1.96.10^{-1}$(1.2) (→ σ_0=4.79b(1.6))

COMMENTS

σ_0 - other compil.: 4.9b(2.0)(NNDC COMPUT.CH.85)
4.91b(CH.NUCL.84)
4.88b(NUKLIDK.81)

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Cr 52.00 3.1 ; 1.6	^{50}Cr	4.35 4.345(0.2) (DEBIEVRE85)	15.9(1.3) 15.2(1.1) (THIS WORK)	7.8(5.1) 8.1(-) ($Q_0 \times \sigma_0$)	0.49(-) 0.53(-) (Table V.3-3)	7530(11.)	^{51}Cr (I)	27.69d(0.04) (YOSHIZAWA85)	320.1	9.83 9.85(0.9) (YOSHIZAWA85)	$2.73 \cdot 10^{-3}$	$2.62 \cdot 10^{-3}$(0.5) (↔ σ_0=15.2b(1.0))

COMMENTS

σ_0 - other compil.: 15.9b(1.3)(NNDC COMPUT.CH.85)
15.8b(CH.NUCL.84)
15.9b(NUKLIDK.81)
- see SIMONITS84

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Mn 54.94 13.3 ; 14.0	^{55}Mn	100 100(0.) (DEBIEVRE85)	13.3(1.5) 13.2(1.) (THIS WORK)	14.0(2.1) 13.9(3.) ($Q_0 \times \sigma_0$)	1.05[3](-) 1.053(2.6) (Table V.3-3)	468(11.)	^{56}Mn (I)	2.5785h(0.02) (KOCHER81)	846.8 1810.7 2113.1	99.0 98.9(0.3)* 27.2 27.2(2.9)* 14.3 14.3(2.8)*	$5.01.10^{-1}$ $1.38.10^{-1}$ $7.23.10^{-2}$	$4.96.10^{-1}$(0.6) (→ σ_0=13.2b(0.7)) $1.35.10^{-1}$(0.4) (→ σ_0=13.1b(2.9)) $7.17.10^{-2}$(0.2) (→ σ_0=13.2b(2.8))

COMMENTS

σ_0, I_0 - $^{55}Mn(n,\gamma)^{56}Mn$ is a CROSS-SECTION STANDARD :
σ_0 = 13.3 ± 0.2b (± 1.5%)
I_0 = 14.0 ± 0.3b (± 2.1%)
see : HOLDEN81; MUGHABGHAB81

γ - * from KOCHER81

NOTE - adopted as α-monitor

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Fe 55.85 2.56 ; 1.4	^{58}Fe	0.28 0.28(3.6) (DEBIEVRE85)	1.28(3.9) 1.31(4.) (THIS WORK)	1.7(5.9) 1.28(4.) ($Q_0 \times \sigma_0$)	1.33(-) 0.97^5(1.) (Table V.3-3)	637(24.)	^{59}Fe (I)	44.63d(0.2) (KOCHER81)	142.6	1.03 0.98(4.1)*	$1.38.10^{-6}$	$1.33.10^{-6}$(1.6) (↔ σ_0=1.30b(4.4))
									192.3	3.11 2.95(2.7)*	$4.17.10^{-6}$	$3.78.10^{-6}$(0.6) (↔ σ_0=1.22b(2.8))
									334.8	0.26 0.27(3.7)*	$3.49.10^{-7}$	$(3.82.10^{-7})$ (↔ σ_0=1.35b)
									1099.2	56.5 56.1(1.8)*	$7.58.10^{-5}$	$7.77.10^{-5}$(0.5) (↔ σ_0=1.32b(1.9))
									1291.6	43.2 43.6(1.8)*	$5.79.10^{-5}$	$5.93.10^{-5}$(0.4) (↔ σ_0=1.30b(1.8))

COMMENTS

σ_0 - other compil.: 1.28b(3.9)(NNDC COMPUT.CH.85)(θ = 0.28%)
1.28b(CH.NUCL.84)(θ = 0.28%)
1.15b(NUKLIDK.81)(θ = 0.3%)

- σ_0 from 192 keV line not consistent; not included in average
- see SIMONITS84

γ - cf. ANDERSSON83 : γ_{143} = 1.02%(3.9)(not consistent); γ_{192} = 3.08%(3.2)(not consistent); γ_{345} = 0.27%(3.7); γ_{1099} = 56.5%(2.7); γ_{1292} = 43.2%(2.5)
- * from LMRI80

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Co 58.93 37.2 ; 74	^{59}Co	100 100(0.) (DEBIEVRE85)	37.13(0.2)** 37.25(0.7)** (THIS WORK)	74(2.7)** 72.6(3.)** ($Q_0 \times \sigma_0$)	1.993(-)** 1.993(2.7)** (Table V.3-3)	136(5.1)	^{60}Co (IV/b)	5.271y(0.02) (KOCHER81)	1173.2 1332.5	99.86 99.88(0.02)* 99.98 99.9816(0.002)*	1.31 1.32	1.32(0.4) (→σ_0=37.3b(0.7)) 1.32(0.5) (→σ_0=37.2b(0.7))

COMMENTS

σ_0, I_0 - ^{59}Co(n,γ)^{60}Co is a CROSS-SECTION STANDARD :
σ_0 = 37.13 ± 0.06b (± 0.2%)
I_0 = 74 ± 2b (± 2.7%)
see : HOLDEN81; MUGHABGHAB81, HOLDEN85B

** - for g + 0.9976m (10.48min)

γ - * from YOSHIZAWA85

NOTE - adopted as α-monitor

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ni 58.69 4.5 ; 2.2	^{64}Ni	0.91 0.91(1.1) (DEBIEVRE85)	1.80(2.2) 1.69(3.7) (THIS WORK)	1.16(15.5) 1.13(-) ($Q_0 \times \sigma_0$)	0.64(-) 0.67(-) (Table V.3-3)	14200(12.)	^{65}Ni (I)	2.520h(0.08) (KOCHER81)	366.3	4.606 4.69(4.5) (SEE COMMENTS)	$2.27.10^{-5}$	$2.51.10^{-5}$(1.0) (→ σ_0=1.65b(3.0))
									1115.5	14.83 14.9(4.2) (SEE COMMENTS)	$7.31.10^{-5}$	$8.14.10^{-5}$(0.5) (→ σ_0=1.69b(2.4))
									1481.8	23.5 23.2(3.4) (SEE COMMENTS)	$1.16.10^{-4}$	$1.27.10^{-4}$(0.6) (→ σ_0=1.69b(0.6))

COMMENTS

θ - see APP.2.2

σ_0 - other compil.: 1.52b(2.)(NNDC COMPUT.CH.85)
1.55b(CH.NUCL.84)
1.49b(NUKLIDK.81)
- experim.: EMERY68; 1.35b(7.4)(with γ_{1482} = 25%, no θ given); normal.1.45b
RYVES70; 1.49b(2.0)(β-γ meas., with θ = 1.08%); normal.1.77b
GLEASON75; 1.49b (no inform.given)
GRYNTAKIS76/78; 1.58b(2.5)(with γ_{1482} = 24.6%, θ = 1.16%); normal.2.14b
ISHAQ77; 1.63b(from thermal neutron capture study)
HEFT79; 1.49b(1.3)(with γ_{1482} = 25.7%, θ = 1.16%); normal.2.10b
- see APP.4.3

γ - see ICRM 85
- γ_{1482} : HOLDEN85, based on MERRITT71 and RAMAN73
γ_{366} and γ_{1115} : from RAMAN73, renormal. to γ_{1482}
- γ redetermination desirable
- see APP.3.2

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Cu 63.55 3.78 ; 4.1	^{63}Cu	69.17 69.17(0.03) (DEBIEVRE85)	4.50(0.44) 4.28(4.3)* (THIS WORK)	4.97(1.6) 4.88(-) ($Q_0 \times \sigma_0$)	1.10(-) 1.14(-) (Table V.3-3)	1040(4.8)	^{64}Cu (I)	12.701h(0.02) (KOCHER81)	511.0 (annih.) 1345.9	38.6 35.74(1.1)** 0.49 0.49(8.2)**	$3.95.10^{-2}$ $5.01.10^{-4}$	$3.44.10^{-2}$(0.4) (↔ σ_0=4.23b(1.2)) $4.91.10^{-4}$(0.9) (↔ σ_0=4.41b(8.2))

COMMENTS

θ - natural variations in normal terrestrial material possible (DEBIEVRE85), range ± 0.38% (FLEMING83)

σ_0 - * weighted mean after assigning 5% extra uncertainty to k_0 (511)(possibly incomplete β^+-annihilation)
- other compil.: 4.50b(0.44)(NNDC COMPUT.CH.85)
4.47b(CH.NUCL.84)
4.5b(NUKLIDK.81)

γ - ** from KOCHER81
- note large discrepancy with ERDTMANN79 for γ_{511}; cf. LMRI80 : 36.2%(1.7), REUS83 : 35.8%

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) (recommended or (tentative)) (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Cu 63.55 3.78 ; 4.1	^{65}Cu	30.83 30.83(0.06) (DEBIEVRE85)	2.17(1.4) 2.48(24.) (THIS WORK)	2.19(3.2) 2.63(-) ($Q_0 \times \sigma_0$)	1.01(-) 1.06(-) (Table V.3-3)	766(17.)	^{66}Cu (I)	5.10min(0.4) (WARD83)	1039.2	8.0 7.4(24.) (WARD83)	$1.76.10^{-3}$	$1.86.10^{-3}$(0.5) (→ σ_0=2.48b(24.))

COMMENTS

θ - natural variations in normal terrestrial material possible (DEBIEVRE85), range ± 0.84% (FLEMING83)

σ_0 - other compil.: 2.17b(1.4)(NNDC COMPUT.CH.85)
2.17b(CH.NUCL.84; NUKLIDK.81)
- cf. experim.: RYVES70; 2.17b(1.4), with β-γ coinc.
HEFT79; 2.18b(3.2), with γ_{1039}=9.0%;
normal.: 2.65b

F_{Cd} - 1.034 (see ELNIMR81)

γ - note large discrepancy with ERDTMANN79 for γ_{1039}; cf. LEDERER78 : γ_{1039} = 8.0%(13.), from level scheme; cf. REUS83 : 8.0%
- accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Zn 65.39 1.1 ; 2.8	^{64}Zn	48.6 48.6(0.6) (DEBIEVRE85)	0.76(2.6) 0.726(1.)* (THIS WORK)	1.45(4.1) 1.42(5.) ($Q_0 \times \sigma_0$)	1.908(-) 1.908(4.9) (Table V.3-3)	2560(10.)	^{65}Zn (I)	244.0d(0.08) (YOSHIZAWA85)	1115.5 TRUE-COINCIDENCE see Table IV.2-4	50.75 50.70(0.24)*	$5.99.10^{-3}$	$5.72.10^{-3}$(0.4) (⇔σ_0=0.726b(0.5))

COMMENTS

σ_0 - other compil.: 0.76b(2.6)(NNDC COMPUT.CH.85)
0.76b(CH.NUCL.84)
0.78b(NUKLIDK.81)

- * see DECORTE85

γ - * see DECORTE85

NOTE - adopted as α-monitor

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} ($\Leftarrow \sigma_0$ from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Zn 65.39 1.1 ; 2.8	^{68}Zn	18.8 18.8(2.1) (DEBIEVRE85)	0.072(5.6) 0.0699(2.3) (THIS WORK)	- 0.223(2.7) ($Q_0 \times \sigma_0$)	- 3.19(1.4) (Table V.3-3)	590(10.)	^{69m}Zn (I)	13.76h(0.15) (KEARNS82)	438.6	94.8 94.8(0.3) (KEARNS82)	$4.10.10^{-4}$	$3.98.10^{-4}$(0.6) ($\Leftarrow \sigma_0$=0.0699b(0.7))

COMMENTS

σ_0 - other compil.: 0.072b(5.6)(*NNDC COMPUT.CH.85*)
0.072b(CH.NUCL.84, NUKLIDK.81)

I_0 - other compil.: 0.24b(CH.NUCL.84)

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ga 69.72 2.9 ; 21	^{71}Ga	39.9 39.9(0.5) (DEBIEVRE85)	4.71(4.9)* 4.61(1.)* (THIS WORK)	31.2(6.1)* 30.6(5.3)* ($Q_0 \times \sigma_0$)	6.62(-)* 6.63(5.2)* (Table V.3-3)	154(12.)	^{72}Ga (IV/b)	14.1h(1.4) (KOCHER81)	629.9	24.37 24.4(2.9)**	$1.37.10^{-2}$	$(1.49.10^{-2})$ (⇔ σ_0=5.11b)
									834.0	95.55 95.65(0.1)**	$5.38.10^{-2}$	$5.24.10^{-2}$(0.6) (⇔ σ_0=4.58b(0.6))
									894.2	9.842 9.85(2.1)**	$5.54.10^{-3}$	$5.47.10^{-3}$(0.9) (⇔ σ_0=4.64b(2.3))
									1050.8	6.921 6.93(2.2)**	$3.90.10^{-3}$	$3.84.10^{-3}$(0.8) (⇔ σ_0=4.63b(2.3))
									2201.7	26.06 26.1(2.3)**	$1.47.10^{-2}$	$1.48.10^{-2}$(1.0) (⇔ σ_0=4.74b(2.5))
									2491.0	7.472 7.48(2.4)**	$4.21.10^{-3}$	$4.20.10^{-3}$(1.7) (⇔ σ_0=4.70b(2.9))
									2501.8 (E_{eff})	20.52 20.5(1.7)**	$1.16.10^{-2}$	$1.15.10^{-2}$(1.4) (⇔ σ_0=4.69b(2.2))
									2507.9 (E_{eff})	13.05 13.0^5(2.3)**	$7.35.10^{-3}$	$7.31.10^{-3}$(1.3) (⇔ σ_0=4.68b(2.6))

COMMENTS

* - for g+m (39.7 ms)

σ_0 - other compil.: 4.71b(4.9)(NNDC COMPUT.CH.85)
4.7b(CH.NUCL.84)
4.71b(NUKLIDK.81)

Y - ** from KOCHER81
- 2501.8 = E_{eff} of 2491.0, 2507.8 & 2515.4;
2507.9 = E_{eff} of 2507.8 & 2515.4

T - accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
As 74.92 4.5 ; 65	^{75}As	100 100(0.) (DEBIEVRE85)	4.5(2.2) 3.86(4.5) (THIS WORK)	61(6.6) 52.5(−) ($Q_0 \times \sigma_0$)	13.6(-) 13.6(−) (Table V.3-3)	106(34.0)	^{76}As (I)	26.32h(0.3) (SINGH84)	559.1	44.6 45.0(4.4)*	$5.60.10^{-2}$	$4.83.10^{-2}$(1.6) (⇔σ_0=3.85b(1.6))
									559.2 (E_{eff})	46.2 46.2(4.3)*	$5.80.10^{-2}$	$4.97.10^{-2}$(0.6) (⇔σ_0=3.86b(0.6))
									563.2	1.6 1.20(6.9)*	$2.01.10^{-3}$	$(1.40.10^{-3})$ (⇔σ_0=4.18b)
									657.1	6.4 6.17(6.8)*	$8.03.10^{-3}$	$6.61.10^{-3}$(1.3) (⇔σ_0=3.84b(5.3))
									1212.9	1.8 1.44(7.7)*	$2.26.10^{-3}$	$(1.49.10^{-3})$ (⇔σ_0=3.71b)
									1215.1 (E_{eff})	5.5 4.86(5.4)*	$6.90.10^{-3}$	$5.25.10^{-3}$(0.8) (⇔σ_0=3.87b(4.2))
									1216.1	3.7 3.42(6.9)*	$4.64.10^{-3}$	$(3.78.10^{-3})$ (⇔σ_0=3.96b)

COMMENTS

σ_0 - other compil.: 4.5b(2.2)(NNDC COMPUT.CH.85)
4.5b(CH.NUCL.84)
4.3b(NUKLIDK.81)
- experim.: POMERANCE51; 4.14b(5.6)
KAPPE65; 4.22b(3.1)
RYVES71; 4.48b(2.5)
HEFT79; 4.0b(2.5)(with γ_{559} = 44.6%);
normal.: 3.96b
KOESTER84; 4.12b(2.4)

γ - * from SINGH84
- note large discrepancies with ERDTMANN79 for γ_{563}, γ_{1213} and γ_{1216}; cf. KOCHER81 : γ_{563} = 1.17% (5.), γ_{1213} = 1.63% (7.), γ_{1216} = 3.84% (6.)
- 559.2 keV = E_{eff} of 559.1 and 563.2;
1215.1 keV = E_{eff} of 1212.9 and 1216.1

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Se 78.96 11.7 ; 14	^{74}Se	0.9 0.9(11.) (DEBIEVRE85)	51.8(2.3) 51.2(11.) (THIS WORK)	520(17.) 512(-) (Q_0 x σ_0)	10.0(-) 10.0(-)+ (Table V.3-3)	29.4(4.1)	^{75}Se (I)	119.770d(0.01) (YOSHIZAWA85)	121.1	16.41 17.17(1.2)*	$2.02.10^{-3}$	$1.98.10^{-3}$(1.0) (→ σ_0=48.4b(1.6))
									136.0	56.02 58.5(1.0)*	$6.91.10^{-3}$	$6.89.10^{-3}$(1.3) (→ σ_0=49.5b(1.6))
									264.7	58.6 58.6(1.0)*	$7.23.10^{-3}$	$7.25.10^{-3}$(0.5) (→ σ_0=51.9b(1.1))
									279.5	24.73 24.94(1.2)*	$3.05.10^{-3}$	$3.06.10^{-3}$(0.9) (→ σ_0=51.5b(1.5))
									400.7	11.13 11.44(1.0^5)*	$1.37.10^{-3}$	$1.45.10^{-3}$(0.6) (→ σ_0=53.2b(1.2))

COMMENTS

θ - natural variations in normal terrestrial material possible (DEBIEVRE85), range ± 1.3% (FLEMING83); more accurate value desired

σ_0 - other compil.: 51.8b(2.3)(NNDC COMPUT.CH.85)
52b(CH.NUCL.84)
51.8b(NUKLIDK.81)
all with θ = 0.9%

γ - * from YOSHIZAWA85

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Br 79.90 6.8 ; ∿ 90	^{79}Br	50.69 50.69(0.1) (DEBIEVRE85)	2.4(25.) 2.04(-) (THIS WORK)	32.0(28.) 26.9(-) ($Q_0 \times \sigma_0$)	13.3(-) 13.2(-) (Table V.3-3)	69.3(9.)	^{80m}Br I.T. F_2=1 ^{80}Br	4.42h(0.2) (SINGH82) 17.68min(0.1)	616.3	7.2 6.7(9.)*	$8.21.10^{-3}$	$(6.67.10^{-3})$ ($\leftrightarrow \sigma_0^g$=7.51b)
			8.6(4.7) 7.81(-) (THIS WORK)	95(11.6) 89(-) ($Q_0 \times \sigma_0$)	11.0(-) 11.(-) (Table V.3-3)		(IV/a)	(SINGH82)	665.8	1.1 1.08(12.)*	$1.25.10^{-3}$	$(1.16.10^{-3})$ ($\leftrightarrow \sigma_0^g$=8.10b)

COMMENTS

THIS WORK (exper.) : $\frac{F_2\sigma_0^m}{\sigma_0^g}$ = 0.26 (-), from double measurement of 616 and 666 keV-lines (SIMONITS80); cf. KEISCH63 : 0.31(6.5), cf. BACSÓ 65 : 0.30(3.3)

$\underline{\sigma_0^m}$ - other compil.: 2.4b(25.)(NNDC COMPUT.CH.85)
2.5b(CH.NUCL.84)
2.6b(NUKLIDK.81)

$\underline{\sigma_0^g}$ - other compil.: 8.6b(4.7)(NNDC COMPUT.CH.85)
8.2b(CH.NUCL.84)
8.5b(NUKLIDK.81)

$\underline{Y}$ - * from SINGH82
- note large uncertainties; accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Br 79.90 6.8 ; ∿90	^{81}Br	49.31 49.31(0.1) (DEBIEVRE85)				152(9.2)	^{82m}Br I.T. F_2=0.976 (LEDERER78)	6.1min(-) (LEDERER78)				
			2.63(15.)* 2.58(1.)* (THIS WORK)	50(10.)*+ 49.8(3.3)* ($Q_0 \times \sigma_0$)	19.0(-)* 19.3(3.1)* (Table V.3-3)		^{82}Br (IV/b)	35.30h(0.08) (LMRI80)	554.3	70.6 70.6(0.4)**	$2.39.10^{-2}$	$2.38.10^{-2}$(1.1) (↔σ_0=2.61b(1.2))
									619.1	43.1 43.3(0.7)**	$1.46.10^{-2}$	$1.45.10^{-2}$(0.8) (↔σ_0=2.60b(1.1))
									698.4	27.9 28.4(1.4)**	$9.46.10^{-3}$	$9.38.10^{-3}$(0.9) (↔σ_0=2.56b(1.7))
									776.5	83.4 83.4(0.2)**	$2.83.10^{-2}$	$2.76.10^{-2}$(0.8) (↔σ_0=2.57b(0.8))
									827.8	24.2 24.1(1.2)**	$8.21.10^{-3}$	$7.99.10^{-3}$(0.9) (↔σ_0=2.57b(1.5))
									1044.0	28.0 27.5(2.2)**	$9.50.10^{-3}$	$9.14.10^{-3}$(0.7) (↔σ_0=2.58b(2.3))
									1317.5	27.0 27.0(3.0)**	$9.16.10^{-3}$	$8.91.10^{-3}$(0.4) (↔σ_0=2.56b(3.0))
									1474.9	16.6 16.4(1.2)**	$5.63.10^{-3}$	$5.42.10^{-3}$(0.5) (↔σ_0=2.56b(1.3))

COMMENTS

* - for F_2 m+g (+ : probably for m+g)

σ_0 - other compil.: 2.63b(15.)(NNDC COMPUT.CH.85)
2.60b(CH.NUCL.84)
2.63b(NUKLIDK.81)
assuming F_2=0.976

γ - ** from LMRI80

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : *continued*

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)! (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Rb 85.47 0.38 ; 6.0	^{85}Rb	72.17 72.16^5(0.02) (DEBIEVRE85)				839(6.0)	^{86m}Rb I.T. F_2=1 ^{86}Rb (IV/b)	1.02min(-) (LEDERER78) 18.66d(0.1) (KOCHER81)	1076.6	8.76 8.78(0.9) (KOCHER81)	$7.42.10^{-4}$	$\frac{7.65.10^{-4}}{(\leftrightarrow \sigma_0=0.494b(1.4))}$(1.0)
			0.48(2.1) * 0.494(1.5) * (THIS WORK)	7.5(6.7) * 7.31(3.) * ($Q_0 \times \sigma_0$)	15.6(-) * 14.8(2.5)* (Table V.3-3)							

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

σ_0 - other compil.: 0.48b(2.1)(NNDC COMPUT.CH.85)
0.48b(CH.NUCL.84)
0.46b(NUKLIDK.81)

* - for g+m (1.02 min)

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Rb 85.47 0.38 ; 6.0	^{87}Rb	27.83 27.83[5](0.05) (DEBIEVRE85)	0.120(25.) 0.102(4.) (THIS WORK)	1.9(10.5) 2.38(5.) ($Q_0 \times \sigma_0$)	15.8(-) 23.3(2.9) (Table V.3-3)	364(3.0)	^{88}Rb (I)	17.8min(0.6) (LMRI80)	898.0 1836.0 2677.9	14.5 14.7(4.1)* 22.1 22.4(3.6)* 2.022 2.05(4.9)*	$1.18.10^{-4}$ $1.80.10^{-4}$ $1.65.10^{-5}$	$1.01.10^{-4}$(1.5) (→ σ_0=0.101b(4.4)) $1.57.10^{-4}$(1.1) (→ σ_0=0.103b(3.8)) ($1.47.10^{-5}$) (→ σ_0=0.105b)

COMMENTS

σ_0 - other compil.: 0.120b(25.)(NNDC COMPUT.CH.85)
0.12b(CH.NUCL.84; NUKLIDK.81)
- experim.: SEREN47; 0.122b(20.)
HEFT79; 0.096b(12.), with γ_{1836}=24.7%; normal. : 0.106b

γ - * from LMRI80
- systematic discrepancy of 5% with γ's from KOCHER81 : γ_{898} = 14.0%(6.), γ_{1836} = 21.4%(6.), γ_{2678} = 1.96%(6.)
- cf. REUS83 : γ_{898} = 14.5%; γ_{1836} = 22.1%; γ_{2678} = 2.02%
- accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Sr 87.62 1.2 ; 10	^{84}Sr	0.56 0.56(1.8) (DEBIEVRE85)	0.6(10.) 0.61(-) (THIS WORK)	0.67(19.)* 8.8(-) ($Q_0 \times \sigma_0$)	1.12(-) 14.5(2.3) (Table V.3-3)	469(7.0)	^{85m}Sr (I)	67.66min(0.1) (KOCHER81)	231.7	85.0 84.72(0.15) (KOCHER81)	$6.81.10^{-5}$	$(6.92.10^{-5})$ (↔ σ_0=0.61b)
(cont'd)							I.T. F_2=0.873 (KOCHER81)					

COMMENTS

θ - natural variations in normal terrestrial material possible (DEBIEVRE85), range small

σ_0 - other compil.: 0.6b(10.)(NNDC COMPUT.CH.85)
0.53b(CH.NUCL.84)
0.55b(NUKLIDK.81)
- cf. experim. : HANS60; 0.6b(33.)
KRAMER65; 0.65b(11.)
MANNHART68; 0.506b(5.)
HEFT79; 0.623b(3.2)

I_0 - * from MUGHABGHAB84 (Errata and addenda); originally quoted : 4.59b(3.3), leading to Q_0 = 7.65 (probably too low)

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Sr (cont'd)			0.87(8.0)* 0.690(2.1)* (THIS WORK)	10.7(12.)*+ 9.14(–)* ($Q_0 \times \sigma_0$)	12.3(-)* 13.2^5(–)* (Table V.3-3)		^{85}Sr (IV/b)	64.84d(0.05) (KOCHER81)	514.0 TRUE-COINCIDENCE see Table IV.2-4	99.28 99.270(0.02) (KOCHER81)	$1.15.10^{-4}$	$9.15.10^{-5}$(0.9) (→ σ_0=0.690b(0.9))

COMMENTS

θ - natural variations in normal terrestrial material possible (DEBIEVRE85), range small

* - for F_2m+g

σ_0 - other compil.: 0.87b(10.)(NNDC COMPUT.CH.85)
0.73b(CH.NUCL.84)
0.74b(NUKLIDK.81)
(all with θ = 0.56% and F_2 assumed to be 0.873)

- cf. HEFT79 : 0.735b(3.8), with θ = 0.56% and F_2 = 0.86

I_0 - + : I_0^m = 0.67b(19.)(as mentioned in MUGHABGHAB84/errata and addenda), leading to $I_0^{F_2m+g}$ = 7.30b (18.) and $Q_0^{F_2m+g}$ = 8.4, is probably incorrect

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇒ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Sr 87.62 1.2 ; 10	^{86}Sr	9.86 9.86(0.1) (DEBIEVRE85)	0.84(7.1) 0.770(0.9) (THIS WORK)	4.79(5.0) 3.17(1.9) ($Q_0 \times \sigma_0$)	5.70(-) 4.11(1.7) (Table V.3-3)	795(2.0)	^{87m}Sr (I)	2.805h(0.1) (KOCHER81)	388.4	83.0 82.3(0.5) (KOCHER81)	$1.64.10^{-3}$	$1.49.10^{-3}$(0.5) (⇒ σ_0≈0.770b(0.7))

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

θ - natural variations in normal terrestrial material (DEBIEVRE85), range small

σ_0 - other compil.: 0.84b(7.)(NNDC COMPUT.CH.85)
0.84b(CH.NUCL.84; NUKLIDK.81)
- experim.: SEREN47; 1.29b(20.)
LYON60; 1.73b(10.)
HANS60; 0.8b(31.)
GULYAS64; 0.769b(6.)
KRAMER65; 1.0b(10.)
PARA67; 0.94b(5.)
MANNHART68; 0.81b(5.) with γ_{388} = 79.4%, normal.: 0.78b
HEFT79; 0.816b(3.) with γ_{388} = 82.5%, normal.: 0.818b
- interference $^{87}Sr(n,n')^{87m}Sr$ ($\bar{\sigma}$ = 112mb(15.); CALAM./IAEA74) corrected for in this work.

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Y 88.91 1.28 ; 1.0	^{89}Y	100 100(0.) (DEBIEVRE85)	0.001(20.)+ 0.00104(1.) (THIS WORK)	- 0.00617(2.5) ($Q_0 \times \sigma_0$)	- 5.93(2.3) (Table V.3-3)	4300(8.)	^{90m}Y (I)	3.19h(0.3) (KOCHER81)	202.5 479.5	97.0 96.6(0.4)* 90.6 90.99(0.3)*	$2.28.10^{-5}$ $2.13.10^{-5}$	$2.36.10^{-5}$(2.0) (→ σ_0=0.00104b(2.0)) $2.23.10^{-5}$(0.9) (→ σ_0=0.00104b(0.95))

COMMENTS

σ_0 - other compil.: 0.001b(20.)(NNDC COMPUT.CH.85)+
0.0010b(CH.NUCL.84)+
0.001b(NUKLIDK.81)+
- + value adopted from HEATH61

Y - * from KOCHER81

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Zr 91.22 0.184 ; 1.0	^{94}Zr	17.28 17.38(0.12) (DEBIEVRE85)	0.0499(4.8) 0.0530(1.) (THIS WORK)	0.230(4.3) 0.268(2.2) ($Q_0 \times \sigma_0$)	4.61(-) 5.05(2.0) (Table V.3-3)	6260(4.)	^{95}Zr (I)	64.03d(0.01)** (NBS82)	724.2	44.2 44.1^5(0.5)*	$8.73.10^{-5}$	$9.321.10^{-5}$(0.6) (σ_0=0.0530b(0.7))
							β^- F_2=0.0111(11.) (LUKSCH83)		756.7	54.8 54.5(0.4)*	$1.08.10^{-4}$	$1.149.10^{-4}$(0.6) (σ_0=0.0530b(0.6))
							^{95m}Nb	86.6h(0.9) (LUKSCH83)	724.2+756.7 (E_{eff}=742.2)	99.0 98.6^5(0.2)*	$1.95.10^{-4}$	$2.094.10^{-4}$(0.6) (σ_0=0.0533b)
							β^- F_{24}=0.989(0.1) (LUKSCH83) I.T. F_3=0.944(0.6) (LUKSCH83)					
							^{95}Nb (III/a)	34.97d(0.09) (LUKSCH83)	765.8	99.0 99.79(0.02)*	$2.05.10^{-6}$	$2.27.10^{-6}$(0.9)$^+$ (σ_0=0.0545b)

COMMENTS

k_0 - + strictly associated with F_{24}/F_2F_3 = 94.38

σ_0 - other compil.: 0.0499b(1.8)(NNDC COMPUT.CH.85)
0.050b(CH.NUCL.84)
0.056b(NUKLIDK.81)
- experim.: RICABARRA70 ; 0.063b(13.)
FULMER71; 0.052b(6.)
SANTRY73; 0.0475b(5.)
RUNDBERG78; 0.052b(-)
GANAPATHY78; 0.0493b(1.2), versus $^{235}U(n,f)^{95}Zr$
HEFT79; 0.055b(4.)
WYRICK83; 0.0494b(3.4)

T - ** weighted average of the reported results

γ - * from LUKSCH83

NOTE : $^{94}Zr(n,\gamma)^{95}Zr$ is a f- and α-monitor; see SIMONITS86

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Zr 91.22 0.184 ; 1.0	^{96}Zr	2.76 2.80(0.4) (DEBIEVRE85)	0.0229(4.4) 0.0213(1.0) (THIS WORK)	5.3(5.7) 5.28 (2.) ($Q_0 \times \sigma_0$)	231(-) 248. (1.5) (Table V.3-3)	338(2.1)	^{97}Zr (I)	16.74h(0.1) (SIMONITS86)	254.2	1.27 1.29(11.)*	$1.84.10^{-7}$	$(1.91.10^{-7})$ (↔ σ_0=0.0231b)
									355.4	2.30 2.38(10.)*	$3.33.10^{-7}$	$(3.06.10^{-7})$ (↔ σ_0=0.0200b)
									507.7	5.10 5.31(9.)*	$7.38.10^{-7}$	$(7.11.10^{-7})$ (↔ σ_0=0.0209b)
									602.4	1.40 1.37(10.3)*	$2.03.10^{-7}$	$(1.99.10^{-7})$ (↔ σ_0=0.0226b)
									703.7	0.95 1.04(18.2)*	$1.38.10^{-7}$	$(1.42.10^{-7})$ (↔ σ_0=0.0213b)
									1148.0	2.70 2.65(11.)*	$3.91.10^{-7}$	$(3.57.10^{-7})$ (↔ σ_0=0.0210b)
							^{97m}Nb (II/a)	60s(13.) (HAESNER85)	743.3	98.0 97.9(0.3)*	$1.37.10^{-5}$	$1.296.10^{-5}$(0.9) (↔ σ_0=0.0213b(1.0))
							^{97}Nb (III/a)	72.1min(1.) (HAESNER85)	657.9	98.2 98.4(0.2)*	$1.38.10^{-5}$	$1.304.10^{-5}$(0.9) (↔ σ_0=0.0213b(1.0))

β⁻ F_{24}=0.032(12.) ; β⁻ F_2=0.968(0.4) (HAESNER85) ; I.T. F_3=1

COMMENTS

σ_0 - other compil.: 0.0229b(4.4)(NNDC COMPUT.CH.85)
0.022b(CH.NUCL.84)
0.017b(NUKLIDK.81)
- experim.: RICABARRA70 ; 0.0057b(18.)
FULMER71; 0.020b(15.)
SANTRY73; 0.0229b(4.4)
HEFT79; < 0.01b
WYRICK83; 0.0203b(3.)

γ - * from HAESNER85

NOTE : $^{96}Zr(n,\gamma)^{97}Zr$ is a f- and α-monitor; see SIMONITS86

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Nb 92.91 1.15 ; 8.5	^{93}Nb	100 100(0.) (DEBIEVRE85)	- 0.863(12.) (THIS WORK)	- 6.34(13.) ($Q_0 \times \sigma_0$)	- 7.35(2.7) (Table V.3-3)	574(8.)	^{94m}Nb (I)	6.26min(0.16) (MULLER85)	871.0	0.48 0.50(12.) (MULLER85)	-	$9.70.10^{-5}$(1.6) (→ σ_0=0.863b(12.))

COMMENTS

σ_0 - other compil.: 0.15b(NUKLIDK.81)

Y - accurate redeterm.desirable

TRUE-COINCIDENCE

see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Mo 95.94 2.60 ; 24	^{98}Mo	24.13 24.13(0.2) (DEBIEVRE85)	0.130(4.6) 0.131(1.) (THIS WORK)	6.9(4.3) 6.96(6.4) ($Q_0 \times \sigma_0$)	53.1(-) 53.1(6.3) (Table V.3-3)	241(20.)	^{99}Mo (I) β^- F_2=0.880^5(0.35) (DICKENS80) β^- ^{99m}Tc I.T. 140.5 keV level (II/d)	66.02h(0.02) (KOCHER81) 6.02h(0.3) (KOCHER81)	181.1 366.4 739.5 778.0 140.5	6.00 6.08(2.6)* 1.21 1.16(4.3)* 13.0 12.14(1.8)* 4.37 4.36(3.7)* 89.3(F_2=0.880^5) 87.2(0.57)* (F_2=0.880^5)*	$4.10.10^{-5}$ $8.27.10^{-6}$ $8.88.10^{-5}$ $2.99.10^{-5}$ $5.37.10^{-4}$	$4.15.10^{-5}$(0.6) (→ σ_0=0.130b(2.7)) $8.36.10^{-6}$(1.3) (→ σ_0=0.137b(4.5)) $8.46.10^{-5}$(0.7) (→ σ_0=0.133b(1.9)) $2.97.10^{-5}$(1.1) (→ σ_0=0.130b(3.9)) $5.27.10^{-4}$(0.5) (→ σ_0=0.131b(0.8))

COMMENTS

σ_0 - other compil.: 0.130b(4.6)(NNDC COMPUT.CH.85)
0.132b(CH.NUCL.84)
0.130b(NUKLIDK.81)

- σ_0 (THIS WORK) from 366 keV line not consistent; not included in average; with γ = 1.21% (ERDTMANN 79; LMRI75) σ_0 = 0.131b is obtained

γ - * from DICKENS80

- SIMONITS81 : $\frac{\gamma_{140,Mo}}{F_2 \cdot \gamma_{140,Tc}}$ = 0.0664, revised : 0.0675;
cf. DICKENS80 = 0.0654

NOTE - adopted as α-monitor

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Mo 95.94 2.60 ; 24	^{100}Mo	9.63 9.63(0.2) (DEBIEVRE85)	0.199(1.5) 0.200(11.)* (THIS WORK)	3.75(4.) 3.77(12.) ($Q_0 \times \sigma_0$)	18.84(-) 18.84(4.3) (Table V.3-3)	672(14.)	^{101}Mo (I)	14.6min(0.7) (BLACHOT85)	80.9	0.03435 3.83^5(4.5)**	$1.43.10^{-7}$	$(1.80.10^{-5})$ (↔ σ_0=0.224b)
									191.9	18.1 18.8(2.1)**	$7.55.10^{-5}$	$(7.71.10^{-5})$ (↔ σ_0=0.196b)
									195.9	2.741 2.86(5.7)**	$1.14.10^{-5}$	$(1.02.10^{-5})$ (↔ σ_0=0.170b)
									192.4 (E_{eff})	20.8 21.7(2.1)**	$8.68.10^{-5}$	$8.36.10^{-5}$(1.6) (↔ σ_0=0.184b(1.6))
									408.7	1.393 1.60(5.2)**	$5.81.10^{-6}$	$(5.85.10^{-6})$ (↔ σ_0=0.174b)
									499.7	1.334 1.47(8.0)**	$5.57.10^{-6}$	$(5.63.10^{-6})$ (↔ σ_0=0.183b)
									505.9 (E_{eff})	11.35 13.1(7.5)**	$4.74.10^{-5}$	$4.71.10^{-5}$(1.9) (↔ σ_0=0.171b(7.4))
							β^- F_2=1		590.7 (E_{eff})	19.3 22.0(9.3)**	$8.05.10^{-5}$	$8.30.10^{-5}$(1.8) (↔ σ_0=0.180b(9.3))
									695.6	6.601 7.20(8.1)**	$2.75.10^{-5}$	$2.79.10^{-5}$(1.6) (↔ σ_0=0.185b(8.0))
									713.0	3.088 3.38(9.1)**	$1.29.10^{-5}$	$(1.37.10^{-5})$ (↔ σ_0=0.193b)
									870.9 (E_{eff})	1.652 2.14(9.4)**	$6.89.10^{-6}$	$(8.61.10^{-6})$ (↔ σ_0=0.192b)
									877.4	3.107 3.40(9.1)**	$1.30.10^{-5}$	$(1.53.10^{-5})$ (↔ σ_0=0.215b)
									934.0 (E_{eff})	3.725 4.15(8.9)**	$1.55.10^{-5}$	$(1.75.10^{-5})$ (↔ σ_0=0.201b)
(cont'd)												

COMMENTS

σ_0 - other compil.: 0.199b(1.5)(NNDC COMPUT.CH.85)
0.195b(CH.NUCL.84)
0.199b(NUKLIDK.81)

- * only from ^{101}Tc-lines (cf. from ^{101}Mo-lines : 0.184b(3.))

γ - ** from BLACHOT85
- note high uncertainties, especially for ^{101}Tc; accurate redetermination desirable
- 192.4 = E_{eff} of 191.9 & 195.9; 505.9 = E_{eff} of 505.1 & 505.9; 590.7 = E_{eff} of 590.1 & 590.9; 870.9 = E_{eff} of 869.7 & 871.1; 934.0 = E_{eff} of 933.3 & 934.2; 1012.3 = E_{eff} of 1011.1 & 1012.5; 1251.0 = E_{eff} of 1249.4 & 1251.1
- note large discrepancies with ERDTMANN79

NOTE : adopted as α-monitor

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Mo (cont'd)									1012.3 (E_{eff})	14.3 15.0(5.6)**	$5.97.10^{-5}$	$\underline{6.18.10^{-5}}$(2.2) (→ σ_0=0.196b(5.6))
									1161.0	3.57 3.97(5.6)**	$1.49.10^{-5}$	$(1.82.10^{-5})$ (→ σ_0=0.219b)
									1251.0 (E_{eff})	4.207 4.87(5.6)**	$1.76.10^{-5}$	$(2.14.10^{-5})$ (→ σ_0=0.210b)
									1304.0	2.374 2.78(5.8)**	$9.91.10^{-6}$	$(1.30.10^{-5})$ (→ σ_0=0.223b)
									1532.5	5.48 5.96(5.5)**	$2.29.10^{-5}$	$(2.73.10^{-5})$ (→ σ_0=0.218b)
							^{101}Tc (II/a)	14.2min(0.7) (BLACHOT85)	127.2	2.264 2.86(11.4)**	$9.45.10^{-6}$	$(1.20.10^{-5})$ (→ σ_0=0.200b)
									184.1	1.308 1.69(11.5)**	$5.46.10^{-6}$	$(5.50.10^{-6})$ (→ σ_0=0.155b)
									306.8	88.0 88.0(11.4)**	$3.67.10^{-4}$	$\underline{3.73.10^{-4}}$(1.3) (→ σ_0=0.202b(5.2))
									531.4	0.8673 1.02(11.5)**	$3.62.10^{-6}$	$(5.01.10^{-6})$ (→ σ_0=0.234b)
									545.1	5.013 5.98(11.1)**	$2.09.10^{-5}$	$\underline{2.49.10^{-5}}$(1.0) (→ σ_0=0.199b(4.5))
									TRUE-COINCIDENCE see Table IV.2-4			

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ru 101.07 2.6 ; 41	^{96}Ru	5.52 5.52(0.9) (DEBIEVRE85)	0.29(6.9) 0.229(1.2) (THIS WORK)	7.34(1.1) 6.12(3.7) ($Q_0 \times \sigma_0$)	25.3(-) 26.5(3.5) (Table V.3-3)	776(16.0)	^{97}Ru (I)	2.9d(3.4) (HAESNER85)	215.7	86.24 86.2(0.5) (HAESNER85)	$2.85.10^{-4}$	$2.25.10^{-4}$(0.5) (↔ σ_0=0.229b(0.7))

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

σ_0 - other compil.: 0.29b(7.)(NNDC COMPUT.CH.85)
0.27b(CH.NUCL.84)
0.25b(NUKLIDK.81)
- experim.: KATCOFF58; 0.210b(15.), KX proport.count.
HALPERIN65; 0.27b(4.), 67.0% ^{96}Ru enrichm., 4π-proport.count.
RAMBAK77; 0.29b(7.), no γ given
HEFT79; 0.218b(2.) with γ_{216} = 87.6%, normal.: 0.222b

T - accurate redetermination desirable

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ru 101.07 2.6 ; 41	^{102}Ru	31.6 31.6(0.6) (DEBIEVRE85)	1.21(5.8) 1.16(2.3) (THIS WORK)	4.2(2.4) 4.21(-) ($Q_0 \times \sigma_0$)	3.5(-) 3.63(-) (Table V.3-3)	181(3.9)	^{103}Ru (I)	39.26d(0.05) (DEFRENNE85)	497.1 610.3	86.4 90.9(3.0)* 5.3 5.73(3.2)*	$6.83.10^{-3}$ $4.19.10^{-4}$	$6.89.10^{-3}$(0.4) (↔ σ_0=1.16b(3.0)) $4.30.10^{-4}$(0.5) (↔ σ_0=1.15b(3.2))

COMMENTS

σ_0 - other compil.: 1.21b(5.8)(NNDC COMPUT.CH.85)
1.2b(CH.NUCL.84)
1.30b(NUKLIDK.81)

γ - * from DEFRENNE85
- note discrepancy with ERDTMANN79 for γ_{497};
cf. LMRI75 : 89.35%(0.6); KOCHER81 : 89%(6.);
MIYAHARA81 : 91.08%(0.8), experimental

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ru 101.07 2.6 ; 41	^{104}Ru	18.7 18.7(1.1) (DEBIEVRE85)	0.32(6.3) 0.491(2.) (THIS WORK)	4.3(2.3) 6.28(3.4) ($Q_0 \times \sigma_0$)	13.4(-) 12.8(2.7) (Table V.3-3)	495(10.1)	^{105}Ru (I)	4.44h(0.5) (DEFRENNE86)	262.8	7.3 6.57(2.4)*	$9.03.10^{-5}$	$1.31.10^{-4}$(1.8) (↔σ_0=0.516b(2.8))
									469.4 (E_{eff})	17.5 17.7(3.1)*	$2.16.10^{-4}$	$3.47.10^{-4}$(1.3) (↔σ_0=0.507b(3.2))
									676.4	16.7 15.6(3.2)*	$2.07.10^{-4}$	$(2.95.10^{-4})$ (↔σ_0=0.489b)
									724.3	49.0 47.3(1.1)*	$6.06.10^{-4}$	$8.87.10^{-4}$(1.7) (↔σ_0=0.485b(1.7))
							^{105m}Rh (II/a)	45s(-) (DEFRENNE86)	129.7	20.5 20.0(2.4)*	$6.21.10^{-5}$	$9.20.10^{-5}$(1.3) (↔σ_0=0.486b(5.3))
							^{105}Rh (III/c)	35.36h(0.2) (DEFRENNE86)	306.1	5.44 5.13(6.0)*	$6.73.10^{-5}$	$1.01.10^{-4}$(1.5) (↔σ_0=0.509b(5.8))
									319.2	19.6 19.2(2.1)*	$2.43.10^{-4}$	$3.57.10^{-4}$(2.1) (↔σ_0=0.481b(2.1))

β⁻ F_{24} = 0.755(1.5); β⁻ F_2 = 0.245(4.5) (KOCHER81); I.T. F_3=1

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

σ_0 - other compil.: 0.32b(6.)(NNDC COMPUT.CH.85)
0.35b(CH.NUCL.84)
0.47b(NUKLIDK.81)
- experim.: LANTZ64; 0.47b(-)
RAMBAK77; 0.32b(6.3)
HEFT79; 0.466b(3.2)
- F_2 = 0.284 from DEFRENNE86 yiels inconsistent result for σ_0 from ^{105m}Rh 129.7 keV-line (0.563b)

γ - * from DEFRENNE86
- note large discrepancies with ERDTMANN79 for γ_{263}, γ_{676} and γ_{306}; cf. KOCHER81 : γ_{263} = 7.2%(4.), γ_{676} = 16.7%(4.), γ_{306} = 5.13%(4.)
- 469.4 = E_{eff} of 469.4 & 470.1

BURN-UP ^{105}Rh(n,γ) : σ_0 = 1600b(20.), I_0 = 17000b(18.) to $^{106(m+g)}$Rh (MUGHABGHAB81); $\bar{E}_r$ unknown (10 eV assumed)

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Rh 102.91 145 ; 1100	^{103}Rh	100 100(0.) (DEBIEVRE85)	10.(10.) 11.(-) (THIS WORK)	75(7.) 82(-) ($Q_0 \times \sigma_0$)	7.5(-) 7.5(-) (Table V.3-3)	1.45(0.7)	^{104m}Rh I.T. F_2=0.9987(0.01) (BLACHOT84B)	4.34min(1.2) (BLACHOT84B)				
			135(1.7) 134(-) (THIS WORK)	1025(5.) 1275(-) ($Q_0 \times \sigma_0$)	7.6(-) 7.6(-) (Table V.3-3)		^{104}Rh (IV/a)	42.3s(0.95) (BLACHOT84B)	555.8 TRUE-COINCIDENCE see Table IV.2-4	1.99 2.0(25.) (BLACHOT84B)	$5.45.10^{-2}$	$(6.11.10^{-2})$ ($\leftrightarrow \sigma_0^g$=150b)

COMMENTS

σ_0^m/σ_0^g - THIS WORK (experim.): $\frac{\sigma_0^m}{\sigma_0^g}$ = 0.082(1.), from double measurement of 556 keV-line (SIMONITS80)
- experim.: CSIKAI63; 0.087 (at 0.032 eV)
KEISCH63; 0.075(2.7)
BISHOP64; 0.076(10.)
WALKER66; 0.081(9.)

σ_0^m - compil.: 10b(10.)(NNDC COMPUT.CH.85)
11b(CH.NUCL.84)
11b(NUKLIDK.81)
- THIS WORK; from σ_0^m/σ_0^g = 0.082 and σ_0^{m+g} = 145b (DILG74), σ_0^m = 11.b is obtained

σ_0^g - other compil.: 135b(1.7)(NNDC COMPUT.CH.85)
134b(CH.NUCL.84)
135b(NUKLIDK.81)
- THIS WORK; σ_0^g calculated from k_0 rejected in view of very unreliable γ_{556}; from σ_0^m/σ_0^g = 0.082 and σ_0^{m+g} = 145b (DILG74), σ_0^g = 134b is obtained (corresponding to γ_{556} = 2.24%)

$g_{WESTCOTT}$ (20°C) = 1.023; (100°C) = 1.041 (WESTCOTT62)

F_{Cd} - possibly < 1 (ELNIMR81)

Y - note large uncertainty on γ_{556}; accurate redetermination desirable

T - accurate redetermination desirable

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Pd 106.42 6.9 ; 90	^{108}Pd	26.46 26.46(0.3) (DEBIEVRE85)				39.7(5.)	^{109m}Pd	4.69min(0.2) (BLACHOT84)				
							I.T. F_2=1					
			8.48(5.9)* 8.77(-)* (THIS WORK)	244(1.6)* 253(-)* ($Q_0 \times \sigma_0$)	28.8(-)* 28.8(-)* (Table V.3-3)		^{109}Pd (IV/b)	13.7h(0.7) (BLACHOT84)	311.1 (E_{eff})	0.0405 0.0368(9.3)**	$1.78.10^{-5}$	$(1.59.10^{-5})$ (↔σ_0=8.32b)
									414.4 (E_{eff})	0.0289 0.0173(8.5)**	$1.27.10^{-5}$	$(8.85.10^{-6})$ (↔σ_0=9.85b)
									602.5	0.0146 0.00798(6.5)**	$6.43.10^{-6}$	$(3.43.10^{-6})$ (↔σ_0=8.27b)
							β^- F_3=1		636.3	0.0177 0.00998(5.5)**	$7.80.10^{-6}$	$(4.62.10^{-6})$ (↔σ_0=8.91b)
									647.3	0.0431 0.0244(2.9)**	$1.90.10^{-5}$	$(1.09.10^{-5})$ (↔σ_0=8.60b)
									781.4	0.0211 0.0112(11.2)**	$9.30.10^{-6}$	$(4.61.10^{-6})$ (↔σ_0=7.92b)
							^{109m}Ag (V/c)	39.6s(0.5) (BLACHOT84)	88.0	3.79 3.61(-)**	$1.67.10^{-3}$	$(1.79.10^{-3})$ (↔σ_0=9.54b)

COMMENTS

θ - natural variations in normal terrestrial material (DEBIEVRE85), range small

* - for m+g

σ_0 - other compil.: 8.483b(5.9)(NNDC COMPUT.CH.85)
8.19b(CH.NUCL.84)
12.20b(NUKLIDK.81)

γ - ** from BLACHOT84
- note large discrepancy with ERDTMANN79 for the ^{109}Pd-lines
- 311.1 = E_{eff} of 309.1 & 311.4;
414.4 = E_{eff} of 413.0 & 415.2
- accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Pd 106.42 6.9 ; 90	^{110}Pd	11.72 11.72(0.8) (DEBIEVRE85)	0.037(16.2) 0.012(-) (THIS WORK)	0.7(29.) 0.24(-) ($Q_0 \times \sigma_0$)	19.(-) 20.(-) (Table V.3-3)	950(9.)	^{111m}Pd (I)	5.5h(2.) (HARMATZ79B)	172.1	32.4 33.0(-) (HARMATZ79B)	$2.76.10^{-5}$	$(9.04.10^{-6})$ (↔ σ_0=0.012b)

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

θ - natural variation in normal terrestrial material (DEBIEVRE85), range small

σ_0 - other compil.: 0.037b(16.2)(NNDC COMPUT.CH.85)
0.02b(CH.NUCL.84)
0.020b(NUKLIDK.81)
- experim.: SEHGAL59; < 0.05b
MANGAL63; 0.037b(15.)
HEFT79; 0.033b(9.), with γ_{172} = 32.4%; normal.: 0.032b
- THIS WORK : when applying k_0-method (with experim. k_0-factors for $^{109}Pd/^{109m}Ag$ and ^{111m}Pd) to the determination of Pd in Ti and Ti-alloys, consistency is obtained (ROOS84)

γ - cf. REUS83 : 33.5%
- accurate redetermination desirable

T - accurate redetermination desirable

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ag 107.87 63.6 ; 750	^{107}Ag	51.83 51.839(0.01) (DEBIEVRE85)	37.3(3.) 33.1(5.) (THIS WORK)	98.8(5.) 96.0(-) ($Q_0 \times \sigma_0$)	2.65(-) 2.90(-) (Table V.3-3)	38.5(4.9)	^{108}Ag (I)*	2.37min(0.4) (HAESE82)	433.9 618.9 633.0	0.47 0.50(8.)** 0.25 0.262(9.4)** 1.67 1.76(5.7)**	$1.76.10^{-3}$ $9.36.10^{-4}$ $6.25.10^{-3}$	$1.59.10^{-3}$(1.8) (↔ σ_0=31.7b(8.2)) ($9.33.10^{-4}$) (↔ σ_0=35.5b) $6.01.10^{-3}$(1.9) (↔ σ_0=34.0(6.0))

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

* - negligible interference from ^{108m}Ag decay ($T = 127y$; $\sigma_0^m = 0.33b$)

σ_0 - other compil.: 37.27b(3.2)(NNDC COMPUT.CH.85)
38b(CH.NUCL.84)
37b(NUKLIDK.81)
- cf. experim. : HEFT79; 35.3b(0.3) with γ_{633} = 1.8%, normal. : 36.1b

γ - ** from HAESE82; cf. KOCHER81 : γ_{434} = 0.51%(20.); γ_{619} = 0.27%(22.); γ_{633} = 1.74%(10.)
- accurate redetermination desirable

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ag 107.87 63.3 ; 750	^{109}Ag	48.17 48.161(0.01) (DEBIEVRE85)	4.7(4.3) 3.90(0.8) (THIS WORK)	72.3(5.5) 69.0(-) ($Q_0 \times \sigma_0$)	15.4(-) 17.5(-)** (Table V.3-3)	6.08(1.0)	^{110m}Ag (I)	249.76d(0.01) (YOSHIZAWA85)	446.8	3.657 3.72(1.1)*	$1.60.10^{-3}$	$1.34.10^{-3}$(1.7) (→ σ_0=3.86b(2.0))
									620.4	2.776 2.802(0.7)*	$1.22.10^{-3}$	$1.00.10^{-3}$(0.7) (→ σ_0=3.83b(1.0))
									657.8	94.74 94.51(0.1^5)*	$4.15.10^{-2}$	$3.44.10^{-2}$(0.6) (→ σ_0=3.90b(0.6))
									677.6 (E_{eff})	10.8621 10.48(0.9)*	$4.76.10^{-3}$	$3.86.10^{-3}$(1.1) (→ σ_0=3.95b(1.4))
									687.0	6.49 6.43(0.9)*	$2.85.10^{-3}$	$2.39.10^{-3}$(1.0) (→ σ_0=3.98b(1.3))
									706.7 (E_{eff})	17.0242 16.66(0.6)*	$7.46.10^{-3}$	$6.01.10^{-3}$(0.7) (→ σ_0=3.87b(0.9))
									744.3	4.661 4.73(0.6)*	$2.04.10^{-3}$	$1.66.10^{-3}$(1.1) (→ σ_0=3.76b(1.3))
									763.9	22.36 22.29(0.5)*	$9.80.10^{-3}$	$8.13.10^{-3}$(0.7) (→ σ_0=3.91b(1.3))
									818.0	7.323 7.33(0.7)*	$3.21.10^{-3}$	$2.64.10^{-3}$(1.2) (→ σ_0=3.86b(1.4))
									884.7	72.86 72.7(0.6)*	$3.19.10^{-2}$	$2.65.10^{-2}$(0.8) (→ σ_0=3.91b(1.0))
									937.5	34.31 34.37(0.5)*	$1.50.10^{-2}$	$1.25.10^{-2}$(0.7) (→ σ_0=3.90b(0.9))
									1384.3	24.35 24.34(0.5)*	$1.07.10^{-2}$	$8.96.10^{-3}$(0.9) (→ σ_0=3.95b(1.0))
									1475.8	3.989 3.990(0.6)*	$1.75.10^{-3}$	$1.47.10^{-3}$(0.5) (→ σ_0=3.95b(0.8))
(cont'd)												

COMMENTS

σ_0
- other compil.: 4.7b(4.3)(NNDC COMPUT.CH.85)
  4.6b(CH.NUCL.84)
  4.5b(NUKLIDK.81)
- see SIMONITS84
- σ_0 from 1562 keV not consistent; rejected for average (note that γ_{1562} = 1.18% leads to σ_0 = 3.89b)
- $g_{WESTCOTT}$ (20°C) = 1.0046(ENDF/B-V82)

γ
- * from YOSHIZAWA85
- good consistency with KOCHER81 & DEGELDER83
- note discrepancy with ERDTMANN79 for γ_{1562}, cf. KOCHER81 : 1.180%(1.1); DEGELDER83 : 1.029%(0.6) (γ_{1562} = 1.18% seems to be correct; see above)
- 677.6 keV = E_{eff} of 676.6 & 677.6; 706.7 keV = E_{eff} of 706.7 & 708.1

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ag (cont'd)									1505.0	13.11 13.05(0.5)*	$5.75.10^{-3}$	$4.74.10^{-3}$(0.8) (→σ_0=3.89b(0.9))
									1562.3	1.184 1.027(0.8)*	$5.19.10^{-4}$	$4.28.10^{-4}$(1.0) (→σ_0=4.47b(1.3))
									TRUE-COINCIDENCE see Table IV.2-4			

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\tilde{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} ↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Cd 112.41 2450 ; 70	^{114}Cd	28.72 28.73(0.7) (DEBIEVRE85)	0.30(6.7) 0.23(-) (THIS WORK)	13(15.4)+ 9.1(-) ($Q_0 \times \sigma_0$)	43.3(-) 39.6(1.3) (Table V.3-3)	207(19.)	^{115}Cd (I)++ IT, F_2=1 ^{115m}In (II/a)	53.47h(0.18) (HARMATZ80) 4.486h(0.1) (HARMATZ80)	527.9 336.2	32.9 27.5(4.6) (HARMATZ80) 46.1 45.8(4.8) (HARMATZ80)	$5.27.10^{-4}$ $7.38.10^{-4}$	$(3.42.10^{-4})$ ↔σ_0=0.23b) $(5.57.10^{-4})$ ↔σ_0=0.23b)

COMMENTS

++ : no I.T. from ^{115m}Cd

σ_0 - other compil.: 0.30b(6.7)(NNDC COMPUT.CH.85)
0.30b(CH.NUCL.84)
0.300b(NUKLIDK.81)
- experim.: PEARLSTEIN66 : 0.30b(50.)
HEFT79 : 0.294b(5.4) with γ_{528} = 26.6% & γ_{336} = 42.6%; normal.: 0.28b

I_0 - + assignment not clear

F_{Cd} = 0.45(3.)(THIS WORK)

T - note large discrepancy with KOCHER81 : 4.36h(2.3); cf. NEMETH87 : 4.485h(0.1)

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
In 114.82 194 ; 3200	^{113}In	4.3 4.3(4.7) (DEBIEVRE85)	8.1(9.9)*+ 8.2(-)* (THIS WORK)	220(6.8)* 224(-)* ($Q_0 \times \sigma_0$)	27.2(-)* 27.3(-)* (Table V.3-3)	6.41(15.)	^{114m}In (IV/b)	49.51d(0.02) (BLACHOT82)	190.3	17.7 15.4(2.6)**	$1.12.10^{-3}$	$(1.01.10^{-3})$ ↔ σ_0=8.4b)
									558.4 ***	4.65 4.39(10.)**	$2.95.10^{-4}$	$(2.75.10^{-4})$ ↔ σ_0=8.0b)
									725.2	4.55 4.33(10.)**	$2.88.10^{-4}$	$(2.73.10^{-4})$ ↔ σ_0=8.1b)

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

* - for $m+m_2$ (43.1 ms)

\+ assignment : σ_0^m = 8.1±0.8b, $\sigma_0^{m_2}$ = 3.1±0.7b; however, quoted σ_0^m originates from KEISCH63, who measured in fact $\sigma_0^{m+m_2}$

σ_0 - other compil.: 8.1b(9.9)(NNDC COMPUT.CH.85)
8b(CH.NUCL.84)
7.5b(NUKLIDK.81)

E_γ - *** contribution from ^{114}In (71.9s) 558.4 keV-line negligible

γ - ** from BLACHOT82
- note large discrepancy with ERDTMANN79 for γ_{190}; cf. KOCHER81 : 15.9%(2.5); REUS83 : 16.0%

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (← σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
In 114.82 194 ; 3200	^{115}In	95.7 95.7(0.2) (DEBIEVRE85)	162.3(0.43)* 157(3.)* (THIS WORK)	2650(3.8)* 2638(4.)* ($Q_0 \times \sigma_0$)	16.3(-)* 16.8(1.9)* (Table V.3-3)	1.56(1.9)	^{116m}In (IV/b)	54.15min(0.1) (BLACHOT81)	137.9	3.33 3.29(3.6)**	$9.41.10^{-2}$	$1.01.10^{-1}$(1.4) (← σ_0=176b(3.3))
									416.9	32.4 29.20(4.9)**	$9.16.10^{-1}$	$7.54.10^{-1}$(1.1) (← σ_0=148b(4.6))
									818.7	11.6 11.48(3.7)**	$3.28.10^{-1}$	$3.36.10^{-1}$(1.2) (← σ_0=168b(3.3))
									1097.2	55.7 56.21(2.0)**	1.57	1.60(1.3) (← σ_0=163b(1.3))
									1293.5	85.0 84.40(2.0)**	2.40	2.29(0.8) (← σ_0=155b(0.8))
									1507.5	10.2 9.96(3.4)**	$2.88.10^{-1}$	$2.69.10^{-1}$(1.4) (← σ_0=155b(3.1))
									2112.2	15.0 15.53(2.8)**	$4.24.10^{-1}$	$4.18.10^{-1}$(1.2) (← σ_0=155b(2.3))

COMMENTS

* - for m+m_2 (2.16 s)

σ_0 - other compil.: 162b(7.)(NNDC COMPUT.CH.85)
162b(CH.NUCL.84)
157b(NUKLIDK.81)
- $g_{WESTCOTT}$ (20°C) = 1.0175; (100°C) = 1.0321 (GRYNTAKIS75)

F_{Cd} = 0.93 (ELNIMR81)

γ - ** from BLACHOT81

T - note discrepancy of recent measurements : 54.29min(0.2)(GOPYCH84); 55.77min(0.2)(NÉMETH86)

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, Z	σ_0, b	I_0, b	Q_0	$\tilde{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, Z (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,Z) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Sn 118.71 0.63 ; 6	^{112}Sn	1.0 0.97(1.) (DEBIEVRE85)				107(2.8)	^{113m}Sn	21.4min(1.9) (LYTTKENS81)				
							I.T. F_2=0.911(2.5) (LYTTKENS81) ↓					
			0.98(11.)* 0.541(2.)* (THIS WORK)	- 26.2(2.)* ($Q_0 \times \sigma_0$)	- 48.4(1.2)* (Table V.3-3)		^{113}Sn	115.09d(0.03) (LYTTKENS81)				
							E.C. F_3=1 ↓					
							^{113m}In (V/c)	1.658h(0.06) (LYTTKENS81)	391.7	64.1 64.9(1.1) (KOCHER81)	$1.11.10^{-4}$	$5.99.10^{-5}$(0.8) (↔ σ_0=0.541b(1.4))

COMMENTS

* - for F_2m+g

σ_0 - other compil.: 0.98b(11.)(NNDC COMPUT.CH.85), with θ = 0.97%
0.97b(CH.NUCL.84), with θ = 1.0%
1.12b(NUKLIDK.81), with θ = 1.0%

- cf. MAENHAUT73 : 0.51b(-)
HEFT79 : 0.562b(2.)
NIKOLOW80 : 0.557b(5.5)
} normalized (see DECORTE85)

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Sn 118.71 0.63 ; 6	^{116}Sn	14.7 14.53(0.8) (DEBIEVRE85)	0.006(33.) 0.00596(2.) (THIS WORK)	0.49(33.) 0.336(3.) ($Q_0 \times \sigma_0$)	82(-) 56.3(1.9) (Table V.3-3)	128(3.1)	^{117m}Sn (I)	13.61d(0.3) (BLACHOT87)	158.5 (E_{eff})	88.41 88.51(0.3) (BLACHOT86)	$1.37.10^{-5}$	$1.35.10^{-5}$(1.1) (↔σ_0=0.00596b(1.5))

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

σ_0 - other compil.: 0.006b(33.)(NNDC COMPUT.CH.85)
0.006b(CH.NUCL.84; NUKLIDK.81)
- experim.: ORNL85 : 0.006b(33.)
MAENHAUT : 0.00585b(-)
NIKOLOW80 : 0.00542b(5.5)
- see DECORTE83

$\bar{\sigma}_{n,n'}$ - strong $^{117}Sn(n,n')^{117m}Sn$ interference :
$\bar{\sigma}_{n,n'} \cong$ 0.09b(11.)(see DECORTE83)

$^{116}Sn(n,\gamma)^{117m}Sn$ IS NOT SUITED FOR COMPARATOR-TYPE NAA, EXCEPT IN STRONGLY THERMALIZED IRRADIATION CHANNELS

γ - 158.5 = E_{eff} of 156.0 & 158.6

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Sn 118.71 0.63 ; 6	^{122}Sn	4.6 4.63(0.6) (DEBIEVRE85)	0.180(11.) 0.146(2.5) (THIS WORK)	0.81(5.)+ 0.788(3.) ($Q_0 \times \sigma_0$)	4.5(-)+ 5.40(0.7) (Table V.3-3)	424(14.)	^{123m}Sn (I)	40.08min(0.2) (TAMURA80)	160.3 TRUE-COINCIDENCE see Table IV.2-4	84.0 85.6(2.3) (TAMURA80)	$1.22.10^{-4}$	$1.02.10^{-4}$(0.5) (⇔ σ_0=0.146b(2.4))

COMMENTS

σ_0 - other compil.: 0.180b(11.)(NNDC COMPUT.CH.85)
(with θ = 4.63%)
0.16b(CH.NUCL.84)(with θ = 4.6%)
0.180b(NUKLIDK.81)(with θ = 4.6%)

- experim.: NELSON50 : 0.100b(20.)
HUGHES53 : 0.160b(19.)
MANGAL63 : 0.206b(15.)
TILBURY68 : 0.15b(13.), with γ_{160} = 87.5%;
MAENHAUT73 : 0.145b(-), with γ_{160} = 86%
RICABARRA73 : 0.18b(11.)
HEFT79 : 0.134b(11.), with θ = 4.72% and
γ_{160} = 84.0%; normal.: 0.134b

\+ - assuming that quoted $I_0 \simeq I_0^m$ (cf. σ_0^g = 0.001b)

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Sn 118.71 0.63 ; 6	^{124}Sn	5.6 5.79(0.9) (DEBIEVRE85)	0.130(3.8) 0.116 (3.) (THIS WORK)	8.0(2.5) 6.97(4.2) ($Q_0 \times \sigma_0$)	61.5(-) 60.1(2.9) (Table V.3-3)	74.2(7.)	^{125m}Sn (I)	9.525min(0.14) (THIS WORK)	331.9	99.0 99.57(2.0) (TAMURA81)	$1.27.10^{-4}$	$1.18.10^{-4}$(2.0) (↔ σ_0=0.116b(2.8))
(cont'd)							β^- F_{24}=1					

COMMENTS

σ_0 - other compil.: 0.130b(3.8)(NNDC COMPUT.CH.85) with θ = 5.79%
0.13b(CH.NUCL.84; NUKLIDK.81), with θ = 5.6%

- experim.: MANGAL63 : 0.125b(15.), with T = 9.8min
TILBURY68 : 0.13b(15.), with T = 9.5min
RICABARRA73 : 0.11b(36.)
GLEASON77 : 0.135b(4.), with T = 9.2min
HEFT79 : 0.070b(6.), with T = 9.7min and θ = 5.94%; normal.(for θ) : 0.072b

T - note literature scatter on T; LEDERER78 : 9.5 min; ERDTMANN79 : 9.7 min; TAMURA81 : 9.52 min (0.5); REUS83 : 9.52 min

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Sn (cont'd)			0.004(50.) 0.0042(-) (THIS WORK)	- 0.25(-) ($Q_0 \times \sigma_0$)	- 60.1(-)* (Table V.3-3)		^{125}Sn (I)	9.64d(0.3) (TAMURA81)		1.35 1.31(4.4)**	$5.32.10^{-8}$	$(5.40.10^{-8})$ (→σ_0=0.00404b)
							β^- F_{24}=1		822.5	3.90 3.99(4.6)**	$1.54.10^{-7}$	$(1.98.10^{-7})$ (→σ_0=0.00487b)
							β^- F_3=1		1067.1	9.00 9.04(2.8)**	$3.55.10^{-7}$	$(4.37.10^{-7})$ (→σ_0=0.00474b)
									1088.9 (E_{eff})	5.3 5.39(4.1)**	$2.09.10^{-7}$	$(2.48.10^{-7})$ (→σ_0=0.00451b)
							^{125}Sb (VII/b)	2.7617y(0.1) (YOSHIZAWA85)	176.3	6.3 6.75(1.2)***	$2.48.10^{-7}$	$(2.47.10^{-7})$ (→σ_0=0.00359b)
									427.9	29.6 29.6(1.0)***	$1.17.10^{-6}$	$(1.23.10^{-6})$ (→σ_0=0.00408b)
									463.4	10.0 10.42(1.2)***	$3.94.10^{-7}$	$(4.43.10^{-7})$ (→σ_0=0.00417b)
									600.6	18.4 17.61(1.1)***	$7.25.10^{-7}$	$(7.05.10^{-7})$ (→σ_0=0.00393b)
									606.6	5.2 5.02(1.2)***	$2.05.10^{-7}$	$(1.71.10^{-7})$ (→σ_0=0.00334b)
									635.9	11.2 11.23(1.2)***	$4.42.10^{-7}$	$(4.91.10^{-7})$ (→σ_0=0.00429b)

COMMENTS

σ_0 - other compil.: 0.004b(50.)(NNDC COMPUT.CH.85)
0.004b(CH.NUCL.84; NUKLIDK.81)
- experim.: MANGAL63 : 0.0039b(56.)

I_0 - no experim.data available
- I_0,calc. : 0.032b(WALKER72), leading to Q_0 = 8.0

Q_0 - * assuming $Q_0^g = Q_0^m$

γ - ** from TAMURA81
- 1088.9 keV = E_{eff} of 1087.1 and 1089.2
- *** from YOSHIZAWA85

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Sb 121.75 5.4 ; 170	^{121}Sb	57.3 57.3(1.6) (DEBIEVRE85)				13.1(3.8)	^{122m}Sb I.T. F_{Cd}=1 ^{122}Sb (IV/b)	4.2min(-) (LEDERER78)				
			5.9(3.4)* 6.33(2.3)* (THIS WORK)	200(10.)* 209(4.2)* ($Q_0 \times \sigma_0$)	33.9(-)* 33.0(3.5)* (Table V.3-3)			2.70d(1.1) (LMRI85)	564.1	71.0 70.55(0.5)**	$4.12.10^{-2}$	$4.38.10^{-2}$(1.5) (↔ σ_0=6.31b(1.6))
									692.8	3.92 3.7(5.4)**	$2.27.10^{-3}$	$2.38.10^{-3}$(2.0) (↔ σ_0=6.54b(5.8))

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

θ - the only experimental θ-determination dates from 1948 (WHITE48)(see DEBIEVRE85); accurate redetermination desirable

* - for m+g

σ_0 - other compil.: 5.9b(3.4)(NNDC COMPUT.CH.85)
6.25b(CH.NUCL.84)
6.255b(NUKLIDK.81)

F_{Cd} = 0.99 (ELNIMR81)

Y - ** from LMRI85

T - accurate redetermination desirable

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Sb 121.75 5.4 ; 170	^{123}Sb	42.7 42.7(2.1) (DEBIEVRE85)				28.2(6.4)	^{124m_2}Sb	20.2min(1.) (TAMURA84)				
							I.T. F_2=1					
							^{124m_1}Sb	93s(5.4) (TAMURA84)				
							I.T. F_3=0.75(7.) (TAMURA84)					
			4.14(2.4)* 4.08(2.3)* (THIS WORK)	125(16.)*+ 118(4.4)* ($Q_0 \times \sigma_0$)	30.2(-)* 28.8(3.7)* (Table V.3-3)		^{124}Sb (VI)	60.20d(0.05) (LMRI85)	602.7	98.1 97.89(0.05)**	$2.98.10^{-2}$	$2.96.10^{-2}$(0.6) (σ_0=4.13b(0.6))
									645.9	7.24 7.42(0.7)**	$2.20.10^{-3}$	$2.21.10^{-3}$(0.7) (σ_0=4.06b(1.0))
									722.8	11.8 10.80(0.6)**	$3.58.10^{-3}$	$3.19.10^{-3}$(0.8) (σ_0=4.03b(1.0))
									1691.0	50.0 47.6(0.4)**	$1.52.10^{-2}$	$1.41.10^{-2}$(1.1) (σ_0=4.04b(1.2))
									2090.9	6.03 5.48(0.9)**	$1.83.10^{-3}$	$1.58.10^{-3}$(2.0) (σ_0=3.93b(2.2))

COMMENTS

θ - the only experimental θ-determination dates from 1948 (WHITE48)(see DEBIEVRE85); accurate redetermination desirable

* - for $F_3(m_2+m_1)$+ g; (+ : assignment not clear)

σ_0 - other compil.: 4.14b(2.4)(NNDC COMPUT.CH.85)
4.145b(CH.NUCL.84)
4.31b(NUKLIDK.81)

γ - * from LMRI85
- note large discrepancy with ERDTMANN79 for γ_{722} & γ_{2091}; cf. TAMURA84 : γ_{722} = 10.76%(1.); γ_{2091} = 5.57%(1.8)

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
I 126.90 6.2 ; ∿150	^{127}I	100 100(-) (DEBIEVRE85)	6.2(3.2) 4.04(10.) (THIS WORK)	147(4.1) 100(11.) ($Q_0 \times \sigma_0$)	23.7(-) 24.8(2.7) (Table V.3-3)	57.6(4.0)	^{128}I (I)	24.99min(0.08) (KIATO83)	442.9 526.6	17.5 16.9(10.1)* 1.68 1.59(11.0)*	$1.79.10^{-2}$ $1.72.10^{-3}$	$1.12.10^{-2}$(1.7) (↔ σ_0=4.03b(1.7)) $1.07.10^{-3}$(1.4) (↔ σ_0=4.09b(4.5))

COMMENTS

σ_0 - other compil.: 6.2b(3.)(NNDC COMPUT.CH.85)
6.2b(CH.NUCL.84; NUKLIDK.81)
- experim.: SEREN47; 6.25b(20.)
HARRIS50; 9.23b(σ_{abs})
COLMER50; 8.0b(σ_{abs})
POMERANCE51; 6.35b(σ_{abs})
GRIMELAND58; 5.7b
TATTERSALL60; 6.6b(4.^{5})(σ_{abs})
MEADOWS61; 6.22b(4.)(σ_{abs})
JOZEFOWICS63; 5.9b(3.)
ROBERTSON65; 6.17b(3.)
STAVISKII65; 5.6b(5.)
RYVES70; 6.12b(2.)
GLEASON77; 6.60b(3.)
FRIEDMAN83; 4.7b(4.) with γ_{443} = 16.0%, normal.: 4.45b

γ - * from KITAO83
- note large uncertainty on γ's; cf. KOCHER81: γ_{443} = 14.2% (11.), γ_{527} = 1.39% (14.); accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, Z	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, Z (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,Z) {recommended or (tentative)} (⇐ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Cs 132.91 29 ; 420	^{133}Cs	100 100(0.) (DEBIEVRE85)	2.5(8.) 2.74(3.) (THIS WORK)	- 32.3(4.2) ($Q_0 \times \sigma_0$)	- 11.8(3.) (Table V.3-3)	9.27(11.)	^{134m}Cs (I)	2.91h(0.3) (SERGEENKOV81)	127.5	13.6 12.7(2.4) (SERGEENKOV81)	$5.35.10^{-3}$	$5.48.10^{-3}$(1.7) (⇐ σ_0=2.74b(2.9))
							I.T. F_2=1		TRUE-COINCIDENCE see Table IV.2-4			
			29(5.2)* 30.7(1.)* (THIS WORK)	437(5.9)* 390(-)* ($Q_0 \times \sigma_0$)	15.1(-)* 12.7(-)* + (Table V.3-3)		^{134}Cs (IV/b)	2.062y(0.2) (SERGEENKOV81)	563.2	8.38 8.38(0.6)**	$3.82.10^{-2}$	$4.14.10^{-2}$(1.7) (⇐ σ_0=31.4(1.8))
									569.3	15.43 15.43(0.7)**	$7.03.10^{-2}$	$7.34.10^{-2}$(1.5) (⇐ σ_0=30.3(1.7))
									604.7	97.6 97.56(0.3)**	$4.45.10^{-1}$	$4.76.10^{-1}$(2.0) (⇐ σ_0=31.0(2.0))
									795.8	85.4 85.44(0.4)**	$3.89.10^{-1}$	$4.15.10^{-1}$(2.0) (⇐ σ_0=30.9(2.0))
									801.9	8.73 8.73(0.5)**	$3.98.10^{-2}$	$4.11.10^{-2}$(2.0) (⇐ σ_0=29.9(2.1))
									TRUE-COINCIDENCE see Table IV.2-4			

COMMENTS

σ_0 - other compil.: 2.5b(8.)(NNDC COMPUT.CH.85)
2.6b(CH.NUCL.84)
2.5b(NUKLIDK.81)
- $g_{WESTCOTT}$ (20°C) = 1.0024(ENDF/B-V82)

γ - note discrepancy with ERDTMANN79 for γ_{127}; cf. KOCHER81 : 12.9%(2.3)

COMMENTS

* - for m+g

σ_0 - other compil.: 29b(5.2)(NNDC COMPUT.CH.85)
29.6b(CH.NUCL.84)
29b(NUKLIDK.81)
- $g_{WESTCOTT}$ (20°C) = 1.0024(ENDF/B-V82)

γ - ** from SERGEENKOV81

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ba 137.33 1.3 ; 10	^{130}Ba	0.106 0.106(1.9) (DEBIEVRE85)	11.3(8.8)*+ 9.04(3.)+ (THIS WORK)	200(10.0)+ 224(-)+ ($Q_0 \times \sigma_0$)	17.7(-)+ 24.8(-)+ (Table V.3-3)	69.9(5.0)	^{131m}Ba I.T. f_{21}=1 ^{131}Ba (IV/b)	14.6min(1.4) (LEDERER78) 11.8d(1.7) (KOCHER81)	123.8	29.05 29.0(3.1)**	$5.29.10^{-5}$	$4.13.10^{-5}$(1.3) (⇔ σ_0 = 8.83b(3.4))
									133.6	2.189 2.16(3.2)**	$3.99.10^{-6}$	$(3.24.10^{-6})$ (⇔ σ_0 = 9.30b)
									216.1	19.90 19.7(2.5)**	$3.63.10^{-5}$	$2.91.10^{-5}$(1.0) (⇔ σ_0 = 9.16b(2.7))
									373.2	13.33 14.0(2.9)**	$2.43.10^{-5}$	$2.03.10^{-5}$(1.5) (⇔ σ_0 = 8.99b(3.3))
									486.5	1.89 2.07(1.9)**	$3.44.10^{-6}$	$(3.44.10^{-6})$ (⇔ σ_0 = 10.3b)
									496.3	43.78 46.8(1.1)**	$7.98.10^{-5}$	$6.84.10^{-5}$(1.4) (⇔ σ_0 = 9.06b(1.8))
									620.1	1.572 1.36(6.6)**	$2.86.10^{-6}$	$(2.34.10^{-6})$ (⇔ σ_0 = 10.7b)

COMMENTS

+ - for g+m (14.6 min)

σ_0^{m+g} - * composed of σ_0^m = 2.5b(12.)(= σ_0^m from TILBURY68) and σ_0^g = 8.8b(10.)(= $\sigma_0^{m+g?}$ from LYON60)
- other compil.: 11.3b(9.)(NNDC COMPUT.CH.85)
11.5b(CH.NUCL.84)
13.5b(NUKLIDK.81)
- experim.: LYON60; 8.8b(10.), probably m+g
ARINO64; 13.7b(16.), probably m+g

γ - ** from KOCHER81
- note large discrepancies with ERDTMANN79 for γ_{487} and γ_{620}; cf. REUS83 : γ_{487} = 2.09%; γ_{620} = 1.37%

T - accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, Z	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, Z (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇐ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ba 137.33 1.3 ; 10	^{132}Ba	0.101 0.101(2.0) (DEBIEVRE85)	0.5(-) 0.82(-) (THIS WORK)	2.8(-) 4.6(-) ($Q_0 \times \sigma_0$)	5.6(-) 5.6(-) (Table V.3-3)	143(-)	^{133m}Ba (I)	38.9h(0.3) (KOCHER81)	276.1 TRUE-COINCIDENCE see Table IV.2-4	18.0 18.0(2.8) (KOCHER81)	$1.38.10^{-6}$	$(2.27.10^{-6})$ (⇐ σ_0=0.82b)

COMMENTS

σ_0 - other compil.: 0.5b(-)(*NNDC COMPUT.CH.85*)
0.6b(CH.NUCL.84)
0.68b(*NUKLIDK.81*)
- experim.: HANS60; 4.1b(37.)
MANGAL63; <0.15b
ISHII69; 0.98b(15.)

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ba 137.33 1.3 ; 10	^{138}Ba	71.70 71.70(0.1) (DEBIEVRE85)	0.360(10.) 0.405(1.4) (THIS WORK)	0.32(12.5) 0.36(–) ($Q_0 \times \sigma_0$)	0.89(-) 0.88(–) (Table V.3-3)	15700(3.2)	^{139}Ba (I)	83.06min(0.3) (GEHRKE80)	165.9 TRUE-COINCIDENCE see Table IV.2-4	18.8 23.76(1.1) (GEHRKE80)	$7.39 \cdot 10^{-4}$	$1.05 \cdot 10^{-3}$(0.7) (→σ_0=0.405b(1.3))

COMMENTS

σ_0 - other compil.: 0.360b(10.)(NNDC COMPUT.CH.85)
0.4b(CH.NUCL.84)
0.35b(NUKLIDK.81)
- experim.: SEREN47; 0.511b(20.)
POMERANCE52; 0.68b(15.)
LYON60; 0.230b(10.)
KRAMER65; 0.360b(10.), with γ_{166} = 22.4%, normal.: 0.339b
GLEASON77; 0.47b(4.)
HEFT79; 0.447b(2.), with γ_{166} = 22.0%, normal.: 0.414b
- $g_{WESTCOTT}$ (20°C) = 0.9986 (ENDF/B-V82)

γ - note large discrepancies in literature for γ_{166}:
LEDERER78 : 22%(18.), KOCHER81 : 17%(35.),
PEKER81 : 22.0%(4.5), REUS83 : 23.8%

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
La 138.91 8.98 ; 12	^{139}La	99.91 99.91(0.01) (DEBIEVRE85)	8.93(0.4) 9.34(1.) (THIS WORK)	11.8(6.8) 11.6(-) ($Q_0 \times \sigma_0$)	1.32(-) 1.24(-) (Table V.3-3)	76.0(3.9)	^{140}La (I)	40.22h(0.05) (KOCHER81)	328.8 487.0 815.8 1596.5	18.5 20.5(1.5)* 43.0 45.5(1.5)* 22.32 23.5(2.1)* 95.47 95.49(0.07)*	$2.48.10^{-2}$ $5.77.10^{-2}$ $3.00.10^{-2}$ $1.28.10^{-1}$	$2.87.10^{-2}$(1.0) (→ σ_0=9.32b(1.8)) $6.37.10^{-2}$(0.9) (→ σ_0=9.32b(1.7)) $3.32.10^{-2}$(0.6) (→ σ_0=9.40b(2.2)) $1.34.10^{-1}$(1.1) (→ σ_0=9.34b(1.1))

COMMENTS

σ_0 - other compil.: 8.93b(0.4)(NNDC COMPUT.CH.85)
8.94b(CH.NUCL.84)
9.0b(NUKLIDK.81)

γ - * from KOCHER81
- note discrepancy with ERDTMANN79 for γ_{329}, γ_{487} & γ_{816}; cf. DEBERTIN77, PEKER79, LMRI80, HOLLOWAY82, REUS83, all consistent with KOCHER81

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ce 140.12 0.6 ; 0.7	^{140}Ce	88.48 88.48(0.1) (DEBIEVRE85)	0.57(7.) 0.575(1.2) (THIS WORK)	0.47(11.) 0.48(-) ($Q_0 \times \sigma_0$)	0.82(-) 0.83(-) (Table V.3-3)	7200(18.)	^{141}Ce (I)	32.501d(0.015) (PEKER85)	145.4	48.0 48.2(0.6) (PEKER85)	$3.61.10^{-3}$	$3.66.10^{-3}$(0.9) (→ σ_0=0.576b(1.1))

COMMENTS

σ_0 - other compil.: 0.57b(7.)(NNDC COMPUT.CH.85)
0.58b(CH.NUCL.84)
0.57b(NUKLIDK.81)

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, Z	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, Z (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,Z) {recommended or (tentative)} (⇐ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ce 140.12 0.6 ; 0.7	^{142}Ce	11.08 11.08(0.9) (DEBIEVRE85)	0.95(5.3) 0.975(2.) (THIS WORK)	1.15(4.3) 1.17(-) ($Q_0 \times \sigma_0$)	1.21(-) 1.20(-) (Table V.3-3)	1540(120.)	^{143}Ce (I)	33.0h(0.6) (KOCHER81)	231.6	2.00 2.04(1.5)*	$3.14.10^{-5}$	$3.37.10^{-5}$(1.4) (⇐ σ_0=1.000b(1.6))
									293.3	43.4 42.8(0.9)*	$6.81.10^{-4}$	$6.89.10^{-4}$(0.5) (⇐ σ_0=0.974b(0.5))
									350.6	3.2 3.27(1.4)*	$5.02.10^{-5}$	$5.14.10^{-5}$(0.5) (⇐ σ_0=0.951b(0.9))
									664.5	5.8 5.60(1.3)*	$9.10.10^{-5}$	$9.18.10^{-5}$(1.5) (⇐ σ_0=0.992b(1.6))
									722.0	5.5 5.32(1.3)*	$8.63.10^{-5}$	$8.78.10^{-5}$(0.9) (⇐ σ_0=0.999b(1.1))

COMMENTS

σ_0 - other compil.: 0.95b(5.3)(NNDC COMPUT.CH.85)
0.95b(CH.NUCL.84; NUKLIDK.81)

γ - * from GEHRKE82

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Pr 140.91 11.4 ; 14.1	^{141}Pr	100 100(0.) (DEBIEVRE85)				296(4.1)	^{142m}Pr I.T. F_2=1 ^{142}Pr (IV/b)	14.6min(3.4) (PEKER84) 19.12h(0.2) (PEKER84)	1575.6	3.7 3.7(14.) (PEKER84)	$6.31.10^{-3}$	$6.12.10^{-3}$(0.6) (→ σ_0=11.2b(14.))
			11.5(2.6)* 11.2(14.)* (THIS WORK)	17.4(11.)* 16.9(-)* ($Q_0 \times \sigma_0$)	1.51(-)* 1.51(-)* (Table V.3-3)							

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

* - for m+g

σ_0 - other compil.: 11.5b(2.6)(NNDC COMPUT.CH.85)
11.4b(CH.NUCL.84)
11.5b(NUKLIDK.81)

γ - note large uncertainty on γ_{1576}; accurate re-determination desirable

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Nd 144.24 49 ; ∿42	^{146}Nd	17.19 17.19(0.5) (DEBIEVRE85)	1.4(7.1) 1.45(3.) (THIS WORK)	3.2(15.6) 2.90(3.^{5}) ($Q_0 \times \sigma_0$)	2.3(-) 2.00(1.2) (Table V.3-3)	874(5.9)	^{147}Nd (I)	10.98d(0.09) (LMRI85)	91.1	28.3 28.1(3.6)*	$9.87.10^{-4}$	$1.02.10^{-3}$(2.5) (↔σ_0=1.46b(4.4))
									120.5	0.4 0.373(4.0)*	$1.39.10^{-5}$	$(1.28.10^{-5})$ (↔σ_0=1.38b)
									275.4	1.0 0.77(3.9)*	$3.49.10^{-5}$	$2.86.10^{-5}$(2.0) (↔σ_0=1.49b(4.4))
									319.4	2.2 1.91(3.1)*	$7.67.10^{-5}$	$6.78.10^{-5}$(0.9) (↔σ_0=1.43b(3.2))
									398.2	0.9 0.83(3.6)*	$3.14.10^{-5}$	$(2.90.10^{-5})$ (↔σ_0=1.40b)
									439.9	1.2 1.17(6.0)*	$4.18.10^{-5}$	$4.22.10^{-5}$(1.4) (↔σ_0=1.45b(6.2))
									531.0	13.5 12.7(2.4)*	$4.71.10^{-4}$	$4.56.10^{-4}$(1.1) (↔σ_0=1.44b(2.6))
									685.9	0.8 0.78(3.8)*	$2.79.10^{-5}$	$(2.68.10^{-5})$ (↔σ_0=1.38b)

COMMENTS

σ_0 - other compil.: 1.4b(7.)(NNDC COMPUT.CH.85)
1.4b(CH.NUCL.84)
1.3b(NUKLIDK.81)

γ - * from LMRI85
- note large discrepancies with ERDTMANN79 for γ_{275} and γ_{319}; cf. KOCHER81 : γ_{275} = 0.80%(7.), γ_{319} = 1.96%(6.)

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} ($\rightarrow\sigma_0$ from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Nd 144.24 49 ; ~42	^{148}Nd	5.76 5.76(0.5) (DEBIEVRE85)	2.5(8.0) 2.36(6.7) (THIS WORK)	14(7.1) 12.1(7.2) ($Q_0 \times \sigma_0$)	5.6(-) 5.08(2.5) (Table V.3-3)	236(5.9)	^{149}Nd (I)	1.72h(0.6) (SZÜCS85)	97.0 (E_{eff})	1.512 1.48(8.0)*	$3.15.10^{-5}$	$(3.32.10^{-5})$ ($\rightarrow\sigma_0$=2.67b)
									114.3	18.58 19.0(8.2)*	$3.88.10^{-4}$	$(4.05.10^{-4})$ ($\rightarrow\sigma_0$=2.55b)
									155.9 (E_{eff})	5.994 5.96(5.2)*	$1.25.10^{-4}$	$(1.22.10^{-4})$ ($\rightarrow\sigma_0$=2.45b)
									198.9 (E_{eff})	1.442 1.44(4.8)*	$3.01.10^{-5}$	$(2.98.10^{-5})$ ($\rightarrow\sigma_0$=2.48b)
									208.1	2.889 2.55(3.9)*	$6.03.10^{-5}$	$(5.71.10^{-5})$ ($\rightarrow\sigma_0$=2.68b)
									211.3	27.00 25.9(5.6)*	$5.63.10^{-4}$	$(5.26.10^{-4})$ ($\rightarrow\sigma_0$=2.43b)
									240.2	3.915 3.94(5.5)*	$8.17.10^{-5}$	$(7.72.10^{-5})$ ($\rightarrow\sigma_0$=2.35b)
									267.7	5.994 6.03(4.6)*	$1.25.10^{-4}$	$(1.16.10^{-4})$ ($\rightarrow\sigma_0$=2.31b)
									270.2	10.61 10.7(4.7)*	$2.21.10^{-4}$	$(2.12.10^{-4})$ ($\rightarrow\sigma_0$=2.37b)
									326.6	4.617 4.56(4.5)*	$9.63.10^{-5}$	$(9.10.10^{-5})$ ($\rightarrow\sigma_0$=2.39b)
									349.1 (E_{eff})	1.647 1.54(4.5)*	$3.43.10^{-5}$	$(2.96.10^{-5})$ ($\rightarrow\sigma_0$=2.30b)
									423.6 (E_{eff})	9.342 7.71(6.4)*	$1.95.10^{-4}$	$(1.60.10^{-4})$ ($\rightarrow\sigma_0$=2.49b)
									540.5	7.587 6.58(5.2)*	$1.58.10^{-4}$	$(1.35.10^{-4})$ ($\rightarrow\sigma_0$=2.46b)
									654.8	7.263 7.95(6.2)*	$1.51^{5}.10^{-4}$	$(1.66.10^{-4})$ ($\rightarrow\sigma_0$=2.50b)
							^{149}Pm (II/a)	53.08h(0.09) (SZÜCS85)	285.9	3.10 3.1(6.5)*	$6.47.10^{-5}$	$6.10.10^{-5}$(1.1) ($\rightarrow\sigma_0$=2.36b(6.6))

β^-, $F_2 = 1$

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

σ_0 - other compil.: 2.5b(8.)(NNDC COMPUT.CH.85)
2.5b(CH.NUCL.84)
2.48b(NUKLIDK.81)
- THIS WORK from non-recommended ^{149}Nd-lines : 2.46b

γ - * from SZÜCS85
- note large discrepancies with ERDTMANN79 for γ_{208}, γ_{424}, γ_{541} and γ_{655}; cf. KOCHER81 : γ_{208} = 2.9% (14.), γ_{424} = 9.4%(11.), γ_{541} = 7.7%(10.), γ_{655} = 7.3%(11.)
- 97.0 keV = E_{eff} of 96.9 and 97.0; 155.9 keV = E_{eff} of 155.1 and 155.9; 198.9 keV = E_{eff} of 197.8 and 198.9; 349.1 keV = E_{eff} of 347.8 and 349.2; 423.6 keV = E_{eff} of 423.6 and 425.2
- accurate redetermination desirable

BURN-UP ^{149}Pm(n,γ) : σ_0 = 1400b(21.)(MUGHABGHAB84);
I_0 ≈ 800b(-)(GRYNTAKIS83);
$\bar{E}_r$ unknown (10 eV assumed)

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Nd 144.24 49 ; ∿ 42	^{150}Nd	5.64 5.64(0.5) (DEBIEVRE85)	1.2(17.) 0.91(-) (THIS WORK)	14(14.) 11.2(-) ($Q_0 \times \sigma_0$)	12(-) 12.3(0.8) (Table V.3-3)	173(12.)	^{151}Nd (I) β⁻, E_β=1 ^{151}Pm (II/a)	12.4min(1.) (LEDERER78) 28.40h(0.14) (KOCHER81)	255.6 1180.6 340.1	16.83 16.9(7.9)* 15.3 15.3(6.5)* 22.4 22.9(3.9) (KOCHER81)	$1.65.10^{-4}$ $1.50.10^{-4}$ $2.20.10^{-4}$	$(1.31.10^{-4})$ (↔σ_0=0.95b) $(1.09.10^{-4})$ (↔σ_0=0.87b) $(1.73.10^{-4})$ (↔σ_0=0.92b)

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

σ_0 - other compil.: 1.2b(17.)(NNDC COMPUT.CH.85)
1.2b(CH.NUCL.84)
1.2b(NUKLIDK.81)
- experim.: SEHGAL59; 1.5b(13.), with T = 18.8min
ALSTAD67; 1.0b(20.), no inform.
KIM72; from ^{151}Pm : 0.94b(2.), with γ_{340} = 21%; normal.: 0.86b
from ^{151}Nd : 1.17b(6.), with γ_{174} = 11.8% (not consistent), γ_{256} = 12.7%, γ_{1181} = 10.0%; normal.: 0.82b (174 keV not considered)
GRYNTAKIS76/78; results identical with KIM72
HEFT79; 1.03b(4.), with γ_{117} = 30.6% (not consistent), γ_{340} = 19.6%; normal.: 0.88b (117 keV not considered)

γ - * from LEDERER78 (γ_{1181} absolute; γ_{256} relative); cf. REUS83 : γ_{256} = 15.3%; γ_{1181} = 15.3% (both largely uncertain)
- accurate redetermination desirable

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Sm 150.36 5900 ; 1400	^{152}Sm	26.6 26.7(0.75) (DEBIEVRE85)	206(2.9) 220(2.4) (THIS WORK)	2970(3.4) 3168(3.2) ($Q_0 \times \sigma_0$)	14.4(-) 14.4(2.1) (Table V.3-3)	8.53(1.1)	^{153}Sm (I)	46.7h(0.2) (LEE82)	69.7 103.2	5.25 5.25(4.8)* 28.3 28.30(2.1)*	$4.00.10^{-2}$ $2.15.10^{-1}$	$(3.60.10^{-2})$ (↔ σ_0=185b) $2.31.10^{-1}$(0.4) (↔ σ_0=220b(2.2))

COMMENTS

σ_0 - other compil.: 206b(2.9)(NNDC COMPUT.CH.85)
208b(CH.NUCL.84)
206b(NUKLIDK.81)

F_{Cd} - possibly < 1 (ELNIMR81)

γ - * from LEE82

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b; I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Sm 150.36 5900 ; 1400	^{154}Sm	22.6 22.7(0.9) (DEBIEVRE85)	8.4(5.9) 7.74(6.) (THIS WORK)	32(18.8) 33.3(9 .) ($Q_0 \times \sigma_0$)	3.81(-) 4.30(7.0) (Table V.3-3)	142(7.0)	^{155}Sm (I)	22.3min(0.9) (LEE87)	141.2 246.0	2.015 2.00(6.6)* 3.732 3.70(5.4)*	$5.32.10^{-4}$ $9.85.10^{-4}$	$4.83.10^{-4}$(1.3) (⇔ σ_0=7.66b(3.9)) $9.05.10^{-4}$(1.4) (⇔ σ_0=7.75b(1.4))

COMMENTS

σ_0 - other compil.: 5.5b(20.)(NNDC COMPUT.CH.85)
8b(CH.NUCL.84)
5.5b(NUKLIDK.81)
- experim.: SEREN44; 5.5b(20.)
SEREN47; 4.8b(20.), if θ_{154} = 22.7%
HEFT79; 8.5b(5.9); 104 keV measured, with γ_{104} = 63.5%; normal. to 74%(*) = 7.3b
- see DECORTE86

γ - * from LEE87
- accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Eu 151.96 4600 ; 2400	^{153}Eu	52.14 52.2(1.0) (DEBIEVRE85)	312(2.2)* 307(4.)* (THIS WORK)	1420(7.0)* 1738(-)* ($Q_0 \times \sigma_0$)	4.55(-)* 5.66(-)* (Table V.3-3)	5.80(4.0)	^{154m}Eu I.T. F_{21}=1 ^{154}Eu (IV/b)	46.0min(0.7) (HARMATZ79) 8.561y(0.3) (YOSHIZAWA85)	248.0 591.8 723.3 756.9 873.2 996.4 1274.4	6.6 6.95(1.3)** 4.6 5.00(1.2)** 19.7 20.28(1.2)** 4.1 4.60(1.3)** 11.3 12.27(1.1)** 10.7 10.50(1.1)** 35.5 34.9(1.1)**	$1.48.10^{-1}$ $1.03.10^{-1}$ $4.41.10^{-1}$ $9.18.10^{-2}$ $2.53.10^{-1}$ $2.40.10^{-1}$ $7.95.10^{-1}$	$(1.55.10^{-1})$*** (→ σ_0=311b) $1.08.10^{-1}$(1.5)*** (→ σ_0=301b(1.5)) $4.46.10^{-1}$(1.5)*** (→ σ_0=306b(1.5)) $(1.08.10^{-1})$*** (→ σ_0=327b) $2.72.10^{-1}$(1.4)*** (→ σ_0=309b(1.4)) $(2.30.10^{-1})$*** (→ σ_0=305b) $7.77.10^{-1}$(1.1)*** (→ σ_0=310b(1.1))

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

T - other recent values : 8.49y(1.3)(NBS82)
8.57y(0.8)(PTB78)
8.583y(0.06)(WOODS86)
- former deviating values : 15.6y(10.)(KASTNER53)
16y(25.)(KARRAKER52)
- note that in the activ.meth., with reasonably short t_{irr}, t_d and t_m, σ_0 is approx. proportional to the introduced T-value .

$k_{0,Au}$(exp.) - *** incl.MOENS84, recalc. for T = 8.561y

* - for m+g

σ_0^{m+g} - other compil.: 390b(8.)(NNDC COMPUT.CH.85)
350b(CH.NUCL.84)
390b(NUKLIDK.81)
- experim.: TATTERSALL60; 317b(2.) pile oscill.
SIMS67; 639b(1.) with T = 16y and γ_{1274} = 38%; normal.: 372b
KIM75; 603b(4.) with T = 16y; normal.: 323b
WIDDER76; 382b(4.), TOF
LUCAS77; 325b(-), with T = 8.6y; normal.: 324b
HEFT79; 295b(2.), with T = 7.84y and γ_{123} = 40.5%; normal.: (γ_{123} = 41.0% **) 318b
- $g_{WESTCOTT}$ (20°C) = 1.0290; (100°C) = 1.00074 (GRYNTAKIS75) = 0.9663 (ENDF/B-V82)
- see DECORTE86

F_{Cd} - possibly < 1 (ELNIMR81)

γ - ** from YOSHIZAWA85
- note good consistency with data in NBS82

BURN-UP $^{154}Eu(n,\gamma)$: σ_0 = 1340b(10.), I_0 = 802b(-)(MUGHABGHAB84); $\bar{E}_r$ = 0.34 eV(-)(THIS WORK); $g_{WESTCOTT} \neq 1$

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b; I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,Z) (recommended or (tentative)) (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Gd 157.25 49000 ; 400	^{158}Gd	24.8 24.84(0.5) (DEBIEVRE85)	2.2(9.1) 3.1(>38.)* (THIS WORK)	73(9.6) 96(-)* ($Q_0 \times \sigma_0$)	33.2(-) 31.0(4.5) (Table V.3-3)	48.2(8.)	^{159}Gd (I)	18.56h(0.4) (KOCHER81)	363.6 TRUE-COINCIDENCE see Table IV.2-4	10.33 8.(38.) (KOCHER81)	$7.49.10^{-4}$	$(8.28.10^{-4})$ (↔ σ_0=3.14b)

COMMENTS

* with γ_{364} = 10.33%, THIS WORK yields σ_0 = 2.4b; this leads to I_0 = 74b

σ_0 - other compil.: 2.5b(20.)(NNDC COMPUT.CH.85)
2.4b(CH.NUCL.84)
2.5b(NUKLIDK.81)
- cf. experim.; HEFT79 : 2.44b, with γ_{364} = 10.0%, normal.: 3.05b

γ - note large discrepancy with ERDTMANN79; cf. LEDERER78: ∿ 10%, from level scheme; REUS83:10.8%(>25.)
- note large uncertainty; accurate redetermination desirable

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} ($\leftrightarrow\sigma_0$ from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Gd 157.25 49000 ; 400	^{160}Gd	21.8 21.86(0.2) (DEBIEVRE85)	0.77(2.6) 1.51(-) (THIS WORK)	- 5.78(-) ($Q_0 \times \sigma_0$)	- 3.83(1.9) (Table V.3-3)	480(7.1)	^{161}Gd (I)	3.66min(1.4) (HELMER84)	102.3	15.25 13.9(5.7)**	$3.40.10^{-4}$	$(7.88.10^{-4})$* ($\leftrightarrow\sigma_0$=1.95b)*
									165.2	1.83 2.58(7.7)**	$4.08.10^{-5}$	$(1.07.10^{-4})$* ($\leftrightarrow\sigma_0$=1.43b)*
									283.6	5.612 5.95(4.2)**	$1.25.10^{-4}$	$(2.84.10^{-4})$* ($\leftrightarrow\sigma_0$=1.64b)*
									314.9	20.31 22.7(4.0)**	$4.53.10^{-4}$	$(1.03.10^{-3})$* ($\leftrightarrow\sigma_0$=1.56b)*
									360.9	61.0 60.1(2.5)**	$1.36.10^{-3}$	$(2.72.10^{-3})$* ($\leftrightarrow\sigma_0$=1.56b)*
									480.1	1.891 2.68(5.6)**	$4.22.10^{-5}$	$(1.04.10^{-4})$* ($\leftrightarrow\sigma_0$=1.34b)*

COMMENTS

σ_0 - other compil.: 0.77b(2.6)(NNDC COMPUT.CH.85)
0.8b(CH.NUCL.84)
0.77b(NUKLIDK.81)
- experim.: MANGAL63; 0.768b(1.6)
- THIS WORK : - σ_0 from 102 keV-line not consistent; rejected for average
- * based on experiments with 98.71% ^{160}Gd-enrichment; ∿ 30 μg $^{160}Gd_2O_3$ on W41-paper

γ - ** from HELMER84
- note large discrepancy with ERDTMANN79 for γ_{102}, γ_{165}, γ_{315} & γ_{480}

T - accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Tb 158.93 23.0 ; 390	^{159}Tb	100 100(0.) (DEBIEVRE85)	23.4(1.7) 23.8(1.) (THIS WORK)	418(4.8) 426(4.) ($Q_0 \times \sigma_0$)	17.9(-) 17.9(3.8) (Table V.3-3)	18.1(5.)	^{160}Tb (I)	72.1d(0.4) (YOSHIZAWA85)	86.8	13.4 13.3(6.0)**	$4.12.10^{-2}$	$4.20.10^{-2}$(1.1) (↔ σ_0=24.0b(6.1))
									197.0	5.24 5.18(1.5)*	$1.61.10^{-2}$	$1.62.10^{-2}$(0.5) (↔ σ_0=23.8b(1.6))
									215.6	4.02 4.06(1.2)*	$1.24.10^{-2}$	$1.27.10^{-2}$(0.4) (↔ σ_0=23.8b(1.3))
									298.6	27.4 26.64(0.6)*	$8.43.10^{-2}$	$8.25.10^{-2}$(1.2) (↔ σ_0=23.6b(1.3))
									879.4	30.0 30.35(0.3)*	$9.23.10^{-2}$	$9.42.10^{-2}$(0.9) (↔ σ_0=23.6b(0.9))
									962.3	10.0 9.72(0.4)*	$3.08.10^{-2}$	$(3.05.10^{-2})$ (↔ σ_0=23.9b)
									965.1 (E_{eff})	35.5 34.78(0.2)*	$1.09.10^{-1}$	$1.08.10^{-1}$(1.4) (↔ σ_0=23.6b(1.4))
									966.2	25.5 25.06(0.3)*	$7.84.10^{-2}$	$(7.84.10^{-2})$ (↔ σ_0=23.8b)
									1178.0	15.5 14.97(0.3)*	$4.77.10^{-2}$	$4.71.10^{-2}$(1.1) (↔ σ_0=23.9b(1.1))
									1199.9	2.36 2.379(0.4)*	$7.26.10^{-3}$	$7.53.10^{-3}$(1.3) (↔ σ_0=24.1b(1.4))
									1271.9	7.6 7.505(0.4)*	$2.34.10^{-2}$	$2.35.10^{-2}$(0.8) (↔ σ_0=23.8b(0.9))
									1312.1	2.97 2.838(0.4)*	$9.14.10^{-3}$	$8.98.10^{-3}$(0.9) (↔ σ_0=24.1b(1.0))

COMMENTS

σ_0 - other compil.: 25.5b(4.3)(NNDC COMPUT.CH.85)
23.0b(CH.NUCL.84)
25.5b(NUKLIDK.81)

F_{Cd} = 0.995 (ELNIMR81)

γ - * from YOSHIZAWA85
- ** from KOCHER81
- note discrepancies with LEE85 : γ_{87} = 12.8%(2.2); γ_{197} = 5.61%(2.3); γ_{216} = 4.41%(2.0); γ_{299} = 28.9%(1.9); γ_{879} = 32.9%(1.8); γ_{962} = 10.5%(1.9); γ_{965} = 37.7%(1.9); γ_{966} = 27.2%(1.8); γ_{1178} = 16.2%(1.9); γ_{1200} = 2.58%(1.9); γ_{1272} = 8.13%(1.9); γ_{1312} = 3.08%(1.9);
- 965.1 keV = E_{eff} of 962.3 & 966.2

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Dy 162.50 920 ; 1600	^{164}Dy	28.1 28.2(0.7) (DEBIEVRE85)	1610(14.9) 1697(-) (THIS WORK)	- 424(-) ($Q_0 \times \sigma_0$)	- 0.25(-) (Table V.3-3)	224(4.9)	^{165m}Dy (I)	1.258min(0.5) (PEKER87)	108.2 515.5	21.2 3.01(1.0)* 11.7 1.527(6.1)*	1.23 $6.81.10^{-1}$	$(1.88.10^{-1})$ (→σ_0=1723) $(9.25.10^{-2})$ (→σ_0=1671)
(cont'd)							I.T. F_2=0.976(0.3) (PEKER87)					

COMMENTS

σ_0 - other compil.: 1700b(15.)(NNDC COMPUT.CH.85)
1700b(CH.NUCL.84; NUKLIDK.81)
- $g_{WESTCOTT}$ (20°C) = 0.9876 (ENDF/B-V82)

T - note discrepancy with BODE75 : 1.275min(0.9)

γ - * from PEKER87
- note large discrepancies with ERDTMANN79

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Dy (cont'd)			2611(9.9)* 2725(13.)* (THIS WORK)	340(5.9)*+ 518(23.)* ($Q_0 \times \sigma_0$)	0.13(-)* 0.19(19.3)* (Table V.3-3)		^{165}Dy (IV/b)	2.334h(0.3) (PEKER87)	94.7	3.343 3.58(13.)**	$3.16.10^{-1}$	$3.57.10^{-1}$(1.4) (→σ_0=2750(13.))
									279.8	0.5015 0.498(13.)**	$4.74.10^{-2}$	$4.88.10^{-2}$(0.8) (→σ_0=2703(13.))
									361.7	0.840 0.84(13.)**	$7.93.10^{-2}$	$8.36.10^{-2}$(0.7) (→σ_0=2745b(13.))
									633.4	0.5628 0.568(12.)**	$5.32.10^{-2}$	$5.62.10^{-2}$(1.5) (→σ_0=2729(12.))
									715.3	0.5309 0.534(12.)**	$5.01.10^{-2}$	$5.23.10^{-2}$(1.2) (→σ_0=2701(12.))

COMMENTS

* - for F_2 m+g (+ : probably for m+g)

$\sigma_0^{F_2 m+g}$ - other compil.: 2659b(11.)(NNDC COMPUT.CH.85)
2659b(CH.NUCL.84; NUKLIDK.81)
- $g_{WESTCOTT}$ (20°C) = 0.9876(ENDF/B-V82)

σ_0^g - THIS WORK : 1063b(-); cf. 1000b(15.)(NNDC COMPUT. CH.85), 1040b(13.5)(MUGHABGHAB84), 1000b(CH.NUCL. 84; NUKLIDK.81)

γ - ** from PEKER87
- note large discrepancy with ERDTMANN79 for γ_{95}
- accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} ($\leftrightarrow\sigma_0$ from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ho 164.93 65 ; 670	^{165}Ho	100 100(0.) (DEBIEVRE85)	61.2(1.8) 58.1(4.) (THIS WORK)	650(3.4) 636(5.) ($Q_0 \times \sigma_0$)	10.6(-) 10.9^5(2.4) (Table V.3-3)	12.3(3.3)	^{166}Ho (I)**	26.80h(0.07) (KOCHER81)	80.6 1379.4 1581.9 1662.4	6.2 6.2(6.5)*+ 0.93 0.93(5.4)* 0.185 0.183(3.3)* 0.118 0.121(3.3)*	$4.81.10^{-2}$ $7.21.10^{-3}$ $1.43.10^{-3}$ $9.15.10^{-4}$	$5.45.10^{-2}$(1.6) (σ_0=69.4b(6.7)) $6.91.10^{-3}$(1.9) (σ_0=58.6b(5.7)) $1.39.10^{-3}$(2.4) (σ_0=60.0b(4.1)) $8.68.10^{-4}$(1.1) (σ_0=56.6b(3.5))

COMMENTS

σ_0 - other compil.: 63.0b(5.2)(NNDC COMPUT.CH.85)
62b(*CH.NUCL.84*)
63.0b(NUKLIDK.81)
- σ_0 (THIS WORK) from 81 keV-line not consistent; rejected for average

** - ^{166m}Ho(T = 1200y) gives no I.T. to ^{166}Ho

F_{Cd} = 0.99 (ELNIMR81)

γ - * from KOCHER81
- + interference from ^{166m}Ho 80.6 keV-line possible after long t_d
- accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Er 167.26 160 ; 740	^{170}Er	14.9 14.9(0.7) (DEBIEVRE85)	5.8(5.2) 8.85(3.) (THIS WORK)	24(12.5) 39.1(4.5) ($Q_0 \times \sigma_0$)	4.1(-) 4.42(3.3) (Table V.3-3)	129(2.3)	^{171}Er (I)	7.52h(0.4) (SHIRLEY84)	111.6 116.7 124.0 210.6 (E_{eff}) 237.1 295.9 308.3	20.5 20.5(3.9)* 2.3 2.30(2.6)* 9.1 9.1(3.3)* 0.649 0.649(3.0)* 0.302 0.302 (3.3)* 28.9 28.9(2.8)* 64.4 64.4(2.5)*	$2.21.10^{-3}$ $2.48.10^{-4}$ $9.82.10^{-4}$ $7.01.10^{-5}$ $3.26.10^{-5}$ $3.12.10^{-3}$ $6.95.10^{-3}$	$3.41.10^{-3}$(0.8) (→ σ_0=8.94b(4.0)) $3.36.10^{-4}$(1.8) (→ σ_0=7.85b(3.2)) $1.52.10^{-3}$(0.6) (→ σ_0=8.97b(3.4)) ($1.09.10^{-4}$) (→ σ_0=9.02b) ($5.23.10^{-5}$) (→ σ_0=9.30b) $4.79.10^{-3}$(1.5) (→ σ_0=8.90b(3.2)) $1.04.10^{-2}$(1.4) (→ σ_0=8.68b(2.9))

COMMENTS

σ_0 - other compil.:5.7b(3.5)(NNDC COMPUT.CH.85)
5.8b(CH.NUCL.84)
5.7b(NUKLIDK.81)
- experim.: BARNES54; 8.72b(20.)
MANGAL63; 4.3b(15.)
GILETTE67; 5.7b(3.)
GOLDMAN68; 6.0b
VERTEBNYI68; 12b(42.)
GLOMSET72; 5.8b(5.)
HEFT79; 6b (17.)
└ σ_0 from 116.7 keV not consistent; rejected for average

γ - * from SHIRLEY84
- 210.6 keV = E_{eff} of 210.1 and 210.6

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : *continued*

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Tm 168.93 105;1710	^{169}Tm	100 100(0.) (DEBIEVRE85)	105(1.9) 107(-) (THIS WORK)	1720(1.7) 1552(-) ($Q_0 \times \sigma_0$)	16.4(-) 14.5(-) (Table V.3-3)	4.80(2.1)	^{170}Tm (I)	128.6d(0.2) (KOCHER81)	84.3 TRUE-COINCIDENCE see Table IV.2-4	10.0 3.26(4.9) (KOCHER81)	$1.30.10^{-1}$	$(4.30.10^{-2})$ (↔σ_0=107b)

COMMENTS

σ_0 - other compil.: 95b(2.1)(NNDC COMPUT.CH.85)
105b(CH.NUCL.84)
103b(NUKLIDK.81)

γ - note large discrepancy with ERDTMANN79 for γ_{84};
cf. LEDERER78 : γ_{84} = 3.2%(9.4), from level scheme;
cf. REUS83 : 3.26%

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (← σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Yb 173.04 35 ; 170	^{174}Yb	31.83 31.8(1.3) (DEBIEVRE85)	69.4(7.2)* 128(6.5)* (THIS WORK)	27.(11.)* 58.9(-)* ($Q_0 \times \sigma_0$)	0.39(-)* 0.46(-)* (Table V.3-3)	602(8.)	^{175}Yb (IV/b)	4.19d(0.2) (KOCHER81)	113.8	1.824 1.88(13.)**	$4.87.10^{-3}$	$9.42.10^{-3}$(1.3) (← σ_0=130b(13.))
									137.7	0.111 0.104(18.)**	$2.96.10^{-4}$	$5.69.10^{-4}$(0.6) (← σ_0=142b(18.))
									144.9	0.317 0.34(18.)**	$8.46.10^{-4}$	$1.59.10^{-3}$(1.5) (← σ_0=122b(18.))
									282.5	2.9 3.0(13.)**	$7.74.10^{-3}$	$1.46.10^{-2}$(0.3) (← σ_0=127b(13.))
									396.3	6.21 6.5(12.)**	$1.66.10^{-2}$	$3.12.10^{-2}$(0.6) (← σ_0=125b(12.))

COMMENTS

* - for g+m (68.2 ms)

σ_0 - other compil.: 65b(7.7)(NNDC COMPUT.CH.85)
65b(CH.NUCL.84; NUKLIDK.81)
- see DECORTE85

γ - ** from KOCHER81
- accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Yb 173.04 35 ; 170	^{176}Yb	12.76 12.7(0.8) (DEBIEVRE85)	2.85(1.8)* 3.11(-)* (THIS WORK)	6.3(9.5)* 7.8(-)* ($Q_0 \times \sigma_0$)	2.21(-)* 2.50(1.8)* (Table V.3-3)	412(5.1)	^{177}Yb (IV/b)	1.9h(5.) (LEDERER78)	121.6	3.379 3.41(20.)**	$1.48.10^{-4}$	$(1.64.10^{-4})$ ↔ σ_0=3.13b)
									138.6	1.328 1.33(21.)**	$5.83.10^{-5}$	$(6.48.10^{-5})$ ↔ σ_0=3.18b)
									150.4	20.04 20.0(20.)**	$8.80.10^{-4}$	$(8.94.10^{-4})$ ↔ σ_0=2.91b)
									899.2	0.6409 0.644(19.)**	$2.81.10^{-5}$	$(3.12.10^{-5})$ ↔ σ_0=3.16b)
									941.7	1.014 1.01(19.)**	$4.45.10^{-5}$	$(4.87.10^{-5})$ ↔ σ_0=3.14b)
									1028.0	0.6409 0.633(19.)**	$2.81.10^{-5}$	$(2.94.10^{-5})$ ↔ σ_0=3.03b)
									1080.1	5.50 5.5(18.)**	$2.42.10^{-4}$	$(2.68.10^{-4})$ ↔ σ_0=3.18b)
									1119.6	0.5477 0.545(19.)**	$2.41.10^{-5}$	$(2.74.10^{-5})$ ↔ σ_0=3.28b)
									1149.7	0.6409 0.643(19.)**	$2.81.10^{-5}$	$(2.96.10^{-5})$ ↔ σ_0=3.00b)
									1241.4	3.356 3.36(19.)**	$1.47.10^{-4}$	$(1.62.10^{-4})$ ↔ σ_0=3.14b)

COMMENTS

* - for g+m (11.4s)

σ_0 - other compil.: 2.4b(8.3)(NNDC COMPUT.CH.85)
3b(CH.NUCL.84)
2.4b(NUKLIDK.81)
- cf. experim.: HEFT79; 3.02b(1.7) with γ_{150} = 21.0%, normal.: 3.17b

γ - ** from LEDERER78 (γ_{1080}^{abs}; others relative)
- note large uncertainties on γ's; accurate redetermination desirable

T - accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Lu 174.97 84 ; ∿ 860	^{175}Lu	97.41 97.41(0.02) (DEBIEVRE85)	16.2(3.1) 16.7(3.8) (THIS WORK)	550(5.5) 581(4.9) ($Q_0 \times \sigma_0$)	34.0(-) 34.8(3.1) (Table V.3-3)	16.1(5.0)	^{176m}Lu (I)	3.635h(0.3) (LAGOUTINE82)	88.4 TRUE-COINCIDENCE see Table IV.2-4	8.76 8.90(1.7) (LOWENTHAL81)	$1.65.10^{-2}$	$1.73.10^{-2}$(1.5) (↔σ_0=16.7b(2.3))

COMMENTS

σ_0 - other compil.: 16.4b(5.5)(NNDC COMPUT.CH.85)
16b(CH.NUCL.84)
16.4b(NUKLIDK.81)
- $g_{WESTCOTT}$ (20°C) = 0.9766(ENDF/B-V82)

F_{Cd} - possibly < 1 (ELNIMR81)

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b; I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Hf 178.49 104 ; 2000	^{174}Hf	0.163 0.162(1.2) (DEBIEVRE85)	561(6.2) 549(1.8) (THIS WORK)	436(8.0) 428(–) ($Q_0 \times \sigma_0$)	0.78(-) 0.78(–) (Table V.3-3)	29.6(7.1)	^{175}Hf (I)	70d(2.9) (LEDERER78)	343.6	86.92 87.0(0.6) (LEDERER78)	$9.30.10^{-3}$	$9.06.10^{-3}$(1.0) (→ σ_0=549b(1.2))

COMMENTS

σ_0 - other compil.: 390b(14.)(NNDC COMPUT.CH.85)
500b(CH.NUCL.84)
390b(NUKLIDK.81)
- experim.: POMERANCE52; 500b(100.), pile oscill.meth. versus σ_{Au} = 95b; normal.:519b
ESCH61; 390b(14.), activ.meth.
HEFT79; 620b(3.), activ.meth.with θ = 0.18% and γ_{344} = 88.0%; normal.: 697b

T - accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Hf 178.49 104 ; 2000	^{179}Hf	13.75 13.629(0.04) (DEBIEVRE85)	0.445(0.7) 0.450(3.) (THIS WORK)	6.9(8.7) 6.4(4.) ($Q_0 \times \sigma_0$)	15.5(-) 14.4(2.4) (Table V.3-3)	16.2(11.7)	^{180m}Hf (I)	5.519h(0.07) (BROWNE86)	93.3	17.05 17.0(2.9)*	$1.22.10^{-4}$	$1.24.10^{-4}$(0.5) (↔ σ_0=0.457b(2.9))
									215.2	82.7 81.7(2.3)*	$5.92.10^{-4}$	$5.91.10^{-4}$(1.5) (↔ σ_0=0.453b(2.7))
									332.3	95.3 94.4(2.6)*	$6.83.10^{-4}$	$6.74.10^{-4}$(2.0) (↔ σ_0=0.448b(3.3))
									443.2	83.65 85(3.5)*	$5.99.10^{-4}$	$5.88.10^{-4}$(1.9) (↔ σ_0=0.434b(4.0))
									500.7	14.8 12.8(8.6)*	$1.06.10^{-4}$	$1.02.10^{-4}$(0.9) (↔ σ_0=0.499b(8.6))

COMMENTS

σ_0 - other compil.: 0.34b(9.)(NNDC COMPUT.CH.85)
0.45b(CH.NUCL.84)
0.34b(NUKLIDK.81)
- value of 0.34b probably originating from SCHARFF66 (σ_0=0.339b(7.4))
- cf. 0.4326b(0.6)(MANNHART75), 0.407b(5.)(HEFT79)
- σ_0 (THIS WORK) from 501 keV line not consistent (not included in average); better consistency would be obtained with γ from ERDTMANN79 and REUS83 (14.5%)

γ - * from BROWNE86

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Hf 178.49 104 ; 2000	^{180}Hf	35.22 35.100(0.02) (DEBIEVRE85)	13.04(0.5) 13.5(1.3) (THIS WORK)	35.0(2.9) 34.0(4.) ($Q_0 \times \sigma_0$)	2.68(-) 2.52(3.6) (Table V.3-3)	115(6.1)	^{181}Hf (I)	42.39d(0.14) (FIRESTONE84)	133.0	43.0 41.7(3.8)*	$2.31.10^{-2}$	$2.37.10^{-2}$(0.6) (↔σ_0=13.8b(3.8))
									133.4 (E_{eff})	50.9 47.7(3.4)*	$2.74.10^{-2}$	$2.76.10^{-2}$(1.0) (↔σ_0=14.1b(3.5))
									136.3 (E_{eff})	7.9 5.96(5.6)*	$4.25.10^{-3}$	($3.65.10^{-3}$) (↔σ_0=14.9b)
									345.9	14.0 17.2(3.5)*	$7.53.10^{-3}$	($7.93.10^{-3}$) (↔σ_0=11.2b)
									482.2	86.0 82.8(1.0)*	$4.62.10^{-3}$	$4.56.10^{-2}$(0.9) (↔σ_0=13.4b(1.3))

COMMENTS

σ_0 - other compil.: 12.6b(5.6)(NNDC COMPUT.CH.85)
13.0b(CH.NUCL.84)
12.6b(NUKLIDK.81)

γ - * from KOCHER81
- note discrepancies with ERDTMANN79; cf. inconsistent data from FIRESTONE84 : γ_{133} = 35.9% (2.2); $\gamma_{133.4}$ = 42.1%(2.); γ_{136} = 6.2%(4.2); γ_{346} = 15.1%(6.4); γ_{482} = 80.6%(-)
- 133.4 keV = E_{eff} of 133.0, 136.2 & 136.9; 136.3 keV = E_{eff} of 136.2 & 136.9
- accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇐ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ta 180.95 ∿ 20.5 ; 660	^{181}Ta	99.988 99.988(0.002) (DEBIEVRE85)				10.4(5.8)	^{182m}Ta I.T. ↓ F_2=1	15.8min(-) (LEDERER78)				
			20.5(2.4)* 20.4(1.1)* (THIS WORK)	660(3.5)* 679(-)* ($Q_0 \times \sigma_0$)	32.2(-)* 33.3(-)* (Table V.3-3)		^{182}Ta (IV/b)	114.43d(0.03) (YOSHIZAWA85)	152.4	7.175 6.95(1.3)**	$1.70.10^{-2}$	$1.61.10^{-2}$(0.7) (⇐ σ_0=20.1b(1.5))
									222.1	7.56 7.50(1.3)**	$1.79.10^{-2}$	$1.78.10^{-2}$(1.1) (⇐ σ_0=20.6b(1.7))
									1121.3	35.0 35.30(0.9)**	$8.28.10^{-2}$	$8.27.10^{-2}$(0.8) (⇐ σ_0=20.3b(1.2))
									1189.0	16.45 16.44(0.9)**	$3.89.10^{-2}$	$3.88.10^{-2}$(0.7) (⇐ σ_0=20.4b(1.1))
									1221.4	27.4 27.17(0.9)**	$6.49.10^{-2}$	$6.45.10^{-2}$(0.8) (⇐ σ_0=20.6b(1.2))
									1231.0	11.58 11.58(0.9)**	$2.74.10^{-2}$	$2.72.10^{-2}$(0.7) (⇐ σ_0=20.3b(1.1))

COMMENTS

* - for m+g

σ_0 - other compil.: 21.0b(3.3)(NNDC COMPUT.CH.85)
20.5b(CH.NUCL.84)
22.0b(NUKLIDK.81)
- $g_{WESTCOTT}$ (20°C) = 1.0038(ENDF/B-V 82)

F_{Cd} - possibly < 1 (ELNIMR81)

γ - ** from INDC83

BURN-UP $^{182}Ta(n,\gamma)$: σ_0 = 8700b(6.), I_0 = 862b(10.) (MUGHABGHAB84);
$\bar{E}_r$ = 0.16 eV(-)(THIS WORK);
$g_{WESTCOTT} \neq 1$

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
W 183.85 18.4 ; 350	^{186}W	28.64 28.6(0.7) (DEBIEVRE85)	37.9(1.6) 38.7(5.) (THIS WORK)	485(3.1) 530(5.3) ($Q_0 \times \sigma_0$)	12.8(-) 13.7(1.8) (Table V.3-3)	20.5(1.)	^{187}W (I)	23.9h(0.4) (ELLIS82)	134.2	9.4 9.5(4.2)*	$1.16.10^{-2}$	$1.13.10^{-2}$(0.7) (↔σ_0=36.6b(4.3))
									479.6	23.4 23.4(4.3)*	$2.89.10^{-2}$	$2.97.10^{-2}$(1.0) (↔σ_0=39.0b(4.4))
									551.5	5.45 5.44(4.2)*	$6.72.10^{-3}$	$6.91.10^{-3}$(0.5) (↔σ_0=39.1b(4.2))
									618.3	6.7 6.7(4.5)*	$8.27.10^{-3}$	$8.65.10^{-3}$(0.5) (↔σ_0=39.7b(4.5))
									685.7	29.2 29.2(4.5)*	$3.60.10^{-2}$	$3.71.10^{-2}$(0.5) (↔σ_0=39.1b(4.5))
									772.9	4.41 4.40(4.3)*	$5.44.10^{-3}$	$5.61.10^{-3}$(0.7) (↔σ_0=39.2b(4.4))

COMMENTS

σ_0 - other compil.: 37.8b(4.)(NNDC COMPUT.CH.85)
38b(CH.NUCL.84)
37.8b(NUKLIDK.81)
- $g_{WESTCOTT}$ (20°C) = 1.0014(ENDF/B-V82)

F_{Cd} = 0.908 (ELNIMR81)

γ - * from KOCHER81
- cf. ∿11% lower data from ELLIS82 : γ_{134} = 8.56%(4.), γ_{480} = 21.1%(4.2), γ_{551} = 4.92%(4.), γ_{618} = 6.07%(4.), γ_{686} = 26.4%(4.1), γ_{773} = 3.98%(4.1); cf. REUS83 : γ_{134} = 10.3%, γ_{480} = 25.3%, γ_{551} = 5.89%, γ_{618} = 7.27%, γ_{685} = 31.6%, γ_{773} = 4.77% (all ∿8% higher than KOCHER81)
- accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Re 186.21 90 ; 830	^{185}Re	37.40 37.40(0.5) (DEBIEVRE85)	112(1.8) + 106(16.) (THIS WORK)	1717(2.9) + 1632(16.) ($Q_0 \times \sigma_0$)	15.3(-) + 15.4(2.5) (Table V.3-3)	3.40(4.1)	^{186}Re ** (I)	90.64h(0.1) (KOCHER81)	122.3 137.2	0.67 0.70(33.)* 9.2 9.5(16.)*	$3.15.10^{-3}$ $4.33.10^{-2}$	$2.79.10^{-3}$(1.1) (↔ σ_0=95.0b(33.)) $4.33.10^{-2}$(0.7) (↔ σ_0=109b(16.))

COMMENTS

σ_0 - other compil.: 112b(2.7)(NNDC COMPUT.CH.85) +
111b(CH.NUCL.84) +
112b(NUKLIDK.81) +
- $g_{WESTCOTT}$ (20°C) = 1.0049(ENDF/B-V82)
- + : assignment not clear

F_{Cd} = 0.98 (ELNIMR81)

γ - * from KOCHER81
- ** negligible contribution from ^{186m}Re ($2.0.10^5$ y)
- note large uncertainties; accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Re 186.21 90 ; 8300	^{187}Re	62.6 62.60(0.03) (DEBIEVRE85)	2.8(3.6) 2.05(4.3) (THIS WORK)	- 9.4(8.) (Q_0 x σ_0)	- 4.57(6.4) (Table V.3-3)	41.1(3.9)	^{188m}Re (I) I.T. F_2=1	18.6min(0.5) (SINGH81)	92.5 106.0	5.45 5.15(5.1)* 11.45 10.8(4.9)*	$1.07.10^{-3}$ $2.25.10^{-3}$	$7.77.10^{-4}$(1.5) (↔σ_0=2.15b(5.2)) $1.50.10^{-3}$(1.6) (↔σ_0=1.98b(5.0))

COMMENTS

σ_0^m - other compil.: 1.6b(19.)(NNDC COMPUT.CH.85)
2.8b(CH.NUCL.84)
1.6b(NUKLIDK.81)
- experim. (from σ_0^g = 73.2b(6.)(THIS WORK) and σ_0^m/σ_0^g):
TAKAHASHI64; 1.3b(17.)
GULYAS64; 6.3b(33.)
ARIFOV78; 2.65b(6.)
- $g_{WESTCOTT}$ (20°C) = 0.9819 (ENDF/B-V82)

γ - * from SINGH81
- accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

(cont'd)

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Re (cont'd)			73.6(1.4) 73.2(4.2) (THIS WORK)	- 318(8.) ($Q_0 \times \sigma_0$)	- 4.34(6.4) (Table V.3-3)		^{188}Re (IV/a)	16.98h(0.1) (SINGH81)	155.0	15.0 15.0(5.3)**	$7.90.10^{-2}$	$7.77.10^{-2}$(0.6) (⇔σ_0=73.7b(2.5))
									478.0	1.11 1.04(5.8)**	$5.85.10^{-3}$	$5.29.10^{-3}$(0.8) (⇔σ_0=72.4b(2.6))
									633.3 (F_{eff})	1.595 1.41(9.7)**	$8.40.10^{-3}$	$7.64.10^{-3}$(1.3) (⇔σ_0=77.1b(9.0))
									829.5	0.444 0.411(5.4)**	$2.34.10^{-3}$	$(2.17.10^{-3})$ (⇔σ_0=75.2b)
									931.3	0.60 0.565(4.4)**	$3.16.10^{-3}$	$(2.85.10^{-3})$ (⇔σ_0=71.8b)

COMMENTS

σ_0^g - other compil.: 73b(5.5)(NNDC COMPUT.CH.85)
75b(CH.NUCL.84)
73b(NUKLIDK.81)
- $g_{WESTCOTT}$ (20°C) = 0.9819 (ENDF/B-V82)

σ_0^m/σ_0^g - THIS WORK : 0.028(8.)
- compil.: 0.038(4.)(MUGHABGHAB84)
0.022(20.)(NNDC COMPUT.CH.85)
0.037(CH.NUCL.84)
0.022(NUKLIDK.81)
- experim.: SIMONS62; 0.19(9.)(spectrum average)
GULYAS64; 0.085(33.)
TAKAHASHI64; 0.018(13.)(spectrum average)
ARIFOV78; 0.036(0.6)

γ - ** from KOCHER81
- note large discrepancies with ERDTMANN79 for γ_{633}; cf. SINGH81 : γ_{633} = 1.40% (10.)
- 633.3 keV = E_{eff} of 633.1 and 635.0
- accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Os 190.2 15 ; 170	^{184}Os	0.02 0.02(50.) (DEBIEVRE85)	3000(5.0) 3613(50.) (THIS WORK)	601(8.5) 1554(-) ($Q_0 \times \sigma_0$)	0.200(-) 0.43(-) (Table V.3-3)	-	^{185}Os (I)	93.6d(0.5) (ELLIS81)	646.1	81.0 81.0(1.2) (ELLIS81)	$5.34.10^{-3}$	$6.43.10^{-3}$(1.5) (↔σ_0=3613b(1.9))

COMMENTS

θ - note 50% uncertainty on θ; the only experimental θ-determination for the Os-isotopes dates from 1937 (NIER37)(see DEBIEVRE84); redetermination desirable

σ_0 - other compil.: 3000b(5.)(NNDC COMPUT.CH.85)
3000b(CH.NUCL.84; NUKLIDK.81)
- experim.: LINDLER51; 20b(-)
KIM68; 3005b(4.), with θ_{184} = 0.018% and γ_{646} = 80.08%; normal.: 2670b
- see DECORTE86

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Os 190.2 15 ; 170	^{190}Os	26.4 26.4(1.5) (DEBIEVRE85)	3.9(15.4) 3.90(3.2) (THIS WORK)	7.9(25.0) 7.9(-) ($Q_0 \times \sigma_0$)	2.03(-) 2.03(-) (Table V.3-3)	114(1.8)	^{191m}Os I.T. F_2=1 ^{191}Os (IV/a)	13.03h(1.6) (KOCHER81) 15.4d(0.6) (KOCHER81)	129.4	35.0 25.9(2.3) (KOCHER81)	$3.96.10^{-3}$	$2.91.10^{-3}$(1.6) (↔ σ_0^g=3.90b(2.8))

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

θ - the only experimental θ ~ determination dates from 1937 (NIER37)(see DEBIEVRE84); redetermination desirable

σ_0^g - other compil.: 3.9b(23.)(NNDC COMPUT.CH.85)
4b(CH.NUCL.84)
3.9b(NUKLIDK.81)
- adopted values : σ_0^m/σ_0^g = 2.36, Q_0^m = 2.40, Q_0^g = 2.03 (MUGHABGHAB84)

γ - note large discrepancy with ERDTMANN79 for γ_{129}; cf. BROWNE80 : 25.7%(9.3); REUS83 : 25.7%

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Os 190.2 15 ; 170	^{192}Os	41.0 41.0(0.7) (DEBIEVRE85)	2.0(5.0) 3.12(5.) (THIS WORK)	4.6(4.3) 7.30(-) ($Q_0 \times \sigma_0$)	2.3(-) 2.34(-) (Table V.3-3)	89.7(4.0)	^{193}Os (I)	30.5h(1.3) (SHIRLEY81)	139.0 (E_{eff})	4.14 4.34(6.0)*	$3.73.10^{-4}$	$5.44.10^{-4}$(1.4) (→ σ_0=2.78b(4.8))
									180.9 (E_{eff})	0.367 0.375(8.4)*	$3.31.10^{-5}$	($4.76.10^{-5}$) (→ σ_0=2.82b)
									219.1 (E_{eff})	0.267 0.285(7.9)*	$2.41.10^{-5}$	($3.86.10^{-5}$) (→ σ_0=3.01b)
									251.6	0.211 0.217(8.2)*	$1.90.10^{-5}$	($3.04.10^{-5}$) (→ σ_0=3.11b)
									280.4	1.24 1.24(6.3)*	$1.12.10^{-4}$	$1.79.10^{-4}$(0.5) (→ σ_0=3.21b(5.1))
									298.8	0.187 0.186(9.3)*	$1.68.10^{-5}$	($2.83.10^{-5}$) (→ σ_0=3.38b)
									321.6	1.32 1.28(6.2)*	$1.19.10^{-4}$	$1.78.10^{-4}$(0.9) (→ σ_0=3.09b(5.0))
									361.8	0.274 0.296(8.9)*	$2.47.10^{-5}$	($3.81.10^{-5}$) (→ σ_0=2.86b)
									387.5	1.20 1.26(6.3)*	$1.08.10^{-4}$	$1.73.10^{-4}$(1.5) (→ σ_0=3.05b(5.2))
									460.5	3.92 3.95(6.3)*	$3.53.10^{-4}$	$5.55.10^{-4}$(1.4) (→ σ_0=3.12b(5.2))
									557.9 (E_{eff})	1.96 1.80 (8.1)*	$1.77.10^{-4}$	$2.54.10^{-4}$(1.7) (→ σ_0=3.13b(7.3))

COMMENTS

θ - the only experimental θ-determination for the Os-isotopes dates from 1937 (NIER37)(see DEBIEVRE84); redetermination desirable

σ_0 - other compil.: 2.0b(5.)(NNDC COMPUT.CH.85)
2.0b(CH.NUCL.84; NUKLIDK.81)
- experim.: KIM68; 2.0b(5.)(with γ_{460} = 3.83%); normal.: 1.9b
- σ_0 from 139 keV not consistent; rejected for average; reasonable consistency is obtained with ERDTMANN79

γ - * from SHIRLEY81
- 139.0 keV = E_{eff} of 138.9 and 142.1;
180.9 keV = E_{eff} of 180.0 and 181.8;
219.1 keV = E_{eff} of 218.8 and 219.1;
557.9 keV = E_{eff} of 556.0, 557.4, 559.3 and 560.0
- accurate redetermination desirable

T - accurate redetermination desirable

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Ir 192.22 426 ; 2000	^{193}Ir	62.7 62.7(0.8) (DEBIEVRE85)	111(4.5)** 115(13.)* (THIS WORK)	1350(7.4)** 1380(14.)* ($Q_0 \times \sigma_0$)	12.2(-)** 12.0(2.9)* (Table V.3-3)	2.21(9.0)	^{194}Ir (IV/b)	19.15h(0.2) (KOCHER81)	293.5 328.4 645.1 938.7	2.9 2.6(15.4)** 13.0 13.1(13.0)** 1.16 1.17(12.8)** 0.65 0.60(13.3)**	$2.19.10^{-2}$ $9.83.10^{-2}$ $8.78.10^{-3}$ $4.92.10^{-3}$	$2.03.10^{-2}$(1.3) (→σ_0=114.6b(15.5)) $1.03.10^{-1}$(1.0) (→σ_0=115.4b(13.0)) ($9.38.10^{-3}$) (→σ_0=117.6b) ($4.76.10^{-3}$) (→σ_0=116.4b)

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

θ - the only experimental θ-determination for the Ir-isotopes dates from 1954 (BALDOCK54)(see DEBIEVRE84); redetermination desirable

* - for g+m_1 (32ms); + : assignment not clear

σ_0 - other compil.: 112.5b(7.)(NNDC COMPUT.CH.85)+
111b (CH.NUCL.84)+
110b(NUKLIDK.81)
- $g_{WESTCOTT}$(20°C) = 1.0218; (100°C) = 1.0400 (GRYNTAKIS75)

F_{Cd} - possibly < 1 (ELNIMR81)

γ - ** from KOCHER81
- for 328 keV-line, contribution from decay (only β^-) of ^{194m_2}Ir (171 d) is negligible in practice, since $\sigma_0^{m_2}$ is very low (> 0.035b; NNDC COMPUT.CH.85)
- note large discrepancies with ERDTMANN79 for γ_{293} and γ_{939}
- note large uncertainties on γ's; accurate redetermination desirable

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Pt 195.08 10 ; 140	^{198}Pt	7.20 7.2(2.8) (DEBIEVRE85)	3.66(5.2)* 3.58(4.)* (THIS WORK)	54(7.4)* 60.9(4.4)* ($Q_0 \times \sigma_0$)	14.8(-)* 17.0(1.8)* (Table V.3-3)	106(2.8)	^{199m}Pt I.T. F_2=1 ^{199}Pt β⁻ F_3=1 ^{199}Au (V/b)	14s(-) (LEDERER78) 30.8min(-) (LEDERER78) 3.139d(0.2) (KOCHER81)	158.4 208.2	40.0 36.8(3.0)** 9.1 8.4(4.8)**	$1.13.10^{-3}$ $2.57.10^{-4}$	$1.03.10^{-3}$(1.4) (↔ σ_0=3.63b(3.3)) $2.26.10^{-4}$(1.0) (↔ σ_0=3.49b(4.9))

COMMENTS

* - for m+g

σ_0 - other compil.: 3.7b(5.4)(NNDC COMPUT.CH.85)
3.8b(CH.NUCL.84)
3.73b(NUKLIDK.81)

γ - ** from KOCHER81
- note large discrepancies with ERDTMANN79 for γ_{158} & γ_{208}; cf. LEDERER78 : γ_{158} = 39%(-), from level scheme; cf. REUS83 : γ_{158} = 36.9%, γ_{208} = 8.38%

TRUE-COINCIDENCE
see Table IV.2-4

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} ↔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Au 196.97 98.7 ; 1550	^{197}Au	100 100(0.) (DEBIEVRE85)	98.65(0.09)	1550(1.8)	15.71(1.8) (Table V.3-3)	5.65(7.1)	^{198}Au (I)	2.695d(0.1) (NBS82)	411.8	95.53 95.56(0.1) (NBS82)	≡ 1	≡ 1

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

σ_0, I_0 - ^{197}Au(n,γ)^{198}Au is a CROSS-SECTION STANDARD :
σ_0 = 98.65 ± 0.09b (± 0.09%)
I_0 = 1550 ± 28b (± 1.8%)
see : HOLDEN81; MUGHABGHAB81, HOLDEN85B
- IN THIS WORK ALL VALUES (σ_0, I_0, Q_0, γ, etc.) ARE CONSIDERED AS ULTIMATE STANDARD DATA
- $g_{WESTCOTT}$ (20°C) = 1.0051 (ENDF/B-V82)

F_{Cd} - F_{Cd} = 0.991 (ELNIMR81)

γ - excellent consistency with AUBLE83 [γ = 95.50%(0.1)]

BURN-UP ^{198}Au(n,γ) : σ_0 = 25800b(4.7)(NNDC COMPUT.CH.85);
I_0 = 31031b(35.)(GRYNTAKIS76);
$\bar{E}_r$ unknown (10 eV assumed)

NOTE - f- and α-monitor

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇐ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Hg 200.59 ∿ 374 ; 80	^{196}Hg	0.15 0.14(71.) (DEBIEVRE85)	109(5.5) 101(71.) (THIS WORK)	58.9(40.7) 46.(-) ($Q_0 \times \sigma_0$)	0.54(-) 0.49(-) (Table V.3-3)	93.5(0.1)	^{197m}Hg (I)	23.8h(0.4) (KOCHER81)	134.0 TRUE-COINCIDENCE see Table IV.2-4	34.0 34.0(2.4) (KOCHER81)	$5.79.10^{-4}$	$4.99.10^{-4}$(1.0) (⇐ σ_0=101b(2.6))

COMMENTS

θ - natural variations in normal terrestrial material possible, range ∿±1.5% (FLEMING83); more accurate value desired

σ_0 - other compil.: 109b(5.5)(NNDC COMPUT.CH.85)
120b(CH.NUCL.84; NUKLIDK.81)
- experim.: SEHGAL59; 420b(19.), no θ given, with γ_{134} = 36.1%; normal.: 446b
MANGAL63; 130b(12.), no θ given, with γ_{134} = 36.1%; normal.: 138b
ARINO64; 117b(11.)(natural (θ_{196} = 0.145%) and enriched material (θ_{196} = 4.2%)) with γ_{134} = 31%; normal. (for γ) : 107b
KIM67; 106.7b(12.), no θ given, with γ_{134} = 32.2%; normal.: 101b
TILBURY68; 125b(10.), no θ given, with γ_{134} = 31%; normal.: 114b
HEFT79; 107.3b(1.4), with θ = 0.146% and γ_{134} = 34.1%; normal.: 112b

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Hg 200.59 ∿374 ; 80	^{202}Hg	29.7 29.80(0.5) (DEBIEVRE85)	4.89(1.0) 4.35(1.9) (THIS WORK)	4.2(4.8) 3.8(-) ($Q_0 \times \sigma_0$)	0.86(-) 0.88(-) (Table V.3-3)	1960(8.2)	^{203}Hg (I)	46.612d(0.04) (SCHMORAK85)	279.2	81.5 81.46(0.2) (SCHMORAK85)	$1.23.10^{-2}$	$1.10.10^{-2}$(1.7) (→ σ_0=4.35b(1.7))

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

θ - natural variations in normal terrestrial material possible, range ≤ ±0.6% (FLEMING83)

σ_0 - other compil.: 4.9b(2.)(NNDC COMPUT.CH.85)
4.9b(CH.NUCL.84; NUKLIDK.81)
- experim.: LYON51; 3.8b(20.), with β counting
SENGAL62; 4.6b(15.), no γ given
KIM67; 5.04b(7.5), with γ_{279} = 83.1%; normal.: 5.14b
SIMS68; 4.87b(1.0), with γ_{279} = 86.2%; normal.: 5.15b
HEFT79; 4.91b(1.0), with γ_{279} = 81.0%; normal.: 4.88b
- note that 279.0 keV line of ^{197m}Hg (γ = 5%) can give significant positive error if t_d not sufficiently large !

γ - note large discrepancy with KOCHER81: γ_{279} = 77.3% (1.); cf. REUS83 : 81.5%

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (→ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
Th 232.04 7.4 ; 85	^{232}Th	100 100(0.) (DEBIEVRE85)	7.37(0.8) 7.26(1.1) (THIS WORK)	85(3.5) 83.7(4.) ($Q_0 \times \sigma_0$)	11.53(-) 11.53(3.6) (Table V.3-3)	54.4(0.9)	^{233}Th β^- $T_{\frac{1}{2}}$=1 ^{233}Pa (II/b)	22.3min(0.4) (KOCHER81) 27.0d(0.4) (KOCHER81)	300.1	5.8 6.64(5.2)*	$3.85.10^{-3}$	$4.37.10^{-3}$(0.3) (→ σ_0=7.31b(5.2))
									312.0	33.7 38.6(1.0)*	$2.24.10^{-2}$	$2.52.10^{-2}$(0.5) (→ σ_0=7.25b(1.1))
									340.5	3.88 4.44(5.4)*	$2.57.10^{-3}$	$2.95.10^{-3}$(0.7) (→ σ_0=7.38b(5.4))
									375.4	0.59 0.676(5.1)*	$3.92.10^{-4}$	$4.49.10^{-4}$(0.6) (→ σ_0=7.38b(5.1))
									398.6	1.29 1.48(5.4)*	$8.56.10^{-4}$	$9.26.10^{-4}$(0.5) (→ σ_0=6.95b(5.4))
									415.8	1.59 1.82(5.0)*	$1.06.10^{-3}$	$1.16.10^{-3}$(1.0) (→ σ_0=7.08b(5.1))

TRUE-COINCIDENCE
see Table IV.2-4

COMMENTS

σ_0 - other compil.: 7.40b(1.1)(NNDC COMPUT.CH.85)
7.4b(CH.NUCL.84; NUKLIDK.81)
- σ_0 (THIS WORK) from 399 keV and 416 keV lines not consistent; rejected for average
- $g_{WESTCOTT}$ (20°C) = 0.9982 (ENDF/B-V82)

γ - * from ZIJP79, normal. to γ_{312} = 38.6%(1.0)(ZIJP79; added in proof)
- note large discrepancies with ERDTMANN79; cf. KOCHER81 : γ_{300} = 6.6%(6.); γ_{312} = 38.6%(1.); γ_{340} = 4.5%(11.); γ_{375} = 0.62%(19.)(not consistent); γ_{399} = 1.27%(13.)(not consistent); γ_{416} = 1.62%(10.)(not consistent). cf. ELLIS78(normal.to γ_{312} = 38.6%): γ_{300} = 6.67%(7.); γ_{340} = 4.51%(12.); γ_{375} = 0.618%(20.)(not consistent); γ_{399} = 1.28%(13.)(not consistent); γ_{416} = 1.62%(11.)(not consistent)
- accurate redetermination desirable

NOTE - adopted as α-monitor

TABLE VIII.3-1 : continued

Element At.Weight σ_{abs},b;I_{abs},b (CH.NUCL.84)	Target isotope	θ, %	σ_0, b	I_0, b	Q_0	$\bar{E}_r$, eV	Isotope formed Activation-decay type (Table I.3-1)	T	Main γ-energies E_γ, keV	γ, % (ERDTMANN79)	$k_{0,Au}$ (calc.)	Measured $k_{0,Au}$ (rel.err.,%) {recommended or (tentative)} (⇔ σ_0 from this line)
		Z = 1-60 : MUGHABGHAB81 Z = 61-100 : MUGHABGHAB84										
U 238.03 7.57 ; 278	^{238}U	99.2746 99.2745(0.002) (DEBIEVRE85)	2.68(0.7) 2.75(2.) (THIS WORK)	277(1.1) 284(2.4) ($Q_0 \times \sigma_0$)	103.4(-) 103.4(1.3) (Table V.3-3)	16.9(1.2)	^{239}U ↓ β^- $T_{1/2}$=1 ^{239}Np (II/b)	23.50min(0.2) (SCHMORAK83) 2.355d(0.2) (SCHMORAK83)	209.8	3.24 3.27(7.1)*	$7.57.10^{-4}$	$7.80.10^{-4}$(0.5) (⇔ σ_0=2.74b(7.0))
									228.1 (E_{eff})	10.72 11.1(6.5)*	$2.50.10^{-3}$	$2.77.10^{-3}$(0.7) (⇔ σ_0=2.86b(6.4))
									277.6	14.1 14.2(1.4)*	$3.29.10^{-3}$	$3.40.10^{-3}$(0.8) (⇔ σ_0=2.75b(0.8))
									285.5	0.776 0.781(9.2)*	$1.81.10^{-4}$	$(1.83.10^{-4})$ (⇔ σ_0=2.69b)
									315.9	1.59 1.61(6.4)*	$3.71.10^{-4}$	$3.68.10^{-4}$(1.5) (⇔ σ_0=2.62b(6.3))
									334.3	2.03 2.05(8.5)*	$4.74.10^{-4}$	$4.81.10^{-4}$(1.0) (⇔ σ_0=2.69b(8.3))

COMMENTS

θ - natural variations in normal terrestrial material possible (DEBIEVRE85), range very small

σ_0 - other compil.: 2.70b(0.7)(NNDC COMPUT.CH.85)
2.68b(CH.NUCL.84)
2.70b(NUKLIDK.81)
- $g_{WESTCOTT}$ (20°C) = 1.0029 (ENDF-B/V82)

γ - * from SCHMORAK83
- 228.1 = E_{eff} of 226.4 & 228.2;
- note high uncertainties (except for 277.6 keV)
- accurate redetermination desirable

NOTE - adopted as α-monitor

TRUE-COINCIDENCE
see Table IV.2-4

- analytically less important (n,γ) reactions, for which σ_0 is less accurately known in literature ;
- analytically less important (i.e. weak) gamma-lines, for which γ is less accurately known in literature.

Fig. VIII.3-1 reveals the accuracy situation when performing (n,γ) activation analysis based on absolute standardization (see I.3.3) without nuclear data control.

All other data in Table VIII.3-1 (for θ, σ_0, I_0, γ, etc.) do not bear upon the k_0-standardization method. They relate to the experimental determination and critical evaluation of σ_0 according to the "activation method" -, as described in the APPENDIX.

3.2. Analytical protocol

The analyst desiring to apply the k_0-standardization method might be deterred by the large number of parameters to be considered and by the numerous and occasionally complex calculations, maybe leading to the desperate feeling that it is impossible to see the wood for the trees.

It should set at ease, however, when realizing that - in the preceeding chapters - all parameters are elaborated not only from theoretical but also from practical standpoint, and that calculation is nowadays a mere concern of computer programming. In fact, it is the latter job - to be done once for all - which is the price of the experimental simplicity and versatility of the k_0-standardization.

Sketched in broad outline, the protocol the analyst should stick to is as follows :

a. Make sure of the sufficient constancy of the relevant neutron flux parameters during irradiation in the reactor facility for use (see VII.5). The most critical parameter is the absolute neutron flux : inspect the in-situ recording of the power versus time in the reactor logbook and, in case of doubt, perform an a priori check of the flux variability in the particular irradiation channel (cf. Fig. II.1-2a/b). Do not allow the samples to be in the irradiation position during start-up and close-down of the reactor.

b. Make use of a computing program for peak area integration which is known to yield reliable and accurate results. Profit can be taken of intercomparisons such as reported in Refs PARR79 and CHRISTENSEN86.

c. Perform an efficiency calibration of the Ge-detector in "reference" conditions, i.e. for point-sources at ∿ 15-20 cm source-detector separation (see III.1.1); check the constancy of the ε_p^{ref}-curve at regular time intervals (see III.1.2).

d. When measuring extended samples at close-in geometries ("geo"), make use of a computer program (e.g. SOLANG) for $\varepsilon_p^{ref} \rightarrow \varepsilon^{geo}$ conversion (see III. 2.1). Ensure the accuracy of the conversion by measuring some "coincidence-free" point sources (from low to high E_γ) at large (e.g. "reference") and small distance to the detector (see III.2.2 and III.2.3; cf. Table III.2-1). Bring the samples to be measured into a cylindrically symmetrical shape (see III.2.2). Eventually, it is advised in practice to select a set of discrete sample-detector distances, e.g. with intervals of 2-3 cm.

e. For true-coincidence correction, determine peak-to-total ratio curves - at the same discrete distances as chosen above - by measuring a set of "coincidence-free" point sources (see IV.3.2; cf. Fig. IV.3-2).

f. Get suited monitors (also serving for in-situ f- and α-determination), to be coirradiated with the samples. Use can be made of thin, pure Zr-foil (e.g. from Goodfellow) and of dilute Au-Al alloy wire (e.g. 0.1% Au, from Reactor Experiments or from CBNM, Geel/Belgium); check the accuracy and homogeneity of the Au-content (see VI.1). Either ^{198}Au (411.8 keV) or ^{95}Zr (724.2 and 756.7 keV) - or both - can serve as flux monitor ["m" in Eqs (I.3-20) and (I.3-21)], and the Au-Al wire or/and Zr-foil should then be measured preferably at the same distance to the detector as the sample (see III.2.3). For in situ α- and f-determination, requiring knowledge of the ^{198}Au, ^{95}Zr and $^{97}Zr/^{97m}Nb$ (743.3 keV) specific count rates, it is advised to measure the Au-Al and Zr monitors at "reference" distance to the detector; for Zr, the "double counting technique" can be applied (see V.2.2). If, in a particular irradiation position, the long-term stability of the neutron flux spectrum with respect to α and f can be established, the latter parameters can be determined a priori (see V.1.5 and V.2); then, it suffices to coirradiate the sample with one single flux monitor. Note that irradiation, decay and measuring times must always be known accurately.

g. The remaining steps are mere calculations, whereby the above measured experimental parameters have to be introduced in the relevant equations, together with nuclear data from Tables VIII.3-1 (k_0, Q_0, $\bar{E}_r$, T, and occasionally some data related to complex activation/decay) and IV.2-4 (cascade schemes and data for true-coincidence correction).
The main equations are :
- for calculation of ε_p^{geo} : Eqs (III.2-2) and (III.2-3) [Program SOLANG].
- for calculation of COI, the true-coincidence correction factor : Eqs (IV.2-2) and (IV.2-3), to be combined with Eq. (IV.1-3) for γ-γ coincidence summing, Eqs (IV.1-7) - (IV.1-11) for γ-γ and γ-KX(IC) coincidence loss, or Eqs (IV.1-18) and (IV.1-19) for γ-KX(EC) coincidence loss [^{175}Hf and ^{185}Os] ; delayed γ-γ emission and other special cases encountered in practice are dealt with in IV.2.4 and IV.2.5 ;
- for calculation of α from the "bare multi-monitor"-method (in situ for NAA) : Eq. (V.1-43); from the "Cd-covered multi-monitor"-method (in situ for ENAA) : Eq. (V.1-39) ; from the "Cd-ratio for multi-monitor"-method (a priori α-determination) : Eq. (V.1-41) ;
- for calculation of f from the "bare bi-isotopic monitor"-method (with Zr ; in situ for NAA) : Eq. (V.2-4) ; from the Cd-ratio method (a priori) : Eq. (V.2-1) ;
- for $Q_0 \rightarrow Q_0(\alpha)$ conversion : Eq. (V.1-15) ;
- for calculation of $\frac{"N_p/t_m"}{SDC}$ (to be divided by w for obtaining A_{sp}) : Table I.3-1 ;
- finally, for calculation of the analyte concentration : Eqs (I.3-20) and (I.3-21).

Again, it should be stressed that, in order to accomplish these calculations, the use of a computer program is dictated (see II.3.2).

3.3. Examples of application

That the k_0-method has actually become an operational and competitive standardization tool in neutron activation analysis, appears from the fact that up to now it is applied by some twenty researchers in various countries and institutes. Reference can be made to the following selection :

- L.Moens et al., INW, Gent/Belgium : provenance study of marble artefacts; archaeometric study of white marble from Italy, Greece and Turkey [MOENS87]; provenance study of ornamental glass beads from Roman graves [VERMEULEN85] ;
- M.Carmo Freitas et al., LNETI/ICEN, Sacavém/Portugal : preparation and analysis of a marble reference material [FREITAS87] ; pollution studies of the river Tagus ;
- R.Cornelis, D.Van Renterghem, Lin Xilei et al., INW, Gent/Belgium : radiochemical NAA of trace elements in human serum (e.g. LIN87) ;
- A.Simonits, H.Rausch et al., KFKI, Budapest/Hungary : various applications, e.g. characterization of Al_2O_3 ceramics [RAUSCH83] ;
- M.L.Verheijke et al., Nat.Lab.Philips Eindhoven/The Netherlands : application in the field of silicon technology [VERHEIJKE84/86A/86B] ;
- G.W.Nelson, Univ.of Arizona, Tucson/USA : development of a PC program for k_0-based instrumental NAA [NELSON86] ;
- Ni Banfa et al., Institute of Atomic Energy, Beijing/China : analysis of Chinese environmental soil standard reference materials [NI83] ;
- M.D.Glascock et al., Research Reactor Facility, Univ.of Missouri, Columbia/USA : determination of α and f from the "Cd-ratio for dual-monitor"-method (with ^{94}Zr-^{197}Au) and the "bare bi-isotopic monitor"-method (with ^{94}Zr-^{96}Zr), respectively [GLASCOCK85] ;
- M.Benjelloun et al., Laboratoire de Chimie Nucléaire du CRNS : Strasbourg/France : analysis of "solar cell"-grade silicon [BENJELLOUN84] ;
- S.Jovanovic et al., Instit. for Mathem. and Physics, Titograd/Yugoslavia and Institute J.Stefan, Ljubljana/Yugoslavia : development of computer programs in progress [JOVANOVIC87] ;
- G.Erdtmann et al., KFA Jülich/FRG : analysis of high-purity metals (Al, Ti,...) [ERDTMANN87] ;
- S.Roth, Atominstitut Wien/Austria : analysis of coal [ROTH87] ;
- Tran Khanh Mai, F.Grass, Nat.Inst.of Atom.Energy, Vietnam and Atominstitut Wien/Austria : determination of k_0-factors for short-lived radionuclides (^{24m}Na, ^{38m}Cl,...) [TRAN87].

Eventually, it should be mentioned that at the INW the k_0-standardization method is applied in case of certification of trace element concentrations in neutron dosimetry materials (Nb, Rh, etc.) distributed by the Central Bureau for Nuclear Measurements (CBNM) of the Commission of the European

Communities (CEC). It goes without saying that, in general, the use of the k_0-method is especially beneficial in case of panoramic analysis, enabling the accurate determination of concentrations for the trace constituents (even unexpected ones) which give rise to an observable gamma-peak in the spectrum, and the evaluation of concentration limits for all others, - totalling about 60 elements.

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APPENDIX

EXPERIMENTAL RESULTS FOR 2200 MS^{-1} (N, γ) CROSS-SECTIONS

1. PRINCIPLE OF THE "ACTIVATION METHOD"

From the $k_{0,Au}$-factors measured in the present work (Table VIII.3-1) it is possible to derive 2200 ms^{-1} (n,γ) cross-sections (σ_0) according to the "activation method" as :

$$\sigma_0 = k_{0,Au} \cdot \frac{\theta_{Au}\ \sigma_{0,Au}\ \gamma_{Au}}{M_{Au}} \cdot \frac{M}{\theta\ \gamma} \qquad \text{(APP.1-1)}$$

Eq. (APP.1-1) has to be modified in case of complex activation/decay (see I.3.4.2).

Evidently, the accuracy on σ_0 is in the last resort limited by the accuracy on the absolute nuclear data to be introduced in Eq. (APP.1-1). These are well-known for the ultimate Au-standard (see Table VIII.3-1) :

- M_{Au} = 196.97 ;
- θ (^{197}Au) = 100% ;
- σ_0 [^{197}Au(n,γ)^{198}Au] = 98.65 $\pm$ 0.09 barn ($\pm$ 0.09%) [HOLDEN81; MUGHABGHAB81/84; HOLDEN85] ;
- γ (^{198}Au, 411.8 keV) = 95.56 $\pm$ 0.08% ($\pm$ 0.1% rel.) [NBS82].

As to the (n,γ) reactions considered in the present work, the status of literature data for θ and γ (note that M is generally well-known), and the criteria for their selection as a "best choice", are dealt with in APP.2 and APP.3. Finally, in APP.4 the σ_0-results of the present work are critically compared with formerly compiled and evaluated data. As a detailed example, the case ^{64}Ni(n,γ)^{65}Ni is chosen.

2. ISOTOPIC ABUNDANCE DATA

2.1. General considerations and "best choice"-data

Eq. (APP.1-1) shows that the propagation factor of the error on the isotopic abundance (θ) is unity towards the σ_0-result. In general, it seems rea-

sonable to require $s_\theta < 1\%$.

Before 1976, the last published evaluation work on the isotopic abundances of the elements appeared in the late 1950's [FULLER58].

In 1973, at the request of the IUPAC Inorganic Division, the IUPAC Spectrometric Evaluation Group (IMSEC) was formed within the International Commission on Atomic Weights (ICAW, later the Commission on Atomic Weights and Isotopic Abundances, CAWIA), with the aim to assemble, evaluate and disseminate data on the mass-spectrometrically determined isotopic compositions of the elements. In 1975, IMSEC was reconstituted as the Subcommittee on the Assessment of the Isotopic Composition of the Elements (SAIC), to be concerned not only with mass-spectrometric but with all measurements for deriving isotopic compositions. This resulted, since 1976, in the release of five subsequent compilation and evaluation reports, published in Pure and Applied Chemistry [ICAW76, ICAW79, CAWIA80, CAWIA83, CAWIA84]. The tables of the latter final report of SAIC, which ended its task in 1983, were published also in the International Journal of Mass Spectrometry and Ion Processes [DEBIEVRE85], and a compilation of all attainable literature on the determination of isotopic compositions until 1983 appeared in the Journal of Physical and Chemical Reference Data [DEBIEVRE84].

In the context of the present work, the most relevant information from the SAIC reports is the list of the "representative isotopic composition" of the elements (in ICAW76 and ICAW79 labelled as "interim isotopic composition for average properties"), from 1980 on accompanied by uncertainties which cover the range of probable variations of the materials as well as experimental errors. The values listed are for normal terrestrial materials only, materials of meteoritic or other extra-terrestrial origin being excluded.

In the present work the data quoted by DEBIEVRE85 ($\equiv$ CAWIA84) are adopted. They are listed in the 3rd column/2nd line of Table VIII.3-1. The values are fully underlined, unless their uncertainty is exceeding 10% (dashed underlining). Fig. APP.2-1 gives an impression of the uncertainties assigned to θ-values for 120 target nuclides of analytical importance in NAA [i.e. completing Table VIII.3-1 with the (n,γ) reactions compiled by GUINN80] . Mere users of nuclear data, like activation analysts, might be surprised to observe for instance that s_θ is exceeding 1% in 28% of the cases and exceeding 5% in 7%

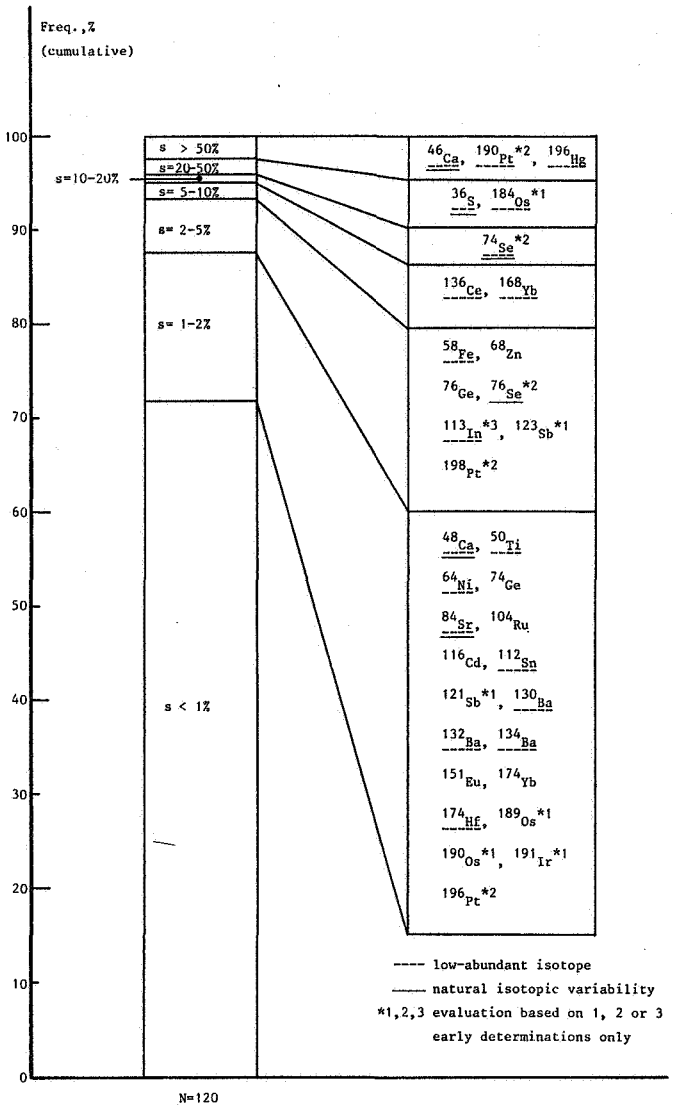

Fig. APP.2-1 : Frequency (Freq.,%; cumulative) of the uncertainty on θ (s,% ; DEBIEVRE85/CAWIA84) falling in a specified interval (s < 1%,etc.)

of the cases. However, the details mentioned in the expansion of the block diagram reveal the principal reasons for this phenomenon, especially for s_θ > 5%. It is firstly due to the fact that mostly low-abundant isotopes are involved (here defined in the sense that θ is at least one order of magnitude lower than for another isotope of the same element), for which the experimental uncertainties are higher (see also DEBIEVRE 83). Two more deteriorating parameters should be added to this :

1. for some nuclides the reported SAIC-values had to be based on a few available determinations from the 1940's or 1950's only (note that there is only 1 determination reported for Sb, Os and Ir) ;
2. there exists a range in isotopic composition in normal terrestrial material for elements like Ca, S, Se, etc. Such natural isotopic variabilities are for instance dealt with by HOLDEN77, FLEMING83 and IUPAC84, and the most important cases relevant to NAA are listed in Table APP.2-1.

Table APP.2-1 reveals that, apart from ^{206}Pb, the natural isotopic variation is only known to be very serious for ^{36}S, for which the abundance range (0.015% - 0.020% ; HULSTON65) coincides with the "evaluated limits of published values" (0.0153% - 0.0199%) as reported by DEBIEVRE85.

TABLE APP.2-1 : Natural isotopic variabilities for some target nuclides of interest in NAA (sources : HOLDEN77, FLEMING83, IUPAC84)

Target nuclide	Natural abundance range
^{30}Si	± 4.2%
^{36}S	± 29%
^{46}Ca	unknown
^{48}Ca	small
^{63}Cu	± 0.38%
^{65}Cu	± 0.84%
^{74}Se	± 1.3%
^{84}Sr	small
^{86}Sr	small
^{108}Pd	small
^{110}Pd	small
^{196}Hg	$\sim$ ± 1.5%
^{202}Hg	$<$ ± 0.6%
^{206}Pb	± 14%

TABLE APP.2-2 : Comparison of the "evaluated limits of published values" and the uncertainty s_θ on the "representative isotopic composition" for nuclides with $s_\theta > 5\%$ (source: DEBIEVRE85)

Nuclide	"Evaluated limits of published values" %	"Representative isotopic composition" %
^{36}S	0.0153 - 0.0199	0.02 ± 0.01
^{46}Ca	0.00313 - 0.0046	0.004 ± 0.003
^{74}Se	0.897 - 0.908	0.9 ± 0.1
^{136}Ce	0.190 - 0.195	0.19 ± 0.01
^{168}Yb	-	0.13 ± 0.01
^{184}Os	0.018 - 0.02	0.02 ± 0.01
^{190}Pt	0.012 - 0.0127	0.01 ± 0.01
^{196}Hg	0.147 - 0.16	0.14 ± 0.10

The above case of ^{36}S, for which the "representative isotopic composition" is reported to be (0.02 ± 0.01)% [DEBIEVRE85], draws the attention to the at first sight curious fact that s_θ is by far larger than the value corresponding to the "evaluated limits of published values". This is generally so, as shown in Table APP.2-2 (only for nuclides with s_θ > 5%). The reason for this apparently conflicting situation is that SAIC, when deriving "representative isotopic compositions" and their uncertainties from the published data (within the "evaluated limits"), adjusted the resulting values in such a way that 1. their sum for a given element is exactly 100%, and 2. conversion to atomic weights yields consistency with the corresponding CAWIA-table of "Standard Atomic Weights" [CAWIA84B]. This adjustment procedure obviously gives the most drastic θ- and s_θ-changes for low-abundant isotopes, sometimes even leading to a "representative isotopic composition" outside the "evaluated limits of published values", as it is the case for ^{190}Pt and ^{196}Hg.

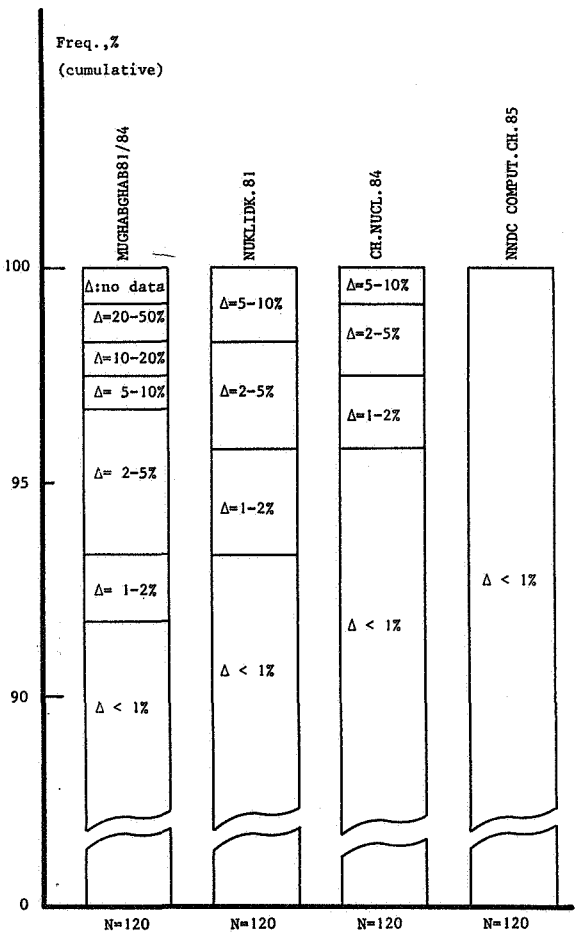

Fig.APP.2-2 : Frequency (Freq.,%; cumulative) of θ-discrepancies (Δ,%; 4 compilations versus DEBIEVRE85/CAWIA84) falling in a specified interval (Δ < 1%, Δ = 1-2%, etc.)

Whether one agrees or not with the above sketched SAIC-evaluation procedure, one has to accept the fact that the SAIC-values are more and more adopted by all international evaluation works on nuclear data, among which those concerned with activation cross-sections. Since a good deal of nuclear data users - activation analysts and others - adopt in their turn the θ-values from such evaluation works, it is quite relevant to analyse the consistency of this type of information versus the latest SAIC-evaluation [CAWIA84/DEBIEVRE85]. For 4 recent compilation works [NUKLIDK.81, MUGHABGHAB81/84, CH.NUCL.84, NNDC COMPUT.CH.85], Fig. APP.2-2 shows the frequency (Freq.,%)

of the deviation (versus CAWIA84/DEBIEVRE85) falling in a specified interval. It can be seen that complete consistency with the latest SAIC-evaluation is reached for the NNDC COMPUTOPE CHART 1985. This microfiche is, however, scantily spread among activation analysts. Note that the θ-data from the frequently consulted MUGHABGHAB81/84-compilation (see Table VIII.3-1, 3rd column, 1st line) were systematically selected for the calculation of k_0-factors (VIII.3-1).

2.2. Literature survey of $\theta(^{64}Ni)$

In former work, commented literature surveys have been given of the isotopic abundance data for ^{50}Cr, ^{58}Fe, ^{109}Ag, ^{64}Zn, ^{112}Sn and ^{174}Yb [SIMONITS84, DECORTE85]. Table APP.2-3 shows a similar study for $\theta(^{64}Ni)$. Note that for Ni no natural isotopic variability has been reported in literature. As seen, early determinations yielded highly inconsistent results, ranging from 0.75 to 1.27%. In compilations, this was almost invariably translated to a value of either 1.08 or 1.16%. Based on the experimental results of ROURKE71, BARNES73 and later MORAND80, recent compilations quote a value of 0.91%, thus following the recommendations made by ICAW/CAWIA. Since 1983, the uncertainty on this value, estimated by CAWIA, is reported as 1.1% (relative). It goes without saying that the huge scatter in reported $\theta(^{64}Ni)$-values is equally perceptible in σ_0-values obtained according to the "activation method" (see APP.4).

3. GAMMA-INTENSITY DATA

3.1. General considerations and "best choice"-data

Eq. (APP.1-1) shows that the propagation factor of the error on the absolute gamma-intensity (γ) is unity towards the σ_0-result. In general, it seems reasonable to require $s_\gamma < 1\%$.

Many compilation and evaluation works on absolute gamma-intensity data have been published. A selection of the most recent ones is shown in Table APP.3-1. In addition to this, very useful information can be extracted from compilation and evaluation works concerned with data for radionuclides used

TABLE APP.2-3 : Literature survey of the isotopic abundance data for ^{64}Ni
(* uncertainty calculated by SAIC)

θ (^{64}Ni), experimental		θ (^{64}Ni), compiled	
θ, %	Author	θ, %	Compiler
∿ 1	DEMPSTER36		
0.9	LUB39		
1.27 ± 0.10	STRAUS41		
0.88	VALLEY41		
0.75 ± 0.03	EWALD44		
0.98 ± 0.02	INGHRAM48		
1.16 ± 0.20	WHITE48		
1.01	MATTRAW52		
		1.16	BNL55
		1.16	BNL58
		1.0	NUKLIDK.58
		1.16	WIRTZ58
		1.16	BECKURTS64
		1.08	NUKLIDK.65
		1.16	LEDERER67
		1.16	CH.NUCL.68
		1.08	NUKLIDK.68
0.928	ROURKE71		
		0.9	CH.NUCL.72
0.904 (± 0.001)*	BARNES73		
		1.08	BNL73
		0.95	NUKLIDK.74
		1.16	IAEA74
		0.91	ICAW76
		0.9	CH.NUCL.77
		0.91	ICAW79
		0.91	LEDERER78
0.9027 (± 0.0008)*	MORAND80	0.91 ± 0.03	CAWIA80
		0.91	NUKLIDK.81
		0.91	MUGHABGHAB81
		0.91	NNDC COMPUT.CH.82
		0.91 ± 0.01	CAWIA83
		0.91 ± 0.01	CAWIA84
		0.91	CH.NUCL.84
		0.91	NNDC COMPUT.CH.85

TABLE APP.3-1 : A selection of the most recent compilation and evaluation works on absolute gamma-intensity data

Reference	Origin	Contents
LEDERER78	Lawrence Berkeley Lab., Berkeley, USA	[extended and updated version (7th ed.) of former editions]; decay schemes and associated data; compilation of γ^{rel} and γ (with uncert.); occasionally evaluated γ's (with uncert.) from level scheme
ERDTMANN79	KFA Jülich, FRG	[extended and updated version of ERDTMANN74]; evaluated γ's (no uncert.)
KOCHER81	ORNL, Oak Ridge, USA	[extended and updated version of KOCHER77]; evaluated γ's (with uncert.), not covering all cases relevant to NAA
REUS83	Inst.f.Kernchemie, Univ. Marburg, FRG	[extended and updated verion of REUS79]; evaluated γ's (no uncert.)
LMRI75 LMRI80 LMRI85	Lab.de Métrol.des Rayonnements Ionisants (LMRI), CEA, Gif-sur-Yvette, France	continued series of decay scheme data, including evaluated γ's (with uncert.); not yet covering all cases relevant to NAA
NDS (NUCL.DATA SHEETS)	National Nuclear Data Center (NNDC), Upton, USA	continued series of decay schemes and associated data (for A $\leq$ 45 reference is made to NUCLEAR PHYSICS); recent editions include evaluated γ's (with uncert.); for some A-chains no recent issue is available, but many revisions are in progress
BROWNE86	Lawrence Berkeley Lab., Univ.of California, USA	data [including evaluated γ's (with uncert.)] adopted from NDS

as calibration standards. Mention can be made for instance of some reports of the International Committee for Radionuclide Metrology [NBS82; ICRM85] and of the IAEA International Nuclear Data Committee [INDC83].

Table APP.3-1 reveals that the only complete, recent evaluation works are ERDTMANN79 and REUS83. Since the latter is not so well-known by activation analysts, the data of ERDTMANN79 (see Table VIII.3-1, 11th column/1st line) were systematically selected for the calculation of k_0-factors (VIII.3.1). On the other hand, none of both works gives information on the uncertainty of the reported data, so that for the calculation of σ_0-values (with uncertainties), according to the "activation method", no other "best choice" was left than to assemble the material from the most recent (and/or supposedly the most reliable) literature. It is of course evident from Table APP.3-1 that the major sources of information are the recent NDS-evaluations, the report of KOCHER81 and the recent LMRI-sheets (in descending order of selection

frequency), not to forget the ICRM85-report (notably YOSHIZAWA85); but occasionally, data from INDC83, NBS82 or from recently published experimental work were adopted as well. In some 5% of the cases it was necessary to go back to data published before 1980 (mostly LEDERER78). The thus obtained "best choice" γ-values are compiled in Table VIII.3-1 (11th column/2nd line). Full underlining denotes that they could be combined with recommended k_0-factors to yield σ_0-values according to the "activation method". Dashed underlining indicates that the thus obtained σ_0-value is of questionable accuracy, either because γ exhibits an uncertainty larger than 10% or is for other reasons of doubtful quality [e.g. when leading to a σ_0 which is inconsistent with results from other gamma's (for instance for the ^{59}Fe 192.3 keV line), or when recent literature data are highly inconsistent (for instance for the ^{187}W lines)].

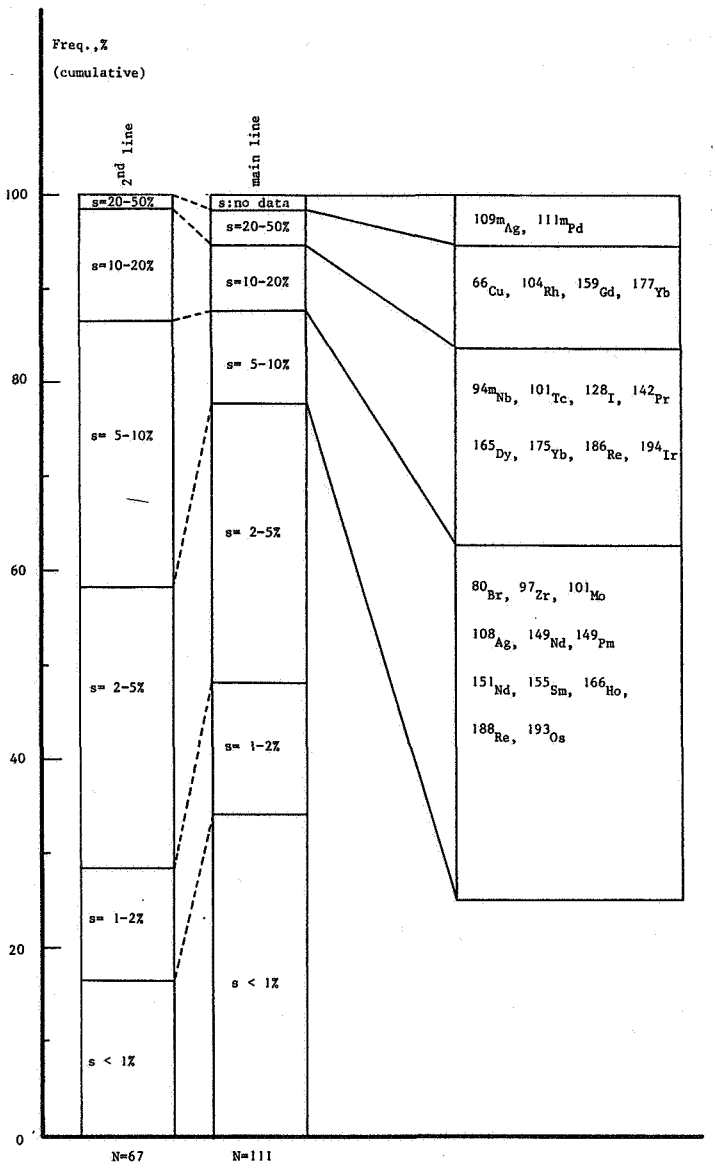

Fig.APP.3-1 : Frequency (Freq.,%; cumulative) of the uncertainty on γ (s,%; "best choice" γ's adopted in the present work) falling in a specified interval (s < 1%, s = 1-2%, etc.). The data refer to the 2 most intense gamma-lines

Fig. APP.3-1 gives an impression of the uncertainties on the "best choice" absolute gamma-intensity values, for the two most intense gamma-lines considered in the present work (see Table VIII.3-1), i.e. 111 main lines (including 44 cases with only 1 line present or considered) and 67 second lines. It is immediately clear that the situation is far the best for the main gamma-lines, especially when taking into account that, with the exception of ^{177}Yb, the cases belonging to the categories "no data"

and "20-50%" refer in fact to radionuclides with only 1 line considered. The list of nuclides exhibiting $s_\gamma \geq 5\%$ for the main line is shown in the expanded block diagram; only for those it is explicitly mentioned in Table VIII.3-1 that more accurate γ-data are desired, although this holds in fact for all cases with $s_\gamma > 1\%$. On the other hand, it is interesting to mention that the category "< 1%", for the two most abundant lines, is for $\sim$ 50% populated by radionuclides used as calibration standards, for which in the last years considerable efforts (including international intercomparisons) have been delivered to arrive at precise and accurate decay data (see e.g. NBS82, INDC83, ICRM85).

Since the most frequently consulted, recent γ-evaluation works are ERDTMANN79 and REUS83, it is interesting to analyse the consistency of their data versus the "best choice" made in the present work. This has been done in Fig. APP.3-2 for the two most intense lines. The older versions, ERDTMANN74 and REUS79 have been included as well, so as to get an impression of the evolution of γ-data in the course of the years. This evolution appears to be significantly positive, and shows that, among the γ-evaluation works covering the whole field of NAA, REUS83 gives the most reliable information (with the restriction that no uncertainties are quoted). The expansion of the block diagram for the main lines shows the five cases for which Δ_γ is exceeding 5%; four of these cases can be found back in Fig. APP.3-1 as exhibiting a large s_γ. It is also striking that the block diagram revealing the consistency REUS83-"best choice" (Fig. APP.3-2) gives a much better impression than the corresponding block diagrams showing s_γ on the "best choice" (Fig. APP.3-1). This suggests strongly a bias of different evaluators, which indeed often have to base their selection on the same old (sometimes obsolete) experimental values; in this context, the example of the ^{65}Ni gamma-intensities will be discussed in APP.3-2.

Table APP.3-2 gives some concise information on remarkable literature scatter or otherwise noteworthy situations, as brought together from Table VIII.3-1. One of the interesting observations is related to the fact that σ_0-determination according to the "activation method" is in fact able to sense the consistency of the introduced γ-data for the considered lines of a radionuclide. In Table VIII.3-1, such occasionally inconsistent σ_0-values calculated from a particular line were not included in the average (see ^{59}Fe, ^{99}Mo, ^{110m}Ag, ^{161}Gd, ^{166}Ho, ^{171}Er, ^{180m}Hf, ^{181}Hf and ^{193}Os). It is, however, meaningful, on condition that the measured k_0-factors are accurate (which is supposed

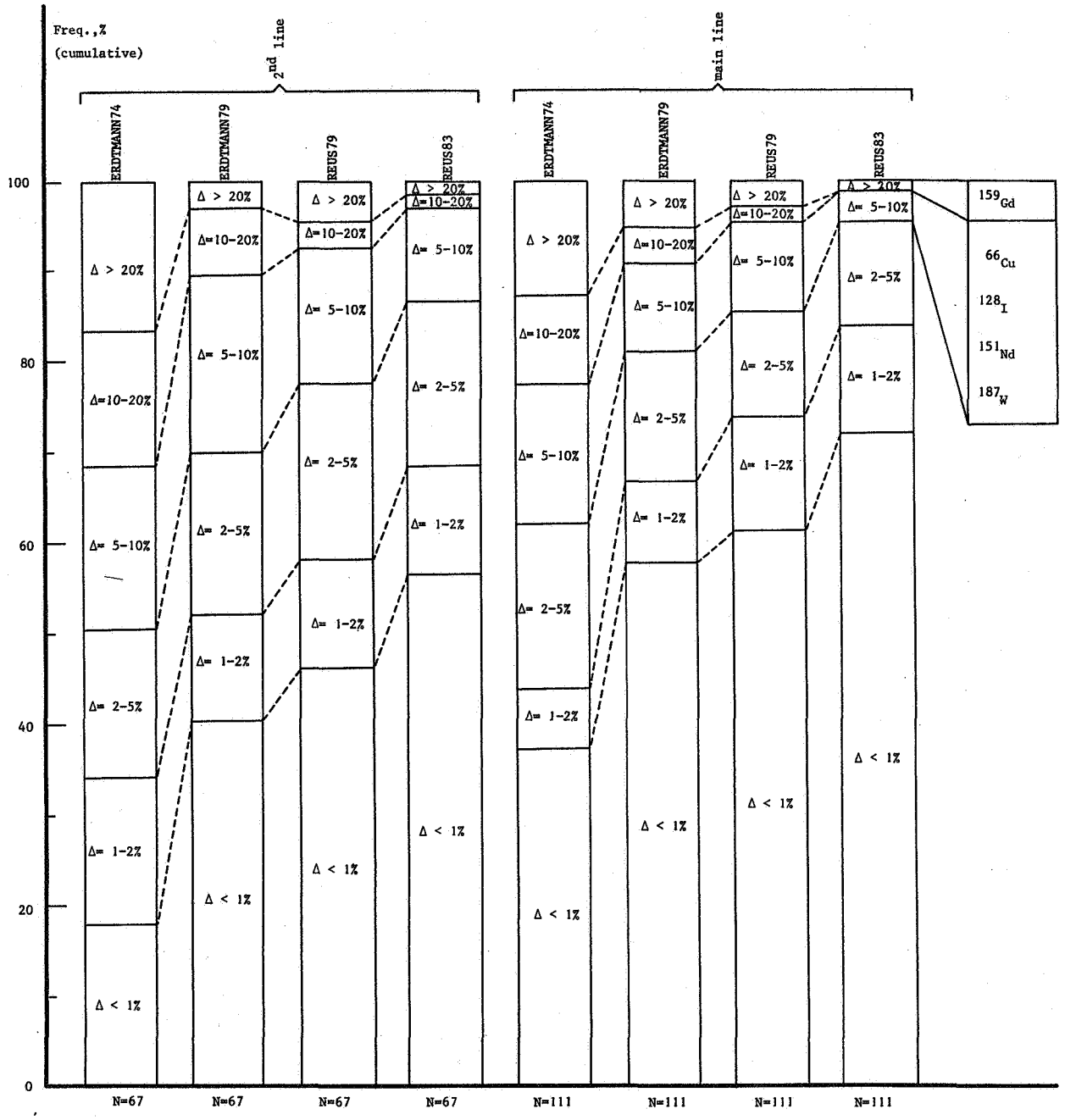

Fig. APP.3-2 : Frequency (Freq.,%; cumulative) of γ-discrepancies (Δ,% ; literature data versus the "best choice" adopted in the present work) falling is a specified interval (Δ < 1%, Δ = 1-2%, etc.). The data refer to the 2 most intense gamma-lines

TABLE APP.3-2 : Some examples of inconsistencies on literature absolute gamma-intensity data (cf. Table VIII.3-1) for radionuclides of interest in NAA

Radio-nuclide	E_γ, keV	γ,% (s_γ,%) "best choice"	Origin	Comments
^{59}Fe	142.6	0.98 (4.1)	KOCHER81	→ consistent σ_0; ANDERSSON83 : 1.02%(3.9) → inconsistent σ_0;
	192.3	2.95 (2.7)	KOCHER81	→ inconsistent σ_0; ANDERSSON83 : 3.08%(3.2) → inconsistent σ_0; from k_0 and σ_0 (THIS WORK) → γ_{192} = 2.75%;
^{65}Ni	366.3	4.69 (4.5)		see APP.3.2
	1115.5	14.9 (4.2)		
	1481.8	23.2 (3.4)		
^{66}Cu	1039.2	7.4 (24.)	WARD83	note high uncertainty; formerly : 8.0% (LEDERER78, ERDTMANN79, REUS83);
^{99}Mo	366.4	1.16 (4.3)	DICKENS80	also REUS83 : 1.16% → inconsistent σ_0; LMRI75, ERDTMANN79 : 1.21% → consistent σ_0; from k_0 and σ_0 (THIS WORK) → γ_{366} = 1.21%
^{111m}Pd	172.1	33.0 (-)	HARMATZ79	note no uncertainty assignment; ERDTMANN79 : 32.4%, REUS83 : 33.5%;
^{110m}Ag	1562.3	1.027 (0.8)	YOSHIZAWA85	→ inconsistent σ_0; DEGELDER83 : 1.029%(0.6) → inconsistent σ_0; LMRI75 : 1.2%(8.3) → consistent σ_0; ERDTMANN79, KOCHER81, INDC83 : 1.18% → consistent σ_0; from k_0 and σ_0 (THIS WORK) → γ_{1562} = 1.18%
^{128}I	442.9	16.9 (10.1)	KIATO83	note high uncertainty; note discrepancies : 17.5% (ERDTMANN79), 14.2%(11.) (KOCHER81), 16.0% (REUS83);
	526.6	1.59 (11.0)	KIATO83	note high uncertainty; note discrepancies : 1.68% (ERDTMANN79), 1.39%(14.) (KOCHER81), 1.50% (REUS83);
^{139}Ba	165.9	23.76 (1.1)	GEHRKE80	note discrepancies : 18.8% (ERDTMANN79), 22.0%(18.) (LEDERER78), 17%(35.) (KOCHER81), 22.0%(4.5) (PEKER81), 23.8% (REUS83);
^{151}Nd	255.6	16.9 (7.9)	LEDERER78	→ ∿ consistent σ_0; note discrepancies : 16.83% (ERDTMANN79), 15.3% (REUS83, "uncertain");
	1180.6	15.3 (6.5)	LEDERER78	→ ∿ consistent σ_0; ERDTMANN79 : 15.3%, REUS83 : 15.3% ("uncertain");
^{159}Gd	363.3	8. (38.)	KOCHER81	note high uncertainty; note discrepancies : ∿ 10% (LEDERER78), 10.33% (ERDTMANN79), 10.8% (REUS83, "uncertainty > 25%");
^{161}Gd	102.3	13.9 (5.7)	HELMER84	→ inconsistent σ_0 (but k_0 not recommended); ERDTMANN79 : 15.25% → inconsistent σ_0; REUS83 : 14.0% → inconsistent σ_0; from k_0 and σ_0 (THIS WORK, not recommended) → γ_{102} = 18.0%;
^{165m}Dy	108.2	3.01 (1.0)	PEKER87	ERDTMANN79 : 21.2%(?); REUS83 : 3.01%;
	515.5	1.527 (6.1)	PEKER87	ERDTMANN79 : 11.7%(?); REUS83 : 1.53%;
^{165}Dy	94.7	3.58 (13.)	PEKER87	note high uncertainty; note discrepancy with ERDTMANN79 : 3.343%; cf. REUS83 : 3.58%;
^{166}Ho	80.6	6.2 (6.5)	KOCHER81	→ inconsistent σ_0; ERDTMANN79, REUS83 : 6.20% → inconsistent σ_0; from k_0 and σ_0 (THIS WORK) → γ_{81} = 7.4%;
^{171}Er	116.7	2.30 (2.6)	SHIRLEY84A	→ inconsistent σ_0; ERDTMANN79, REUS83 : 2.30% → inconsistent σ_0; from k_0 and σ_0 (THIS WORK) → γ_{117} = 2.04%;
cont'd				

TABLE APP.3-2 : continued

Radio-nuclide	E_γ, keV	γ,% (s_γ,%) "best choice"	Origin	Comments
^{170}Tm	84.3	3.26 (4.9)	KOCHER81	ERDTMANN79 : 10.0%(?); LEDERER78 : 3.2%(9.4), REUS83 : 3.26%;
^{177}Yb	121.6	3.41 (20.)	LEDERER78	from γ_{1080} and γ_{all}^{rel}?: note high uncertainty; consistent with ERDTMANN79 and REUS83;
	138.6	1.33 (21.)		
	150.4	20.0 (20.)		
	899.2	0.644 (19.)		
	941.7	1.01 (19.)		
	1028.0	0.633 (19.)		
	1080.1	5.5 (18.)		
	1119.6	0.545 (19.)		
	1149.7	0.643 (19.)		
	1241.4	3.36 (19.)		
^{180m}Hf	500.7	12.8 (8.6)	BROWNE86	→ inconsistent σ_0; ERDTMANN79 : 14.8% → ∿ consistent σ_0; REUS83 : 14.5% → consistent σ_0; from k_0 and σ_0 (THIS WORK) → γ_{501} = 14.2%;
^{181}Hf	133.0	41.7 (3.8)	KOCHER81	→ consistent σ_0; FIRESTONE84 : 35.9%(2.2) → inconsistent σ_0;
	133.4	47.7 (3.4)		→ consistent σ_0; FIRESTONE84 : 42.1%(2.) → inconsistent σ_0;
	136.3	5.96 (5.6)		→ ∿ consistent σ_0 (k_0 not recommended); FIRESTONE84 : 6.2%(4.2) → consistent σ_0;
—	345.9	17.2 (3.5)		→ inconsistent σ_0 (but k_0 not recommended); FIRESTONE84 : 15.1%(6.4) → ∿ consistent σ_0; ERDTMANN79, REUS83 : 14.0% → consistent σ_0; from k_0 and σ_0 (THIS WORK, not recommended) → γ_{346} = 14.3%
	482.2	82.8 (1.0)		→ consistent σ_0; FIRESTONE84 : 80.6%(-) → consistent σ_0
^{187}W	134.2	9.5 (4.2)	KOCHER81	REUS83 : 10.3%; ELLIS82 : 8.56%(4.);
	479.6	23.4 (4.3)		REUS83 : 25.3%; ELLIS82 : 21.1%(4.2);
	551.5	5.44 (4.2)		REUS83 : 5.89%; ELLIS82 : 4.92%(4.);
	618.3	6.7 (4.5)		REUS83 : 7.27%; ELLIS82 : 6.07%(4.);
	685.7	29.2 (4.5)		REUS83 : 31.6%; ELLIS82 : 26.4%(4.1);
	772.9	4.40 (4.3)		REUS83 : 4.77%; ELLIS82 : 3.98%(4.1); the data of KOCHER81, ELLIS82 & REUS83 are internally consistent, but REUS83 is ∿ 8% higher than KOCHER81 and ELLIS82 is ∿ 11% lower than KOCHER81;
^{193}Os	139.0	4.34 (6.0)	SHIRLEY84B	→ inconsistent σ_0; ERDTMANN79 : 4.14% → ∿ consistent σ_0; KOCHER81 : 4.3%(7.) → inconsistent σ_0; REUS83 : 4.27% → inconsistent σ_0; from k_0 and σ_0 (THIS WORK) → γ_{139} = 3.87%;
^{233}Pa	300.1	6.64 (5.2)	ZIJP79	→ consistent σ_0; KOCHER81 : 6.6%(6.) → consistent σ_0;
	312.0	38.6 (1.0)		→ consistent σ_0; KOCHER81 : 38.6%(1.) → consistent σ_0;
	340.5	4.44 (5.4)		→ consistent σ_0; KOCHER81 : 4.5%(11.) → consistent σ_0;
	375.4	0.676 (5.1)		→ consistent σ_0; KOCHER81 : 0.62%(19.) → inconsistent σ_0;
	398.6	1.48 (5.4)		→ consistent σ_0; KOCHER81 : 1.28%(13.) → inconsistent σ_0;
	415.8	1.82 (5.0)		→ consistent σ_0; KOCHER81 : 1.62%(11.) → inconsistent σ_0.

to be the case for recommended k_0-factors), to reverse the procedure and to calculate for those particular lines a γ-value from the average σ_0 (obtained from the other consistent lines). This has been done in Table APP.3-2, not without success for ^{99}Mo, ^{110m}Ag, ^{180m}Hf, ^{181}Hf and ^{193}Os, where the thus calculated γ-values are confirmed by recent evaluation data. In fact, the reliability of this converse procedure was, in the context of the present work, first demonstrated for the γ-values of the ^{56}Mn 1810.7 and 2113.1 keV lines [MOENS77; MOENS78]. The reasoning at that moment being based on preliminary k_0-factors (obtained at the INW only), it can be repeated now based on the recommended INW/KFKI k_0-factors (see Table VIII.3-1). From the irrefutably accurate γ-value for the 846.8 keV line [98.9 $\pm$ 0.3% ($\pm$ 0.3% relat.)] and from the relevant k_0-factor one obtains σ_0 = 13.2 $\pm$ 0.1 barn ($\pm$ 0.7%); this result is quite consistent with the recommended value [13.3 $\pm$ 0.2 barn ($\pm$ 1.5%)], whereby it should be noted that $^{55}Mn(n,\gamma)^{56}Mn$ is a cross-section standard. Next, combination of σ_0 (from the 846.8 keV line) with the k_0-factors for the 1810.7 and 2113.1 keV lines yields γ-values of 27.0 $\pm$ 0.2% ($\pm$ 0.8% relat.) and 14.3 $\pm$ 0.1 ($\pm$ 0.7% relat.), respectively, which are in complete agreement with the "best choice" from KOCHER81. The $\gamma_{1810.7}$ and $\gamma_{2113.1}$ data of the latter, as of all evaluation works since 1976, are based on the experimental results of TIRSELL74 [resp. 27.19 $\pm$ 0.79% ($\pm$ 2.9% relat.) and 14.34 $\pm$ 0.40% ($\pm$ 2.8% relat.)], which are significantly deviating from formerly reported values : e.g. PAGDEN71 (resp. 29.7 and 15.15%), ERDTMANN74 (resp. 30.0 and 15.5%) and BOWMAN74 (resp. 30.0 and 15.0%). Note that the three latter compilations quoted $\gamma_{846.8}$ = 99.0%, negligibly deviating from the nowadays adopted value. Thus, the results of the present work, in a preliminary form dating from 1977, confirm the internationally adopted data of TIRSELL74.

3.2. Literature survey of $\gamma(^{65}Ni)$

From comparison of Figs APP.3-1 and APP.3-2 it was concluded that a good deal of the γ-data published in different evaluation works are biased, because only old experimental values are available. In this context, the now following considerations with respect to ^{65}Ni were initialized by a search for the "best" literature γ-data, which should be introduced to calculate $\sigma_0[^{64}Ni(n,\gamma)^{65}Ni]$ according to the "activation method". The situation encountered in evaluation works is shown in Table APP.3-3. It can be seen that the Nuclear Data

TABLE APP.3-3 : Evaluated data for the ^{65}Ni absolute gamma-intensities (* assuming that the conversion factor specified as $3.4.10^{-2}$ is a misprint and should read as $1.0.10^{-2}$)

Evaluation work	$\gamma \pm 2\ s_\gamma$,%		
	366.3 keV	1115.5 keV	1481.8 keV
FILBY70	4.93	14.8	24.7
PAGDEN71	4.4*	16.1*	24.6*
ERDTMANN74	4.8	15.2	25.4
BOWMAN74	4.78	15.42	25.70
AUBLE75	4.61 ± 0.20	14.83 ± 0.60	23.5 ± 0.8
KOCHER77	4.61 ± 0.20	14.8 ± 0.6	23.5 ± 0.8
ERDTMANN79	4.606	14.83	23.5
REUS79	4.61	14.8	23.5
KOCHER81	4.61 ± 0.20	14.8 ± 0.6	23.5 ± 0.8
REUS83	4.61	14.8	23.5
WARD86	4.61 ± 0.20	14.83 ± 0.53	23.5 ± 0.8

Sheets evaluation [AUBLE75] was invariably reproduced in all later compilations. A closer look reveals that AUBLE75 adopted the experimental γ-value for the 1481.8 keV line as reported by Merritt and Taylor [MERRITT71], who measured the ^{65}Ni-desintegration rate by $4\pi\beta$-γ coincidence counting and the γ-emission rate in a calibrated $4\pi\gamma$ ion chamber; then, MERRITT71 adopted the relative γ-intensities measured by CLINE63 (leading to $\gamma_{1481.8}/\Sigma\gamma = 0.530$) to arrive at $\gamma_{1481.8} = 23.5 \pm 0.8\%$. Next, AUBLE75 combined the latter value with the weighted averages of the relative γ-intensities from PARADELLIS72 and RAMAN73 (yielding $\gamma_{366.3} : \gamma_{1115.5} : \gamma_{1481.8} = 19.6 \pm 0.5 : 63.1 \pm 1.4 : 100$), finally leading to $\gamma_{366.2} = 4.61 \pm 0.20\%$ and $\gamma_{1115.5} = 14.83 \pm 0.60\%$. This procedure of AUBLE75 is not very straightforward since in fact two different sets of relative gamma-intensities are now involved : the set of CLINE63, introduced by MERRITT71 to find $\gamma_{1481.8}$, and the set of PARADELLIS 72/RAMAN73 for converting $\gamma_{1481.8}$ to $\gamma_{366.2}$ and $\gamma_{1115.5}$. It would have been

more consistent either to base this conversion on the data of CLINE63 ($\gamma_{366.3}$: $\gamma_{1115.5}$: $\gamma_{1481.8}$ = 18 ± 1 : 63 ± 3 : 100) or better to renormalize $\gamma_{1481.8}$ from MERRITT71 to the weighted average from PARADELLIS72 and RAMAN73 for $\gamma_{1481.8}/\Sigma\gamma$ (= 0.529, which is however not significantly differing from the value of CLINE63).

The above considerations were part of a report [DECORTE83], which was brought to the attention of the members of the ICRM Working Group on Non-Neutron Nuclear Data, who made many interesting comments (see ICRM85). It was suggested by N.E.Holden (NNDC, BNL) to reject the now more than 20 years old NaI(Tl) data by CLINE63 and to repeat the procedure followed by MERRITT71 but using the $\Sigma_{1481.8}/\Sigma\gamma$-value of RAMAN73, obtained from Ge(Li) measurements. This leads to $\gamma_{1481.8}$ = 23.2 ± 0.8%. The Ge(Li) data of PARADELLIS72 are discarded because of inferior sample enrichment (factor 100) and detector resolution (factor 2). The results of RAMAN73 can further be used to calculate $\gamma_{1115.5}$ = 14.9 ± 0.6% and $\gamma_{366.3}$ = 4.69 ± 0.21%. Furthermore, it was remarked that, whatever combination of measurements is taken, one cannot deny that all available data are more than 10 years old. In addition it is striking that, except CLINE63, no one performed a complete and independent experimental determination of the ^{65}Ni absolute γ-intensities. The data of CLINE63 [$\gamma_{366.3}$ = 4.50 ± 0.30%; $\gamma_{1115.5}$ = 15.80 ± 0.80%; $\gamma_{1481.8}$ = 25.0 ± 2.0%] are, however, not consistent with the above mentioned ones. Finally, it was strongly suggested to undertake a remeasurement of the data, and two laboratories in principle complied with this request.

3.3. Data for fractional decay factors (F)

Additional decay parameters, important in the relevant equations for complex activation and decay, are the fractional decay factors F (see I.3.4.2). Fortunately, in most of the cases the branching is 100% (F = 1), thus causing no accuracy problems due to unreliable knowledge of F ; to cite some examples from different activation/decay types :

$^{47}Ca \xrightarrow{F_2=1} \underline{^{47}Sc}$ (type II/a), $^{233}Th \xrightarrow{F_2=1} \underline{^{233}Pa}$ (type II/b), $^{80m}Br \xrightarrow{F_2=1} \underline{^{80}Br}$ (type IV/A), $^{24m}Na \xrightarrow{F_2=1} \underline{^{24}Na}$ (type IV/b), $^{199m}Pt \xrightarrow{F_2=1} {}^{199}Pt \xrightarrow{F_3=1} \underline{^{199}Au}$ (type V/b), $^{109m}Pd \longrightarrow {}^{109}Pd \longrightarrow \underline{^{109m}Ag}$ (type V/c), and $^{125m}Sn \xrightarrow{F_{24}=1} {}^{125}Sn \xrightarrow{F_3=1} \underline{^{125}Sb}$ (type VII/b). The cases (from Table VIII.3-1) with F≠1 are commented in Table APP.3-4.

TABLE APP.3-4 : Cases of complex activation/decay (from Table VIII.3-1) with fractional decay factor F different from unity

Activation/decay type Case (— = isotope measured)	Adopted F (s_F,%) (Reference)	Comments
II/a		
$^{97}Zr \xrightarrow{F_2} \underline{^{97m}Nb}$	F_2 = 0.968(0.4) (HAESNER85)	0.4% uncertainty transferred to σ_0; others : 0.973 (LEDERER78), 0.947(0.3) (KOCHER81), 0.945 (REUS83);
$^{105}Ru \xrightarrow{F_2} \underline{^{105m}Rh}$	F_2 = 0.245(4.5) (KOCHER81)	4.5% uncertainty transferred to σ_0; gives consistency with σ_0 from ^{105}Rh; others : 0.28(3.6) (LEDERER78), 0.28 (REUS83), 0.284 (DEFRENNE86), all giving inconsistency with σ_0 from ^{105}Rh;
II/d		
$^{99}Mo/\underline{^{99m}Tc}$		see VII.2.3.
III/a		
$^{95}Zr \xrightarrow{F_2} \underline{^{95m}Nb} \xrightarrow{F_3} \underline{^{95}Nb}$ $^{95}Zr \xrightarrow{F_{24}} \underline{^{95}Nb}$	F_2 = 0.0111(11.) F_{24} = 0.989(0.1) F_3 = 0.944(0.6) (LUKSCH83)	in practice $k_{0,exp}$ is inversely proportional to F_{24}/F_2F_3; only $s_{F_{24}}$ (= 0.1%) is transferred to σ_0, since the latter is inversely proportional to F_2F_3; the adopted F-data give consistency with σ_0 from ^{95}Zr; other F_{24}-data : 0.991 (LEDERER78), 0.989(0.1) (LMRI80), 0.9922(0.04) (KOCHER81), 0.991 (REUS83);
$^{97}Zr \xrightarrow{F_2} \underline{^{97m}Nb} \xrightarrow{F_3} \underline{^{97}Nb}$ $^{97}Zr \xrightarrow{F_{24}} \underline{^{97}Nb}$	F_2 = 0.968(0.4) F_{24} = 0.032(12.) F_3 = 1 (HAESNER85)	in practice $k_{0,exp}$ is nearly insensitive to F_{24}/F_2F_3; only s_{F_2} (= 0.4%) is transferred to σ_0, since the latter is inversely proportional to F_2F_3; other F_2-data : 0.973 (LEDERER78), 0.947(0.3) (KOCHER81), 0.945 (REUS83);
IV/a		
$^{104m}Rh \xrightarrow{F_2} \underline{^{104}Rh}$	F_2 = 0.9987(0.01) (BLACHOT84)	others : 0.9987 (LEDERER78); 0.999 (REUS83); s_{F_2} causes negligible uncertainty on k_0 and σ_0;
IV/b		
$^{60m}Co \xrightarrow{F_2} \underline{^{60}Co}$	F_2 = 0.9976(0.03) (KOCHER81)	others : 0.9975(0.09) (LMRI75), 0.9975 (LEDERER78), 0.998 (REUS83);
$^{82m}Br \xrightarrow{F_2} \underline{^{82}Br}$	F_2 = 0.976(~) (LEDERER78)	others : 0.976 (REUS83);
$^{85m}Sr \xrightarrow{F_2} \underline{^{85}Sr}$	F_2 = 0.873(~) (KOCHER81)	others : 0.87 (LEDERER78), 0.867 (REUS83);
$^{165m}Dy \xrightarrow{F_2} \underline{^{165}Dy}$	F_2 = 0.976(0.3) (PEKER87)	others : 0.9776 (REUS83, LEDERER78)
		F_2 is only needed for calculating $F_2\sigma_0^m + \sigma_0^g$ from σ_0^m and σ_0^g literature data;
V/c		
$^{113m}Sn \xrightarrow{F_2} ^{113}Sn \xrightarrow{F_3} \underline{^{113m}In}$	F_2 = 0.911(2.5) F_3 = 1 (LYTTKENS81)	other F_2-data : 0.91 (LEDERER78), 0.911 (REUS83); F_2 is only needed for calculating $F_2\sigma_0^m + \sigma_0^g$ from σ_0^m and σ_0^g literature data;
VI		
$^{124m_2}Sb \xrightarrow{F_2} ^{124m_1}Sb \xrightarrow{F_3} \underline{^{124}Sb}$	F_2 = 1 F_3 = 0.75(7.) (TAMURA84)	other F_3-data : 0.80 (LEDERER78), 0.80 (REUS83); F_2 and F_3 are only needed for calculating F_3 $(F_2\sigma_0^{m_2} + \sigma_0^{m_1})$ + σ_0^g from $\sigma_0^{m_2}$, $\sigma_0^{m_1}$ and σ_0^g literature data

4. (n,γ) CROSS-SECTIONS

4.1. Experimental results

The experimental σ_0's for 101 (n,γ) reactions [the ultimate standard $^{197}Au(n,\gamma)^{198}Au$ not included] are compiled in Table VIII.3-1. Let it be repeated that the values are obtained according to the "activation method" [Eq. (APP.1-1)], and that "best choice" literature data are introduced for θ and γ (APP.2.1 and APP.3.1, resp.) listed in the 3rd column/2nd line and the 11th column/2nd line of Table VIII.3-1, respectively.

First, an intermediate σ_0-result is given for each individual gamma-line in the 13th column/2nd line of Table VIII.3-1. The associated uncertainty s_{σ_0} (of course only in case of recommended k_0-factors), is obtained from quadratic summation of s_{k_0} and s_γ, and - if possible - only uncorrelated uncertainties are considered for the latter (see below). Then, a σ_0-value labelled "THIS WORK" (4th column/2nd line of Table VIII.3-1) is the weighted average of these intermediate results, i.e. only of those which are originating from recommended k_0-factors and which are not rejected because of inconsistency (mentioned in the "COMMENTS"). The final uncertainty is obtained as follows : when making the weighted average of the intermediate σ_0's, the larger of the internal or external error is adopted ; this uncertainty is quadratically summed with the correlated uncertainty on the γ's (if known), which is for instance resulting from a common normalization factor with its associated uncertainty as mentioned in the Nuclear Data Sheets. Further quadratic summation is performed with the uncertainties on all relevant nuclear data for the isotope under investigation and for Au, not forgetting extra uncertainties due to the neglect of $g_{WESTCOTT}$-factors. The σ_0-values for 70 (n,γ) reactions are fully underlined as being reliable; they include the nuclear data standards Mn, Co and Au, for which, however, the "standard" literature data are underlined. When a σ_0-value exhibits an uncertainty which exceeds 10% (due to θ or γ) or when it is for another reason considered as being of doubtful accuracy, a dashed underlining is used [14 (n,γ) reactions]. No underlining indicates that the σ_0-results are obtained from tentative k_0-factors only [18 (n,γ) reactions].

Since recommended Q_0-values are listed as well (Table VIII.3-1, 6th column/2nd line), it is possible to calculate $I_0 = Q_0 \times \sigma_0$ (Table VIII.3-1, 5th column/2nd line). Underlining (fully, dashed or not) is following the worst situation for either Q_0 or σ_0. For comparison, the data quoted in Ref. MUGHABGHAB81/84 are shown in the 5th column/1st line of Table VIII.3-1.

4.2. Comparison with literature

The recent evaluation and compilation works which are most frequently used by activation analysts are : MUGHABGHAB81/84, CH.NUCL.84, NUKLIDK.81 and NNDC COMPUT.CH.85, the latter being scarcely spread among activation analysts. Uncertainties on the quoted σ_0-values are given only by MUGHABGHAB81/84 and NNDC COMPUT.CH.85. Isotopic abundance values of the target isotopes are compiled in all works, with very few exceptions for MUGHABGHAB81/84 (e.g. ^{36}S). The half-lives of the produced isotopes are systematically listed in all works except in MUGHABGHAB81/84, where T is specified only in case of m- and g-formation. No information on gamma-intensities is given. Only MUGHABGHAB81/84 contains a list with the experimental origin of the evaluated data, but the real procedure to arrive at the evaluated σ_0-values is not specified.

Since mainly experimental "activation method"-results serve as the basis for the compiled σ_0-values, the ideal situation would be that evaluators, prior to the evaluation, renormalize all these available results towards the same input data, which should thus be specified by the experimentalists. The latter requirement is far from being fulfilled, and highly illustrative in this context is a paper by Gleason [GLEASON75], who reports the experimentally measured σ_0-values for 18 nuclides without revealing any information on the introduced θ, γ and T-values. It is evident that such a situation is confronting the evaluators with a difficult task, especially when the evaluation is uniquely based on such undocumented experimental literature data. This is for instance so for $^{124}Sn(n,\gamma)^{125m}Sn$, where evaluators invariably adopt a σ_0-value of 0.13 barn [BNL73, NUKLIDK.74, CH.NUCL.77, MUGHABGHAB81, NUKLIDK.81, NNDC COMPUT.CH.82, CH.NUCL.84, NNDC COMPUT.CH.85], which is apparently based on experimental results reported in Refs MANGAL63 [0.125b (15.)], TILBURY68

[0.13 b (15.)] and GLEASON77 [0.135 b (4.)]. However, since none of these experimentalists quoted the value introduced for $\theta(^{124}Sn)$, the evaluators could not perform any (re)normalization, although reported θ-values range from 5.94% to 5.6%. Note that in the present work a σ_0-value of 0.116 barn is obtained with $\theta(^{124}Sn)$ = 5.79% [CAWIA84, DEBIEVRE85]. The discrepancy with the formerly obtained results ($\sim$ 0.13 b) cannot be explained fully by the range in θ, and is probably further enlarged by the ^{125m}Sn half-life introduced [9.8 min (MANGAL63); 9.5 min (TILBURY68); 9.2 min (GLEASON77); 9.525 min (THIS WORK)]; this makes a judgment of the consistency completely impossible.

In general, one should take into account that the listed evaluated σ_0-values are correlated with the input nuclear data, albeit in a complicated way and mostly to an unknown degree. Only occasionally this correlation is very clear, as for instance in the case of $^{58}Fe(n,\gamma)^{59}Fe$. For this reaction BNL73 reports $\theta(^{58}Fe)$ = 0.31% and σ_0 = 1.15 b, whereas - on the basis of a new SAIC-evaluation - MUGHABGHAB81 gives $\theta(^{58}Fe)$ = 0.28% and σ_0 = 1.28 b, thus reflecting the constancy of $\theta \times \sigma_0$ in the "activation method". Note that this double adjustment was not done by NNDC COMPUT.CH.82, where the inconsistent set $\theta(^{58}Fe)$ = 0.3% / σ_0 = 1.28 b is tabulated. Another example of inconsistency is the case $^{184}Os(n,\gamma)^{185}Os$. All evaluation and compilation works quote a σ_0-value of 3000 b, which is in fact the rounded result from the sole experimental determination by Kim et al. [KIM68], who obtained 3005 b when introducing $\theta(^{184}Os)$ = 0.018%. However, all recent works adopted the $\theta(^{184}Os)$ = 0.02% SAIC-evaluation and should thus have quoted a renormalized σ_0-value of 2700 b.

In Table VIII.3-1, the σ_0-data from MUGHABGHAB81/84 are systematically shown in the 4th column/1st line, and those from NNDC COMPUT.CH.85, CH.NUCL.84 and NUKLIDK.81 are given in the "COMMENTS" (where also former experimental results are quoted in case of serious and puzzling discrepancies with the results of the present work). A comparison with the results of the present work is shown in Fig. APP.4-1. It can be seen that the best consistency is obtained with the data from CH.NUCL.84. Further, it is striking that the situation is invariably far the best for the "recommended" INW/KFKI σ_0-values. As a first reflex one could consider this as quite logical, since the accuracy on the "tentative" values is certainly worse. It is difficult to believe, however, that this fact could induce such a remarkable deterioration for the large

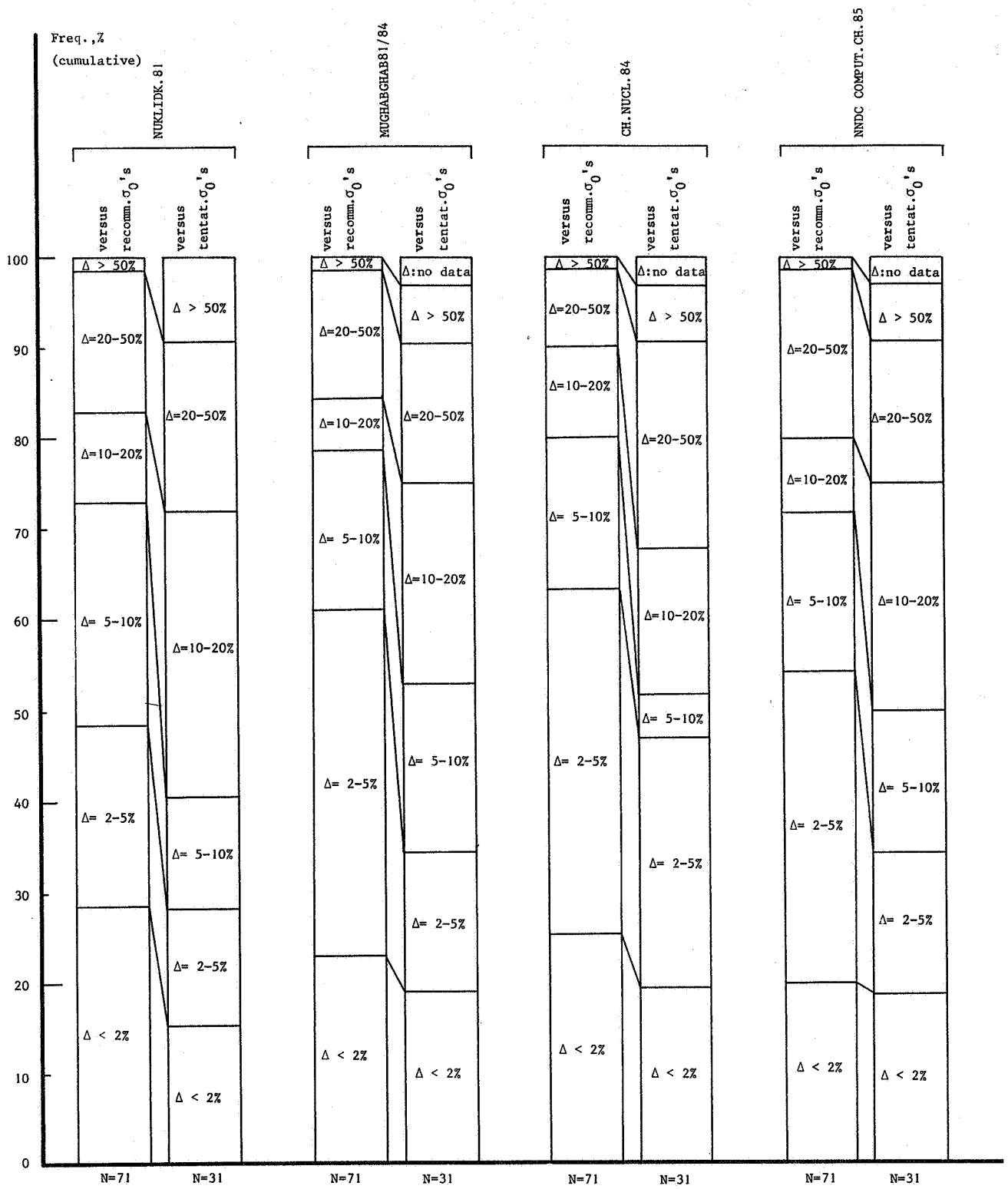

Fig. APP.4-1 : Frequency (Freq.,% ; cumulative) of σ_0-discrepancies (Δ,% ; literature data versus the results of the present work) falling in a specified interval. The comparison is shown for "recommended" and "tentative" σ_0's (see text)

discrepancies (> 10%) as well. A more decisive parameter is probably the fact that the category of preliminary values contains more cases for which σ_0 is less accurately known in literature. This is seen for instance when calculating the average of the uncertainties quoted by MUGHABGHAB81/84 : $\bar{s}_{\sigma_0}$ = 9.2% for the "tentative" group, versus $\bar{s}_{\sigma_0}$ = 5.2% for the "recommended" group; a similar conclusion is reached when considering, for both groups, the fraction with a reported uncertainty larger than 10% (again from MUGHABGHAB81/84) : 31% for the "tentative" group, versus 13% for the "recommended" group;

4.3. σ_0 [^{64}Ni(n,γ)^{65}Ni]

Detailed results of σ_0-determination, including a critical comparison with literature data, have been published for the cases ^{50}Cr(n,γ)^{51}Cr, ^{58}Fe(n,γ)^{59}Fe, ^{109}Ag(n,γ)^{110m}Ag [SIMONITS84], ^{64}Zn(n,γ)^{65}Zn, ^{112}Sn(n,γ)$^{113(F_2^{m+g})}$Sn, ^{174}Yb(n,γ)$^{175(m+g)}$Yb [DECORTE85], ^{184}Os(n,γ)^{185}Os, ^{154}Sm(n,γ)^{155}Sm and ^{153}Eu(n,γ)$^{154(m+g)}$Eu [DECORTE86]. Another interesting example concerns the reaction ^{64}Ni(n,γ)^{65}Ni.

In the present work, T (^{65}Ni) = 2.520 $\pm$ 0.002 h [KOCHER81], Q_0 = 0.67 [SIMONITS84B] and $\bar{E}_r$ = 14200 eV [JOVAN.86] are adopted ; in view of the low Q_0-value, the latter two data are of minor importance.

The history and the present status of the $\theta(^{64}Ni)$-value have been outlined in APP.2.2. It can be recalled here that the recent SAIC/IUPAC recommendation of 0.91 $\pm$ 0.01% ($\pm$ 1.1% relat.) was adopted in the present work, but that formerly values as high as 1.16% have been quoted. It is important to note also that for Ni no isotopic variability has been reported in literature.

A detailed analysis of the ^{65}Ni gamma-intensity data has been given in APP.3.2. It was concluded that a remeasurement should be performed, but that - making shift as best one can - the most reliable values are obtained by combining the experimental results of MERRITT71 and RAMAN73, leading to $\gamma_{366.3}$ = 4.69 $\pm$ 0.21% ($\pm$ 4.5% relat.), $\gamma_{1115.5}$ = 14.9 $\pm$ 0.6% ($\pm$ 4.2% relat.) and $\gamma_{1481.8}$ = 23.2 $\pm$ 0.8% ($\pm$ 3.4% relat.).

Together with the INW/KFKI recommended k_0-factors, the above mentioned input data yield the σ_0-results listed in Table APP.4-1. The weighted average of the three consistent values is 1.69 $\pm$ 0.01 b ($\pm$ 0.6%; originating from s_{k_0} and s_γ only, the latter being correlated through the 3.4% error on γ_{1482}), or

1.69 ± 0.06b (± 3.7%, total uncertainty).

TABLE APP.4-1 : Results of the σ_0-determinations [for $^{64}Ni(n,\gamma)^{65}Ni$] in the present work. Only uncorrelated uncertainties are given

E_γ, keV	σ_0, barn
366.3	1.65 ± 0.05
1115.5	1.69 ± 0.04
1481.8	1.69 ± 0.01

Table APP.4-2 gives a literature survey of σ_0-data for the reaction $^{64}Ni(n,\gamma)^{65}Ni$. Whenever possible, the originally reported experimental results are normalized to the input data selected in the present work. The experimental error given by the authors is considered to be of random nature only (index *); the total uncertainty is obtained by quadratic summation of the relative random error and the relative errors on the input nuclear data (among which s_γ is the most important in this case). It is puzzling that the four normalized results [RYVES70, GRYNTAKIS76/78, HEFT79 and THIS WORK] show no consistency. In fact, two separate sets with reasonable internal consistency can be distinguished : RYVES70 - THIS WORK [weighted mean 1.70 b (considering random uncertainties only) with external and internal random errors of resp. 1.2% and 0.6%] and GRYNTAKIS76/78 - HEFT79 [weighted mean 2.11 b (considering random uncertainties only) with external and internal random errors of resp. 1.0% and 1.2%]. Finalization of the results is left to the discretion of the evaluators. A last remark is concerned with the evaluated data. Apart from MUGHABGHAB81, all evaluation works quote values which are obviously strongly inspired by the results reported by RYVES70, GRYNTAKIS76/78 and HEFT79. These results were, however, obtained with θ = 1.08 - 1.16%, whereas the evaluation works quote a θ-value of 0.91% - thus leading to a regrettable inconsistency.

TABLE APP.4-2 : Literature survey of σ_0-data for $^{64}Ni(n,\gamma)^{65}Ni$
(* random ; ** total)

Reference	σ_0, barn	Comments
	experimental	
SEREN44	1.4 ± 0.3	no information
HUGHES46	2.6	no information
SEREN47	1.96 ± 0.39	activ.meth.; θ = 0.88% ; T = 2.6 h ; β^--counting
ORNL < 58	1.6 ± 0.2	referred to in BNL58; no information
ORNL < 60	1.52 ± 0.14	referred to in BNL60; no information
LYON60	1.45 ± 0.15	activ.meth.; versus σ_0(Co) = 36.7b & σ_0(Mn) = 13.3b; no further information
STORY65	1.50 ± 0.15	no information
EMERY68	1.35 ± 0.1	activ.meth.; γ_{1482} = 25%; versus σ_0(Au) = ?
RYVES70	1.49 ± 0.03	activ.meth.; θ = 1.08% ; β-γ counting ; T = 2.56 h ; versus σ_0(Au) = 98.8b
	↓	
	$1.77 \pm {}^{0.03*}_{0.04**}$	normalized
GLEASON75	1.49	activ.meth.; no information
GRYNTAKIS76/78	1.58 ± 0.04	activ.meth.; θ = 1.16% ; T =2.564 h ; γ_{1115} = 16%, γ_{1482} = 24.6%; versus σ_0(Au) = 98.8b
	↓	
	$2.15 \pm {}^{0.05*}_{0.10**}$	normalized
ISHAQ77	1.63	from thermal neutron capture studies
HEFT79	1.49 ± 0.02	activ.meth.; θ = 1.16% ; T = 2.561 h ; γ_{1482} = 25.7%; versus σ_0(Au) = 98.8b, σ_0(Co) = 37.5b & σ_0(U) = 2.720b
	↓	
	$2.10 \pm {}^{0.03*}_{0.08**}$	normalized
THIS WORK	$1.69 \pm {}^{0.01*}_{0.06**}$	activ.meth.; θ = 0.91% ; T = 2.520 h ; γ_{366} = 4.69%, γ_{1115} = 14.9%, γ_{1482} = 23.2%; versus σ_0(Au) = 98.65b
	evaluated	
NUKLIDK.81	1.49	with θ = 0.91%; probably adopted from RYVES70 (with θ = 1.08%) and HEFT79 (with θ = 1.16%)
MUGHABGHAB81	1.80 ± 0.04	with θ = 0.91%;
CH.NUCL.84	1.55	with θ = 0.91%;
NNDC COMPUT.CH.85	1.52 ± 0.03	with θ = 0.91%

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SUMMARY

Concerned for the competitiveness of (n,γ) reactor neutron activation analysis [NAA] with other powerful determination methods, the k_0-method is advanced in the present work as an optimized standardization technique.

One of the bases of the k_0-method is the Høgdahl convention for the physicomathematical description of the (n,γ) reaction rate (Chapter I.1). It is fully recognized that by selection of this convention (n,γ) reactions with a Westcott g-factor deviating from unity in principle have to be left out of consideration. It is shown, however, that the thereby induced errors are small to negligible, except for $^{151}Eu(n,\gamma)$ and $^{176}Lu(n,\gamma)$ [out of some 120 analytically interesting cases]; this is estimated to justify the refusal of more complex conventions that would endanger the experimental simplicity aimed at (Chapter VII.4).

In the present work, the activation equation - whereto the k_0-method is firmly bound - is extended in order to cope with thermal and epithermal neutron self-shielding and with different types of burn-up (Chapter I.2). For both effects appropriate correction formulae are given. But also for the more fundamental phenomena of branching activation and mother-daughter decay suited modifications of the basic equations have been elaborated (Chapter I.3). Occasionally, this necessitates the introduction of nuclear data for activation and decay (in addition to the inevitable half-lives), which may be responsible for systematic errors; although this inconvenience is by no means specific to the k_0-method, large attention was paid to a "best choice" from literature of these data (Appendix.3), including accurate (re)determination in cases of doubt, as for ^{80}Br, ^{99}Mo and ^{104}Rh (Chapter VII.2). The half-lives being mentioned just now, they too were carefully selected from compilation and evaluation works, and for ^{97}Zr and ^{125m}Sn new values were measured.

The principles and features of relative, single-comparator and absolute standardization are reviewed concisely (Chapter I.3). It was concluded that their main drawbacks are - respectively - laboriousness (standard preparation, counting and γ-spectrum processing), inflexibility (as to the irradiation and counting conditions) and inaccuracy (by introduction of absolute nuclear data for activation and decay). These considerations led, in 1975, to the launching of the k_0-standardization concept, planned to be developed cooperatively by

the Institute for Nuclear Sciences (INW, Gent/Belgium) and the Central Research Institute for Physics (KFKI, Budapest/Hungary). Consequently, results reported in the present work are based on parallel but independent experiments, carried out by making use of the irradiation facilities, counting equipment and computational devices and methods of both institutes (Chapter II). Occasionally, additional results were obtained from work performed at other laboratories, such as the Isotope Division at Risø/Denmark.

The k_0-method can be interpreted either as an absolute standardization (flexible and experimentally simple) where the absolute nuclear data, some of them bearing a large uncertainty, are replaced by a compound nuclear constant - the k_0-factor - experimentally determinable with high accuracy; or as a single-comparator technique (accurate and experimentally simple), made flexible with respect to the experimental conditions (Chapter I.3). The fundamental principles and parameters of the k_0-method are outlined and it is stressed that epicadmium NAA [ENAA] based upon these is possible as well. For the latter type of application, the Cd-transmission factor for epithermal neutrons is needed as an extra parameter, and data from literature have been compiled and evaluated for 60 (n,γ) reactions, not to forget the new measurements for $^{186}W(n,\gamma)$ and $^{114}Cd(n,\gamma)$ [Chapter V.3].

Before coming to the k_0-factor and its use, attention had to be paid to several problems and pitfalls which arise from the flexibility aimed at, and which could endanger the quality of the final analytical results. So, the existence of an epithermal neutron flux component, in addition to the thermal (Maxwellian) one, imposes to take into account the therewith associated (n,γ) activation, and even the effect of the non-ideality of the epithermal neutron flux distribution should be corrected for (Chapter V). Next, measurement of extended sources (samples) at small distance to a Ge-detector has two consequences : the accuracy of the full-energy peak detection efficiency might become precarious (Chapter III), and correction for true-coincidence of cascading radiation is unavoidable (Chapter IV).

In the present work a description is given of a semi-empiric yet accurate method for tackling the problem of detection efficiency (Chapter III). It is based on experimental determination of efficiency values for point-source geometries at large detector separation (feasible to within 1-2% accuracy in the

gamma-energy range of analytical relevancy), followed by computational conversion (with the aid of the computer program SOLANG) to the geometric configuration on hand. This conversion, making use of so called effective solid angles - including gamma-attenuation effects -, imposes the Ge-detector and the source to be cylindrically symmetrical and requires the knowledge of source and detector dimensions, source-detector distance, thickness of all interposed absorbers and the absorption coefficients (function of the gamma-energy) of all materials involved. Examination of the practical applicability revealed that no insuperable hindrances are to be expected, and the accuracy of the conversion was experimentally proved to be better than $\sim$ 2%. As a matter of course, these statements only hold for cylindrically-shaped Ge-detectors with specified geometric parameters - of which the radius, the n-layer thickness and the separation from the window are the most crucial ones. Some fortunate circumstances, however, are almost smoothing away this obstacle : the advancing availability of this type of detectors (the manufacturers being convinced by documented requests), the possibility of adjusting the numerical data of the most crucial parameters (by comparing experimental to calculated conversion factors, a prerequisite in the context of quality assurance), and the fact that the above mentioned uncertainty of $\sim$ 2% is significantly reduced towards the analytical results (especially if sample and monitor are measured at the same detector separation).

A comprehensive survey is given of the analytically relevant true-coincidence effects (Chapter IV) : γ-γ coincidence summing, and γ-γ and γ-KX coincidence loss, the latter being considered in more detail. It is argued that for conventional Ge(Li) or p-type HPGe detectors, with an efficiency going down at energies below $\sim$ 100 keV, γ-KX coincidence events should only be considered from ^{175}Hf onwards (with KX $\gtrsim$ 50-60 keV). Algorithms were developed for correction of measured peak areas, and criteria for the relevancy of true-coincidence effects were established - aiming at a loss of accuracy not exceeding a few tenths of percents. Attention was paid to special problems such as delayed γ-γ emission, summed peak area calculation of multiplets, and identical gamma-rays emitted by both a mother and a daughter isotope. For the relevant gamma's of 152 analytically interesting radionuclides, the cases of coincidence summing and loss are collected in a user-orientated table, together with the associated nuclear data - which were carefully selected from literature. Exemplary, numerical values of coincidence correction factors - taken

from life - are given as well. The experimental parameter needed to enable the coincidence correction is the total detection efficiency, obtainable upon dividing the full-energy peak detection efficiency by the peak-to-total ratio. It is shown that the latter can be determined by counting a few "coincidence-free" sources with an appropriate spread in gamma-energy (e.g. ^{241}Am, ^{109}Cd, ^{57}Co, ^{203}Hg, ^{137}Cs and ^{65}Zn). Eventually, the accuracy of the correction for true-coincidence could be established as being $\sim$ 1.5% on the average, as evidenced by experimental check.

The contribution of epithermal activation is dealt with in detail (Chapter V). It is evidenced that assuming the epithermal neutron flux distribution to follow the ideal 1/E dependence leads to unacceptable systematic errors. Therefore, the $1/E^{1+\alpha}$ dependence was proposed as a more realistic approximation. This necessitates the introduction not only of the parameter α - a measure of the deviation from ideality - but also of the concept of the effective resonance energy $\bar{E}_r$. Based on considerations with respect to error propagation, it was shown that $\bar{E}_r$-values, in principle a function of α, can be considered as nuclear constants, computable from resonance parameter data. Also, it was proved that the applicability of the $\bar{E}_r$-concept is independent of the choice of a reference energy - taken here as 1 eV. Finally, a compilation is given of $\bar{E}_r$-values for 126 analytically interesting (n,γ) reactions. As to experimental α-determination, the principles and uncertainties (and their propagation) are elaborated thoroughly, and three possible techniques are proposed : the "Cd-covered multi-monitor"-method (suited for in-situ monitoring in ENAA), the "Cd-ratio for multi-monitor"-method (suited for a priori determination), and the "bare multi-monitor"-method (suited for in-situ monitoring in NAA). Experimental determination of f, the thermal-to-epithermal neutron flux ratio, was a next matter of concern. It was revealed that, in addition to the well-known cadmium-ratio technique (suited for a priori determination), the "bare bi-isotopic monitor"-method using Zr (^{95}Zr and ^{97}Zr) is eminently suited for this purpose, especially for in-situ monitoring in NAA. Moreover, when adding Au (^{198}Au) as a third monitor, in-situ α-monitoring according to the "bare triple-monitor"-method becomes possible. The accuracy of Q_0-values (resonance integral to thermal cross-section ratios) was another topic to be considered. Critical evaluation of data from literature - based on comparison of k_0-factors -, and experimental determination (at the INW and the KFKI)

based on Cd-ratio measurements, were the strategies followed in the present work. This led to a compilation of "adopted" Q_0-values for 107 (n,γ) reactions, including a detailed comparison with formerly compiled and evaluated data. In view of the important role of Zr, considerable efforts were spent to arrive at very accurate values of Q_0 - and also of the epithermal neutron self-shielding - for the above mentioned Zr-isotopes. Finally, the quality of the correction for epithermal activation was investigated : the validity of the $1/E^{1+\alpha}$ and $\bar{E}_r$ concepts was proved by experimental control in various irradiation positions of reactors Thetis (Gent), WWR-M (Budapest) and DR-3 (Risø); and extensive error propagation calculation showed that the residual uncertainty on the analytical results is of the order of $\sim$ 1% (from Q_0), $\sim$ 1.5% (from α) and $\sim$ 1% (from f), on the average.

Attention was also paid to a number of other specific problems (Chapter VII). Primary interferences - especially from (n,n') activation - are evaluated with respect to their practical consequences, and the formerly unknown fission-neutron averaged cross-sections for the reactions $^{117}Sn(n,n')^{117m}Sn$ and $^{135}Ba(n,n')^{135m}Ba$ were experimentally determined. Next to the precautions which can be taken to avoid the nuisance caused by primary interferences, it is argued that they can be corrected for with acceptable accuracy - at least in favorable cases - by measuring the fast flux component via the $^{90}Zr(n,2n)^{89}Zr$ threshold reaction. Next, the possible variability of the neutron flux during irradiation was a topic to be taken very seriously. Mathematical treatment of the problem revealed that the resulting effects with respect to accuracy are rather moderate and can occasionally even be corrected for. Nevertheless, it must be concluded that the flux variability during irradiation - if not appraisable - is the very limiting factor for applicability of the k_0-standardization method. Eventually, relevant formulae are developed for handling the situation of intermittent irradiation; on condition that the experimental work is properly done, no significant loss of accuracy is estimated to occur.

The epicenter of the present work is the experimental determination of k_0-factors - more specific, of $k_{0,Au}$-factors, since they are related to Au as a comparator [$^{197}Au(n,\gamma)^{198}Au$], which is irradiated with the elements under study as a dilute Au-Al alloyed wire (Chapter VI). The utmost care was taken to obtain reliable and accurate results, and - among many other precau-

tions - the cooperative, but independent work done at the INW and the KFKI was absolutely essential, since it allowed to detect and to eliminate systematic errors. Experimental details of k_0-measurements for the relevant gamma's of 112 analytically interesting radionuclides are shown. Most of the k_0's are "recommended", with an established accuracy of better than 2% ($\sim$ 1% on the average). For reasons explained earlier, special attention went to the k_0-factors of the Zr-isotopes.

Based on all above described experimental results and considerations it was possible to evaluate the accuracy, traceability and applicability of the k_0-standardization method (Chapter VIII). By taking into account all previously mentioned sources of error, a priori estimation of the accuracy yielded a value better than 4%. This could be confirmed from analysis results for a number of reference materials. Traceability is a special problem in the sense that no generally approved definition exists. Notwithstanding this difficulty, it could be shown - by scrutinizing the steps and parameters of the k_0-method - that adequate traceability is provided in every respect, as well for certification work as for routine analysis; a "conditio sine qua non" is - of course - that the "k_0-protocol" is followed correctly. On the other hand, it is made clear that the absolute standardization method is highly untraceable, due to the "untransparency" of the required nuclear data. In order to enhance the applicability of the k_0-method, it was felt compulsory to collect all relevant data in a user-orientated table. But also the analytical protocol to be followed is clearly outlined. In this context it is emphasized that, in order to accomplish the numerous and complex calculations, the use of a computer program is dictated; accordingly, at the INW, the computer code SINGCOMP was developed (Chapter II). Finally, a selection is given of examples of application, hitherto described in literature.

It can be concluded that the k_0-standardization method has now grown into an operational tool in (n,γ) reactor neutron activation analysis. It is, on the whole, experimentally simple, flexible, accurate, traceable, and suitable for computerization.

Although not directly related to the k_0-standardization method, the present work offered the possibility of deriving 2200 ms^{-1} cross-sections [σ_0] for all the (n,γ) reactions under study, based on the "activation method"

(Appendix). This required a critical examination of the input data for the most crucial parameters : isotopic abundances and gamma-intensities. The resulting σ_0's for 101 (n,γ) reactions were critically compared with recent literature data. Throughout, the case $^{64}Ni(n,\gamma)^{65}Ni$ is examined in detail. It had to be concluded that the quality of published σ_0-values, and their consistency with the input nuclear data, leaves much to be desired, thus discrediting to a large extent the absolute standardization method with respect to its accuracy and traceability.

SAMENVATTING

De k_0-methode, voorgesteld in dit werk als een geoptimaliseerde standaardisatietechniek, werd ontwikkeld uit bezorgdheid voor de competitiviteit van (n,γ) reactorneutronenactiveringsanalyse [NAA].

Eén van de grondslagen van de k_0-methode is de Høgdahl-conventie voor de fysico-mathematische beschrijving van de (n,γ) reactiesnelheid (Hoofdstuk I.1). Door de keuze van deze conventie kunnen (n,γ) reacties met een Westcott g-factor verschillend van één in principe niet in aanmerking genomen worden. Het kon echter aangetoond worden dat de daardoor veroorzaakte fouten klein tot verwaarloosbaar zijn, behalve voor ^{151}Eu(n,γ) en ^{176}Lu(n,γ) [van de ongeveer 120 analytisch interessante gevallen]; dit wordt beschouwd als een rechtvaardiging voor het niet toepassen van meer ingewikkelde conventies die de beoogde experimentele eenvoud in gevaar zouden brengen (Hoofdstuk VII.4).

De activeringsvergelijking - waarmee de k_0-methode grondig verbonden is - werd in dit werk uitgebreid om te voorzien in thermische en epithermische neutronenschaduw en in verschillende types van opbranding (Hoofdstuk I.2). Geschikte correctieformules worden gegeven voor beide effecten. Maar ook voor de meer fundamentele verschijnselen van vertakte activering en moeder-dochter verval werden aangepaste modificaties van de basisvergelijking uitgevoerd (Hoofdstuk I.3). Soms vereist dit de invoering van nucleaire gegevens voor activering en verval (naast de onvermijdelijke halveringstijden), die systematische fouten kunnen veroorzaken; alhoewel deze toestand in geen geval specifiek is voor de k_0-methode, werd grote aandacht besteed aan een "beste keuze" uit de literatuur van deze gegevens, eventueel leidend tot een accurate (her) bepaling in geval van twijfel, zoals voor ^{80}Br, ^{99}Mo en ^{104}Rh (Hoofdstuk VII.2). Ook de waarden voor de zojuist vermelde halveringstijden werden zorgvuldig geselecteerd uit compilatie- en evaluatiewerken, en nieuwe bepalingen werden uitgevoerd voor ^{97}Zr en ^{125m}Sn.

Er werd een beknopt overzicht gegeven van de principes en kenmerken van relatieve, "single-comparator" en absolute standaardisatie (Hoofdstuk I.3). Er kon besloten worden dat de voornaamste nadelen hiervan zijn (respectievelijk) : hoge arbeidsintensiteit (bereiding, meting en spectrumverwerking van de standaarden), rigiditeit (met betrekking tot de bestralings- en meetvoorwaarden) en inaccuraatheid (door de invoering van absolute nucleaire gegevens voor activering en verval). Deze beschouwingen leidden, in 1975, tot de lancering van de k_0-standaardisatie, waarvan de ontwikkeling gepland werd op basis van een samenwerking tussen het Instituut voor Nucleaire Wetenschappen (INW, Gent/België) en het "Central Research Institute for Physics" (KFKI,Budapest/ Hongarije). Bijgevolgd steunen de resultaten, voorgesteld in dit werk, op parallelle maar onafhankelijke experimenten, uitgevoerd met behulp van de bestralingsfaciliteiten, de telapparatuur en de rekenmachines en -methoden van beide instituten (Hoofdstuk II). Occasioneel werden bijkomende resultaten verkregen van werk uitgevoerd in andere laboratoria, zoals de "Isotope Division" in Risø/Denemarken.

De k_0-methode kan opgevat worden hetzij als een absolute standaardisatie (flexibel en experimenteel eenvoudig) waarin de soms onzekere absolute nucleaire gegevens vervangen zijn door een samengestelde nucleaire constante - de k_0- factor -, die op een accurate wijze experimenteel kan bepaald worden, hetzij als een "single-comparator" techniek (accuraat en experimenteel eenvoudig) die flexibel gemaakt is met betrekking tot de experimentele voorwaarden (Hoofdstuk I.3). De fundamentele principes en parameters van de k_0-methode werden

uitgestippeld, en het wordt benadrukt dat - hierop gebaseerd - epicadmium NAA [ENAA] eveneens mogelijk is. Voor deze toepassing is de kennis nodig van de Cd-transmissiefactor voor epithermische neutronen, waarvoor literatuurwaarden voor 60 (n,γ) reacties gecompileerd en geëvalueerd werden, en waarvoor nieuwe metingen uitgevoerd werden voor $^{186}W(n,\gamma)$ en $^{114}Cd(n,\gamma)$ [Hoofdstuk V.3].

Vooraleer te komen tot de k_0-factor en zijn gebruik, moest eerst aandacht geschonken worden aan verschillende problemen en valstrikken die het gevolg zijn van de beoogde flexibiliteit, en die de kwaliteit van de uiteindelijke analytische resultaten in gevaar zouden kunnen brengen. Ten eerste noodzaakt het bestaan van een epithermische neutronenfluxcomponent, naast de thermische (Maxwelliaanse), tot het in rekening brengen van de hiermee geassocieerde (n,γ) activering, en er moet zelfs gecorrigeerd worden voor de niet-idealiteit van de epithermische neutronenfluxverdeling (Hoofdstuk V). Ten tweede heeft de meting van uitgebreide bronnen (monsters) op kleine afstand tot een Ge-detector twee gevolgen : de accuraatheid van de volle-energie piekdetectie-efficiëntie kan in gevaar komen (Hoofdstuk III), en een correctie voor echte coïncidentie van cascade-straling wordt onvermijdelijk (Hoofdstuk IV).

In dit werk wordt een semi-empirische maar accurate methode beschreven voor de behandeling van het probleem van de detectie-efficiëntie (Hoofdstuk III). Deze methode is gebaseerd op de experimentele bepaling van efficiënties voor puntgeometrie op grote detectorafstand (meetbaar met 1-2% accuraatheid in het analytisch relevante gamma-energiegebied), gevolgd door omrekening hiervan (via het computerprogramma SOLANG) naar de voorhanden zijnde geometrische configuratie. Deze conversie, die gebruik maakt van zogenaamde effectieve ruimtehoeken - rekening houdend met gamma-attenuatie effecten -, vereist dat de Ge-detector en de bron cylindrisch symmetrisch zijn, en dat de volgende parameters gekend zijn : bron- en detectorafmetingen, de bron-detector afstand, de dikte van alle tussengelegen absorbers, en de absorptiecoëfficiënten (een functie van de gamma-energie) van alle relevante materialen. Uit een onderzoek van de practische toepasbaarheid bleek dat geen onovermkomelijke obstakels te verwachten zijn, en er werd experimenteel aangetoond dat de accuraatheid van de conversie beter is dan $\sim$ 2%. Uiteraard gelden deze conclusies enkel voor cylindrische Ge-detectoren met gespecificeerde geometrische parameters, waarvan de straal, de dikte van de n-laag en de afstand tot het venster de meest cruciale zijn. Deze hindernis wordt echter zo goed als uit de weg geruimd door een aantal gelukkige omstandigheden : de toenemende beschikbaarheid van dit type detectoren (wegens de overredingskracht uitgaande van goed gedocumenteerde studies), de mogelijkheid om de numerieke gegevens voor de meest cruciale parameters aan te passen (door vergelijking van experimentele en berekende conversiefactoren, een absolute vereiste voor kwaliteitsgarantie), en het feit dat de hierboven vermelde onzekerheid van $\sim$ 2% aanzienlijk gereduceerd wordt naar de analytische resultaten toe (vooral wanneer monster en monitor op dezelfde detectorafstand gemeten worden).

Er wordt een uitgebreid overzicht gegeven van de analytische belangrijke effecten veroorzaakt door echte coïncidentie : γ-γ coïncidentiesommatie, en - meer gedetailleerd - γ-γ en γ-KX coïncidentieverlies. Het wordt aangevoerd dat voor conventionele Ge(Li) of p-type Ge detectoren, met een dalende efficiëntie bij energieën beneden $\sim$ 100 keV, γ-KX coïncidentie slechts vanaf ^{175}Hf moet beschouwd worden (waar KX $\geq$ 50-60 keV). Er werden mathematische procedures ontwikkeld voor de correctie van gemeten piekoppervlakten, en criteria werden opgesteld voor de relevantie van echte coïncidentie-effecten, met de

bedoeling niet meer verlies aan accuraatheid toe te laten dan een paar tienden percent. Er werd aandacht besteed aan speciale problemen, zoals vertraagde γ-γ emissie, som-oppervlakteberekening van elkaar overlappende pieken en identieke gamma-straling uitgezonden door zowel de moeder- als de dochterisotoop. De gevallen van coïncidentiesommatie en -verlies voor de relevante gamma's van 152 analytisch interessante radionucliden werden verzameld in een gebruikersgeoriënteerde tabel, samen met geassocieerde nucleaire gegevens die zorgvuldig geselecteerd werden uit de literatuur. Bij wijze van voorbeeld werden tevens reële coïncidentiecorrectiefactoren getabelleerd. De experimentele parameter nodig voor coïncidentiecorrectie is de totale detectie-efficiëntie, die kan verkregen worden uit deling van de piek detectie-efficiëntie door de piek-tot-totaal verhouding. Deze verhouding kan bepaald worden door meting van enkele "coïncidentievrije" bronnen met een geschikte spreiding van de gamma-energieën (bv. ^{241}Am, ^{109}Cd, ^{57}Co, ^{203}Hg, ^{137}Cs en ^{65}Zn). Tenslotte kon de accuraatheid van de correctie voor echte coïncidentie - via experimentele controle - geschat worden op $\sim$ 1.5% gemiddeld.

De bijdrage van epithermische activering wordt grondig behandeld (Hoofdstuk V). Het wordt aangetoond dat onaanvaardbare systematische fouten gemaakt worden wanneer aangenomen wordt dat de epithermische neutronenfluxverdeling de ideale 1/E afhankelijkheid volgt. Daarom werd de $1/E^{1+\alpha}$ afhankelijkheid voorgesteld als een meer realistische benadering. Dit vereist de invoering zowel van de parameter α - een maat voor de afwijking van de idealiteit -, als van het begrip effectieve resonantie-energie ($\bar{E}_r$). Er kon aangetoond worden - gebaseerd op beschouwingen over foutenpropagatie - dat $\bar{E}_r$-waarden, in principe een functie van α, mogen beschouwd worden als nucleaire constanten, die te berekenen zijn uit resonantieparameters. Er werd eveneens bewezen dat de toepasbaarheid van het $\bar{E}_r$-concept onafhankelijk is van de keuze van een referentie-energie - hier 1 eV. Tenslotte werden de $\bar{E}_r$-waarden voor 126 analytisch interessante (n,γ) reacties gecompileerd. De principes en onzekerheden (en hun propagatie) van de experimentele α-bepaling werden grondig onderzocht, en drie mogelijke technieken worden voorgesteld : de "Cd-covered multi-monitor"-methode (geschikt voor in-situ bepaling in ENAA), de "Cd-ratio for multi-monitor"-methode (geschikt voor a priori bepaling), en de "bare multi-monitor"-methode (geschikt voor in-situ bepaling in NAA). Een volgend onderzoeksgebied was de experimentele bepaling van f, de thermische tot epithermische neutronenfluxverhouding. Er werd aangetoond dat, naast de welbekende techniek van de cadmiumverhouding (geschikt voor a priori bepaling), de "bare bi-isotopic monitor"-methode met Zr (^{95}Zr en ^{97}Zr) uitstekend geschikt is voor dit doel, in het bijzonder voor in-situ bepaling in NAA. In-situ α-bepaling volgens de "bare triple-monitor"-methode wordt bovendien mogelijk wanneer Au (^{198}Au) als een derde monitor toegevoegd wordt. Een volgend te beschouwen punt is de accuraatheid van de Q_0-waarden (de verhoudingen van de resonantie-integralen tot de thermische werkzame doorsneden). De gevolgde strategie bestond uit de kritische evaluatie van literatuurwaarden - gebaseerd op een vergelijking van k_0-factoren -, en de experimentele bepaling (aan het KFKI en het INW) gebaseerd op metingen van de Cd-verhouding. Dit leidde tot een compilatie van "aangenomen" Q_0-waarden voor 107 (n,γ) reacties, waarbij een diepgaande vergelijking gemaakt werd met eerder gecompileerde en geëvalueerde gegevens. Gezien de belangrijkheid van Zr werden grote inspanningen geleverd om te komen tot zeer accurate waarden van Q_0- en van de epithermische neutronenzelfschaduw - voor de hierboven vermelde Zr-isotopen. Tenslotte werd de kwaliteit onderzocht van de

correctie voor epithermische activering, en werd de geldigheid van de $1/E^{1+\alpha}$ en $\bar{E}_r$ concepten bewezen door experimentele controle in verschillende bestralingsposities van de reactoren Thetis (Gent), WWR-M (Budapest) en DR-3 (Risø); een uitgebreide berekening van de foutenpropagatie toonde aan dat de residuele onzekerheid op de analytische resultaten gemiddeld van de orde is van $\sim$ 1% (vanwege Q_0), $\sim$ 1.5% (vanwege α) en $\sim$ 1% (vanwege f).

Er werd eveneens aandacht besteed aan een aantal specifieke problemen (Hoofdstuk VII). Er werd een evaluatie uitgevoerd van de practische gevolgen van eerste-orde interferenties - in het bijzonder van (n,n') activering -, en de gemiddelde werkzame doorsneden voor de reacties $^{117}Sn(n,n')^{117m}Sn$ en $^{135}Ba(n,n')^{135m}Ba$ werden experimenteel bepaald. Naast de voorzorgen die kunnen genomen worden om de storende effecten van eerste-orde interferenties te vermijden, wordt aangevoerd dat deze met een aanvaarde accuraatheid kunnen gecorrigeerd worden - tenminste voor gunstige gevallen -, door meting van de snelle-fluxcomponent via de $^{90}Zr(n,2n)^{89}Zr$ drempelreactie. Vervolgens was de mogelijke variabiliteit van de neutronenflux gedurende bestraling een zeer ernstig te nemen verschijnsel. Wiskundige behandeling van het probleem toonde aan dat de effecten op de accuraatheid eerder gering zijn en dat er bovendien kan voor gecorrigeerd worden. Nochtans moest besloten worden dat een niet-evalueerbare fluxvariabiliteit gedurende bestraling de werkelijk beperkende factor is voor de toepasbaarheid van de k_0-standaardisatiemethode. Tenslotte werden geschikte formules ontwikkeld om het hoofd te bieden aan de situatie van onderbroken bestralingen; de accuraatheid wordt niet significant aangetast op voorwaarde dat het experimenteel werk naar behoren uitgevoerd wordt.

Het epicentrum van dit werk is de experimentele bepaling van k_0-factoren - meer bepaald van $k_{0,Au}$-factoren, aangezien ze betrekking hebben op Au als comparator [$^{197}Au(n,\gamma)^{198}Au$], die meebestraald wordt als een verdunde Au-Al legering (Hoofdstuk VI). Er werd speciaal gelet op het verkrijgen van betrouwbare en accurate resultaten, en naast andere voorzorgen was het cooperatief maar onafhankelijk werk uitgevoerd aan het INW en het KFKI absoluut essentieel, omdat het toeliet systematische fouten te detecteren en te elimineren. Er worden experimentele details getoond van k_0-metingen voor de relevante gamma's van 112 analytisch interessante radionucliden. De meeste k_0's konden "gerecommandeerd" worden, met een accuraatheid beter dan 2% (gemiddeld $\sim$ 1%). Wegens eerder genoemde redenen, werd bijzondere aandacht besteed aan de k_0-factoren van de Zr-isotopen.

Het was mogelijk, gebaseerd op alle hierboven vermelde resultaten en beschouwingen, een evaluatie uit te voeren van de accuraatheid, de "traceability" en de praktische toepasbaarheid van de k_0-standaardisatiemethode (Hoofdstuk VIII). Met inachtneming van alle opgesomde foutenbronnen, leverde een a priori schatting van de accuraatheid een waarde op beneden de 4%. Dit kon bevestigd worden door analyseresultaten van een aantal referentiematerialen. "Traceability" is een speciaal probleem omdat er geen algemeen aanvaarde definitie voorhanden is. Ondanks deze moeilijkheid kon aangetoond worden - door nauwkeurig onderzoek van alle stappen en parameters van de k_0-methode - dat de "traceability" gegarandeerd wordt zowel voor certificatiewerk als voor routine-analysen; een "conditio sine qua non" is uiteraard dat het "k_0-protocol" correct gevolgd wordt. Anderzijds is het duidelijk dat de absolute standaardisatiemethode hoegenaamd niet "traceable" is, wegens de "ondoorzichtigheid" van de vereiste nucleaire gegevens. Om de toepasbaarheid van de k_0-methode te verhogen, werden alle relevante gegevens samengebracht in een gebruikersgeoriënteerde tabel. Ook het te volgen analytisch protocol werd

scherp uiteengezet. In dit verband moet opgemerkt worden dat, voor het uitvoeren van de talrijke en ingewikkelde berekeningen, het gebruik van een computerprogramma aangewezen is : aldus werd aan het INW de computercode SINGCOMP ontwikkeld (Hoofdstuk II). Tenslotte wordt een selectie gegeven van toepassingen die tot dusver in de literatuur beschreven werden.

Er kan besloten worden dat de k_0-standaardisatiemethode thans uitgegroeid is tot een bruikbaar hulpmiddel in (n,γ) reactorneutronenactiveringsanalyse. Over het geheel genomen is de methode experimenteel eenvoudig, flexibel, accuraat, "traceable", en geschikt voor computerverwerking.

Alhoewel niet rechtstreeks in verband met de k_0-standaardisatiemethode, bood dit werk de mogelijkheid om, gebaseerd op de "activeringsmethode", 2200 ms^{-1} werkzame doorsneden [σ_0] te bepalen voor alle bestudeerde (n,γ) reacties (Appendix). Dit vereiste een kritisch onderzoek van de invoergegevens voor de meest cruciale parameters : isotopische voorkomens en gammaintensiteiten. De bekomen σ_0's voor 101 (n,γ) reacties werden kritisch vergeleken met recente literatuurgegevens. Als leidraad werd het geval ^{64}Ni (n,γ)^{65}Ni grondig bestudeerd. Er moet besloten worden dat de kwaliteit van de gepubliceerde σ_0-waarden, en hun consistentie met de nucleaire invoergegevens, veel te wensen overlaat, zodat de absolute standaardisatiemethode sterk in diskrediet gebracht wordt wegens onvoldoende accuraatheid en "traceability".

RESUME

Soucieux de la compétitivité de l'analyse par activation (n,γ), dite NAA, avec d'autres méthodes de détermination efficaces, on propose dans le présent ouvrage la méthode k_0 comme technique de standardisation optimale.

Une des bases de la méthode k_0 est la convention de Høgdahl pour la description physico-mathématique du taux de réaction (n,γ) [Chap. I.1]. On reconnaît pleinement qu'en choisissant cette convention, des réactions (n,γ) avec un facteur g Westcott s'écartant de l'unité sont en principe à exclure de toute considération. Il est toutefois démontré que les erreurs ainsi suscitées sont minimes voire négligeables, à l'exception de $^{151}Eu(n,\gamma)$ et de $^{176}Lu(n,\gamma)$ [parmi quelques 120 cas intéressants du point de vue analytique]. On juge ces considérations suffisantes pour justifier le rejet de conventions plus complexes qui risqueraient de compromettre le but visé, à savoir l'élaboration d'une méthode expérimentale qui soit simple (Chap. VII.4).

Dans le présent ouvrage, l'équation d'activation - à laquelle la méthode k_0 est intimement liée - a été élargie pour tenir compte du phénomène d'autoabsorption des neutron thermiques et épithermiques ainsi que des différents types de "burn-up" (Chap. I.2). Pour ces deux phénomènes, des formules de correction appropriées sont fournies. Egalement pour le phénomène plus fondamental d'activation avec embranchement et de filiations radioactives, des modifications appropriées des équations fondamentales ont été élaborées (Chap. I.3), ce qui a quelquefois nécessité l'introduction de données nucléaires pour l'activation et la décroissance (en plus des inévitables périodes), qui pourraient être responsables d'erreurs systématiques. Bien que cet inconvénient ne soit pas du tout spécifique à la méthode k_0, on a porté une attention particulière à la sélection du "meilleur choix" de la littérature ad hoc (App.3), allant même jusqu'à déterminer à nouveau certaines valeurs en cas de doute, comme c'est le cas pour le ^{80}Br, le ^{99}Mo et le ^{104}Rh (Chap. VII.2). Quant aux périodes dont il est question ci-dessus, elles aussi ont été soigneusement sélectionnées à partir d'ouvrages de compilation et d'évaluation, tandis que pour le ^{97}Zr et le ^{125m}Sn de nouvelles valeurs ont été mesurées.

Les principes et les caractéristiques des méthodes de standardisation relative, monocomparateur et absolue ont été brièvement passés en revue (Chap. I.3). On en a conclu que les principales entraves en étaient respectivement la masse de travail et le caractère laborieux des opérations (préparation, comptage et traitement du spectre gamma des standards), l'inflexibilité (à l'égard des conditions d'irradiation et de comptage) et l'inexactitude (par l'introduction de données nucléaires absolues pour l'activation et la décroissance). Ces considérations ont conduit en 1975 au lancement du concept de la standardisation k_0, projeté pour être développé par l'Institut des Sciences Nucléaires (INW) de Gand, Belgique, en coopération étroite avec l'Institut Central de Recherches Physiques (KFKI) de Budapest, Hongrie. Par conséquent, les résultats mentionnés dans cet ouvrage se basent sur des essais parallèles, mais tout à fait indépendants, effectués par ces deux institutions en faisant usage des facilités d'irradiation, des instruments de comptage et des ordinateurs et des méthodes informatiques disponibles dans leurs centres respectifs (Chap. II). De temps à autres, des résultats complémentaires furent obtenus par des travaux de recherche effectués dans d'autres laboratoires, tels que la Division Isotope de Risø au Danemark.

La méthode k_0 peut être interprétée de deux façons : comme une standardisation absolue (flexible et simple à appliquer), dans laquelle les données nucléaires absolues, dont certaines incorporant une très grande incertitude, ont été remplacées par une seule constante nucléaire composée, à savoir le facteur k_0, expérimentalement déterminable avec un très haut degré d'exactitude, ou comme une technique monocomparateur (exacte et simple à appliquer), rendu flexible à l'égard des conditions d'expérimentation (Chap. I.3). Les principes et paramètres fondamentaux de la méthode k_0 sont esquissés dans les grandes lignes. On attire l'attention sur le fait qu'en se basant sur ces mêmes principes et paramètres, il est également possible d'effectuer le NAA sous cadmium [ENAA], mais que pour ce dernier type d'application il est indispensable d'avoir un paramètre supplémentaire, à savoir le facteur de transmission Cd des neutrons épithermiques. En plus, de nombreuses données puisées dans la littérature ad hoc ont été compilées et évaluées pour 60 réactions (n,γ), pour ne pas oublier les nouvelles mesures effectuées pour $^{186}W(n,\gamma)$ et $^{114}Cd(n,\gamma)$ [Chap. V.3].

Avant d'arriver au facteur k_0 et ses applications particulières, l'attention est attirée sur les problèmes et les pièges que pourrait comporter la flexibilité visée et qui le cas échéant pourraient nuire à la qualité des résultats finaux des analyses. C'est ainsi que l'existence d'une composante de flux de neutrons épithermiques en plus du flux thermique (Maxwellien) exige qu'on tienne compte de l'activation (n,γ) qui y est associée, et requiert une correction pour l'effet de la distribution non idéale du flux de neutrons épithermiques (Chap. V). Ensuite, le comptage de sources étendues (échantillons) à faible distance du détecteur Ge comporte deux conséquences : l'exactitude de la valeur de l'efficacité d'absorption totale peut devenir précaire (Chap. III) d'une part, et d'autre part rend inévitable une correction pour tenir compte de la coïncidence réelle des radiations en cascade (Chap. IV).

Dans le présent ouvrage on décrit une méthode exacte bien que semi-empirique pour aborder le problème de l'efficacité de détection (Chap. III). Elle se fonde sur la détermination expérimentale des valeurs d'efficacité des sources ponctuelles se trouvant à une grande distance du détecteur (faisable avec une exactitude de 1 à 2% dans le domaine de l'énergie gamma analytiquement valable), suivie de la conversion, programmable à l'aide d'un ordinateur (programme SOLANG), de ces valeurs dans la configuration géométrique donnée. Cette conversion, qui fait usage d'angles solides "effectifs" et inclut les effets d'atténuation gamma, demande toutefois que le détecteur Ge ainsi que la source aient une forme cylindrique, parfaitement symétrique et que les dimensions de la source et du détecteur soient connues, ainsi que la distance entre les deux, l'épaisseur de tous les atténuateurs interposés et les coefficients d'absorption (en fonction de l'énergie gamma) de tous les matériaux concernés. L'examen de l'applicabilité pratique a révélé que des obstacles insurmontables n'étaient pas à craindre et que l'inexactitude de la conversion (expérimentalement prouvée) ne dépasse pas $\sim$ 2%. Il va de soi que ces affirmations ne tiennent que pour des détecteurs Ge cylindriques, avec des paramètres géométriques bien définis; le rayon, l'épaisseur de la couche n et la distance de la fenêtre étant à cet égard les paramètres les plus cruciaux. Heureusement quelques faits sont venus atténuer l'importance de cet obstacle, à savoir la disponibilité grandissante de ce genre de détecteur (fabricants finalement convaincus à coup de demandes avec documents à l'appui), la possibilité d'ajustement des

valeurs numériques des paramètres les plus importants (en comparant les facteurs de conversion expérimentaux à ceux obtenus par calcul, la condition sine qua non pour la sauvegarde de la qualité), ainsi que le fait que l'inexactitude de $\sim$ 2% dont il est question ci-dessus a pu être réduite de façon significative à l'égard des résultats d'analyse (en particulier, lorsque l'échantillon et le moniteur sont mesurés à une distance identique du détecteur Ge).

Un large aperçu est donné des effets de coïncidence réelle analytiquement valables : gain de comptage dû aux coïncidences de sommation γ-γ et perte due aux coïncidences γ-γ et γ-KX, cette dernière étant expliquée plus en détail. On démontre que pour les détecteurs conventionels Ge(Li) ou HPGe du type p, dont l'efficacité décroît rapidement aux énergies inférieures à $\sim$ 100 keV, les cas de coïncidence γ-KX ne devraient être pris en considération qu'à partir de ^{175}Hf (KX $\gtrsim$ 50-60 keV). Des algorithmes ont été développés pour la correction des pics gamma mesurés et des critères ont été établis pour juger de la validité des effets de coïncidence réelle - visant une perte d'exactitude n'excédant pas quelques dixièmes de pourcentage. Une attention particulière a été consacrée à certains problèmes spéciaux tels que l'émission de rayons γ-γ retardée, le calcul de multiplets des pics d'addition ainsi que le problème d'émission de rayons gamma identiques pour les deux, l'isotope-père et l'isotope-fils. Quant aux gammas valables de 152 radionucléides analytiquement intéressants, les cas de coïncidence de sommation et de perte ont été rassemblés dans un tableau à l'usage des utilisateurs, avec indication des données nucléaires associées, soigneusement sélectionnées à partir de la littérature ad hoc. On donne également, à titre d'exemple, les valeurs numériques des facteurs de correction de coincidence, relevées sur "le vif". Le paramètre expérimental indispensable pour permettre cette correction est l'efficacité de détection totale qu'on peut obtenir en divisant l'efficacité d'absorption totale par le rapport pic au total. On démontre que ce dernier peut être déterminé en comptant quelques sources exemptes de coïncidences avec un étalement approprié des énergies gamma (par exemple, ^{241}Am, ^{109}Cd, ^{57}Co, ^{203}Hg, ^{137}Cs et ^{65}Zn). Finalement, l'exactitude de la correction pour coïncidence réelle a pu être établie comme étant d'environ 1.5% en moyenne sur base de vérifications expérimentales.

La contribution de l'activation épithermique est traitée en détail (Chap. V). On prouve que l'hypothèse selon laquelle la distribution du flux de neutrons épithermiques suivrait la dépendence idéale 1/E conduit à des erreurs systématiques inacceptables. C'est pourquoi on propose la dépendence $1/E^{1+\alpha}$ comme approximation plus réaliste. Ce qui rend indispensable l'introduction non seulement du paramètre α - une mesure de la déviation de l'idéal -, mais également du concept de l'énergie de résonance effective $\bar{E}_r$. En se basant sur les considérations de la propagation d'erreurs, on démontre que les valeurs $\bar{E}_r$, en principe une fonction de α, peuvent être considérées comme étant des constantes nucléaires, pouvant être calculées à partir de paramètres de résonance. On apporte également la preuve que l'application du concept $\bar{E}_r$ ne dépend aucunement du choix de l'énergie de référence - en l'occurence 1 eV. Finalement, on dresse la liste des valeurs $\bar{E}_r$ pour 126 réactions (n,γ) analytiquement intéressantes. Quant à la détermination experimentale de α, on en examine ici soigneusement les principes et les incertitudes (et leur propagation) et on propose trois techniques possibles : la

L' "épicentre" de ce travail est la détermination expérimentale des facteurs k_0, et plus spécifiquement des facteurs $k_{0,Au}$, étant donné qu'ils se réfèrent à l'Au en tant que comparateur [$^{197}Au(n,\gamma)^{198}Au$], qui est irradié avec les éléments à l'étude comme un alliage dilué Au-Al (Chap. VI). Il a fallu procéder avec un soin minutieux pour obtenir des résultats fiables et exactes : parmi les nombreuses précautions prises figure notamment le travail en coopération, indépendant toutefois, entre l'INW et le KFKI, une mesure absolument essentielle étant donné qu'elle a permis de détecter et d'éliminer les erreurs systématiques. On montre ainsi les détails expérimentaux des mesures k_0 pour les gammas valables de 112 radionucléides analytiques. La plupart de ces k_0 sont "recommandés" avec une exactitude établie ne dépassant pas 2% (environ 1% en moyenne). Pour les raisons expliquées précédemment, le plus grand soin a été consacré à la détermination des facteurs k_0 des isotopes Zr.

Sur le base des résultats expérimentaux et des considérations énumérées ci-dessus, il a été possible d'évaluer l'exactitude, la traçabilité et l'applicabilité de la méthode de standardisation k_0 (Chap. VIII). En tenant compte de toutes les sources d'erreurs mentionnées antérieurement, une estimation à priori de l'inexactitude de la méthode k_0 a donné une valeur ne dépassant pas 4%. Ceci a pu être confirmé par les résultats d'analyse d'un certain nombre de matériaux de référence. La traçabilité est un problème un peu spécial dans ce sens qu'il n'existe aucune définition généralement approuvée. Malgré cette difficulté on a pu démontrer - en vérifiant la méthode k_0 pas par pas et paramètre par paramètre - que la traçabilité possible est adéquate sous tous les rapports, pour le travail de certification comme pour l'analyse de routine. La condition sine qua non étant bien entendu que le protocole k_0 soit suivi à la lettre. D'autre part on établit clairement que la méthode de standardisation absolue, par contre, est intraçable à cause de l' "intransparance" des données nucléaires requises. Pour souligner l'applicabilité de la méthode k_0 on a estimé necessaire de rassembler toutes les données ad hoc dans un tableau à l'usage des utilisateurs. Le protocole d'analyse à suivre pas à pas a également été clairement tracé. Dans ce contexte il faut noter que l'on conseille l'utilisation d'un ordinateur pour réaliser les calculs qui sont nombreux et complexes. Dans ce but l'INW a d'ailleurs développé le programme SINGCOMP (Chap. II). Pour finir on donne une liste d'examples pratiques d'applications réalisées, jusqu'à présent décrites dans la littérature ad hoc.

Pour conclure on peut affirmer que la méthode de standardisation k_0 est devenue un outil opérationel pour l'analyse par activation neutronique. Cette méthode est, somme toute, expérimentalement simple à appliquer, flexible, exacte et traçable tout en se prêtant à l'utilisation d'un ordinateur.

Bien que nullement en relation directe avec la méthode de standardisation k_0, le présent ouvrage conduit en outre aux valeurs des sections efficaces à 2200 ms^{-1} [σ_0] pour toutes les réactions (n,γ) étudiées, basées sur la méthode d'activation (Annexe). Ceci a rendu indispensable un examen critique de toutes les valeurs utilisées pour les paramètres les plus importants, c'est-à-dire les abondances isotopiques et les intensités gamma. Les σ_0's qui en résultent pour 101 réactions (n,γ) ont été comparés avec les données de récentes publications. On en conclut que la qualité des valeurs σ_0 publiées et leur compatibilité avec les données nucléaires requises laissent beaucoup à désirer, rendant ainsi dubieuse, dans une large mesure, la méthode de standardisation absolue du point de vue exactitude et traçabilité.

méthode dite "Cd-covered multi-monitor" (qui convient pour le contrôle in situ dans l'ENAA), la méthode dite "Cd-ratio for multi-monitor" (adaptée pour une détermination à priori), et la méthode dite "bare multi-monitor" (qui convient pour le contrôle in situ dans le NAA). Le sujet suivant concerne la détermination expérimentale de f, c'est-à-dire du rapport du flux thermique/épithermique. On y révèle qu'à côté de la technique bien connue du rapport cadmium (qui convient pour une détermination à priori), la méthode dite "bare bi-isotopic monitor" qui fait usage de Zr (en l'occurence ^{95}Zr et ^{97}Zr) est la méthode par excellence pour le cas visé, surtout s'il s'agit de contrôles in situ dans le NAA. En plus, lorsque l'on fait usage d'Au (^{198}Au) comme troisième moniteur, le contrôle de α in situ suivant la méthode dite "bare triple-monitor" devient également possible. L'exactitude des valeurs Q_0 (le rapport de l'intégral de résonance à la section efficace thermique) fut un autre point à prendre en considération. L'évaluation critique des données puisées dans les publications ad hoc, en se basant sur la comparaison des facteurs k_0, et la détermination expérimentale (à Gand et à Budapest), basée sur les mesures du rapport Cd, furent les stratégies suivies. Ceci a conduit à compiler des valeurs "adoptées" de Q_0 pour 107 réactions (n,γ), y compris une comparaison détaillée avec des données précédemment compilées et évaluées. En vue du rôle prépondérant du Zr, des efforts considérables ont été faits pour arriver à des valeurs très exactes de Q_0 - et également de l'auto-absorption des neutrons épithermiques - pour les isotopes Zr mentionnés ci-dessus. Enfin, on a examiné la qualité de la correction pour l'activation épithermique : on démontre la validité des concepts $1/E^{1+\alpha}$ et $\bar{E}_r$ par un contrôle expérimental dans plusieurs positions d'irradiation des réacteurs Thetis (Gand), WWR-M (Budapest) et DR-3 (Risø); des calculs poussés de la propagation d'erreurs démontrent que l'incertitude résiduelle sur les résultats d'analyse est de l'ordre d'environ 1% (due à Q_0), d'environ 1.5% (due à α) et d'à-peu-près 1% (due à f), en moyenne.

Un certain nombre d'autres problèmes spécifiques sont également passés en revue (Chap. VIII). Les interférences primaires - spécialement celles dues à l'activation (n,n') - sont évaluées par rapport à leurs conséquences pratiques. Les section efficaces moyennes des neutrons de fission, précédemment inconnues, pour les réactions $^{117}Sn(n,n')^{117m}Sn$ et $^{135}Ba(n,n')^{135m}Ba$ ont été expérimentalement déterminées. A côté des précautions qu'on peut prendre pour éviter les erreurs causées par les interférences primaires, on soutient que ces interférences peuvent encore être corrigées avec une exactitude acceptable - tout au moins dans les cas favorables - par la mesure de la composante du flux de fission au moyen de la réaction de seuil $^{90}Zr(n,2n)^{89}Zr$. La variabilité possible du flux de neutrons au cours de l'irradiation fut le prochain point à prendre sérieusement en considération. Le traitement mathématique du problème a révélé que les effets qui en résultent pour l'exactitude sont assez faibles et se laissent le cas échéant facilement corriger. Il faut toutefois en conclure que si la variabilité du flux pendant l'irradiation ne peut être évaluée, ce facteur entrave l'applicabilité de la méthode de standardisation k_0. Finalement des équations valables sont développées pour faire face au problème de l'irradiation intermittente. On estime qu'aucune perte d'exactitude significative n'est à craindre, à condition toutefois que le travail expérimental soit convenablement fait.