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Papers presented

at the

IAEA Specialists' Meeting on the

Development of an International Nuclear Decay Data and Cross-Section Database

Vienna, 24-28 October 1994

H.D. Lemmel (ed.)

IAEA NUCLEAR DATA SECTION, WAGRAMERSTRASSE 5, A-1400 VIENNA

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Abstract: The present report contains 20 papers presented at the IAEA meeting on the Development of an International Nuclear Decay Data and Cross-Section Database, Vienna, 24-28 October 1994, covering the following topics: Wall-charts of nuclides, PC systems presenting nuclear data, nuclear decay-data and uncertainties, nuclear spectroscopy, thermal neutron cross-sections and resonance-integrals, reactor-neutron activation analysis, nuclear data standards.

List of papers

Note: A minus sign in the page column indicates that the paper is not reproduced in the present report.

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Introduction

The IAEA Specialists Meeting on the Development of an International Nuclear Decay Data and Cross-Section Database took place at the Vienna International Center, 24-28 October 1994.

For a summary report with the conclusions and recommendations see report INDC(NDS)-328.

The present report contains most of the papers presented at this Specialists' Meeting.

1. Charts of Nuclides

Page

Status and future plans for the „Karlsruher Nuklidkarte", prepared by

Institut für Radiochemie, Kernforschungszentrum Karlsruhe
P.O.B. 3640
D-76021 Karlsruhe

Report to the IAEA Specialist's Meeting on the Development of an International Nuclear Half-Life and Cross-Section Database

Aim of the „Karlsruher Nuklidkarte":

This chart (wallchart and folded desk version with information booklet) is mainly intended to give a survey over all observed radionuclides, their half-lives and decay modes together with basic information on type and energy of the emitted radiation. It covers the interests of and is requested by schools, students, teachers, nuclear energy and technology plants, and many nuclear scientists. It was and is not intended to implement or replace complete and/or evaluated data bases (e.g. Nuclear Data Sheets, Lederer, etc.), which have to be used anyway, if more detailed and specific information is needed. Selection of data to be included is on the basis of Nuclear Data Sheets and other compilations, and on the original literature, especially for new nuclides. In cases of multiple data for one item some kind of „evaluation" (i.e. decision for one of the values or an average) is done on a more or less subjective basis.

Present status:

A new edition of the chart is presently prepared, which includes all the newly detected nuclides since the last edition of 1981. Furthermore, some relevant changes taken from more recent editions of Nuclear Data Sheets (and some original publications) are applied. Also, recommended half-life values e.g. from IAEA Techn. Reports and Documents are used preferentially. The new (6.) edition with the same layout and the same information range as the former ones will probably be available at the beginning of 1995. In addition, we will try to update an already existing computer readable file of the 1981 edition, which contains all numerical and layout information (like position, size, and colour of fields and subfields etc.) in coded form (this file was originally intended to be used as input for automated typesetting and printing of future editions). According to several demands, we will eventually prepare - in co-operation with a suitable group or company - a PC version of the chart enabling a display of selectable portions of the chart. No further retrieval, evaluate, or compare functions are planned and meaningful, when regarding the defined (and restricted) range of information of our chart.

Future plans:

Firstly, there are no plans to increase the range of information e.g. by giving specific intensities, uncertainties, groundstate spins etc., mainly due to lack of interest of our „customers", of manpower, and of space on the limited format of the wall chart. In addition, also a change of the used „data base" seems not useful to us, since it will be very difficult to prepare a complete chart on the basis of an (at least at the beginning) very small evaluated data base and an ample amount of non-evaluated and mostly less accurate data. Everybody interested in extended and/or more accurate data will anyway have to go into special compilations and literature.

Furthermore, it is presently unclear, whether or not there will be possible any future activities in the field of nuclear decay data. This is mainly due to the fact that the „Kernforschungszentrum Karlsruhe" has changed its research areas; nuclear research will be only a minor contribution in the future. And last but not least, miss Pfennig, who is the main „promoter" of all past and present editions of the chart, will retire next year, and nobody with her experience will be available to continue this work. Consequently, the only foreseeable activities will be the production and distribution of the new 6. edition and eventually some reprinting after a couple of years, if there will be sufficient interest (presently still several hundred copies of the wall chart and several thousand copies of the booklet with folded chart per year of the old **fifth** edition).

We regret that there are no better perspectives for our future activities, and we can only offer some co-operation on the basis of our existing data and procedures - as far as our (very limited) time and manpower will permit.

With our best wishes for a successful meeting and special greetings to our „old" friends and colleagues from the EXFOR-groups,

sincerely

(Gerda Pfennig and Hanns Klewe-Nebenius)

Kernforschungszentrum Karlsruhe

Institut für Radiochemie

The Activities of Nuclear Data Center of JAERI in the Evaluation of Nuclear Decay Data and Cross-Section Data for Nuclear Wall-Chart

J. Katakura
Nuclear Data Center
Japan Atomic Energy Research Institute

1. Introduction

The nuclear data evaluation has been performed at Nuclear Data Center (NDC) of Japan Atomic Energy Research Institute (JAERI) in cooperation with Japanese Nuclear Data Committee (JNDC). The major effort of the data evaluation activities aims at providing a complete set of neutron reaction data. The JENDL-3.2 file[1] was released at the end of June 1994 as a results of the effort and is used as a general purpose file for nuclear technology field in Japan.

The decay data evaluation has also been carried out. There are two kinds of activities for the decay data evaluation. The first one is for decay heat estimation of nuclear reactors to which many short-lived nuclides contribute. The decay data of most of the short-lived nuclides have not or partly been measured and are estimated using a model calculation of a nuclear theory. The JNDC nuclear data library of fission products[2], which contains the decay data of fission products, measured and estimated ones, can produce a good decay heat estimation for various fissioning nuclides. The second one is for the international network of nuclear structure and decay data evaluation. The database produced by the network effort is known as the Evaluated Nuclear Structure and Decay Data File (ENSDF). The Japanese group has a responsibility for A=118-129 mass chain evaluation. The evaluations of A=123, 125 and 126 were published in Nuclear Data Sheets[3] last year.

Under those activities, "Chart of the Nuclides" has been published every 4 years from late 1970's by JNDC and Nuclear Data Center of JAERI[4].

Apart from the JNDC activities, Japan Radioisotope Association has commercially published a booklet[5] of isotopes which contains information about important radioisotopes such as half-life, decay mode, beta, gamma and/or alpha energy and branching ratio, main production reaction neutron cross section, fission yield and other data for shielding, dose estimation and so on. Some JNDC members contribute to the compilation of the booklet. The first edition was published in 1959 and the present edition (the 8th edition) in 1990. The next edition is planned to be published next year.

2. "Chart of the Nuclides" by JNDC

Japanese Nuclear Data Committee published "Chart of the Nuclides" in 1977 as the first edition. After released the second version in 1980, new edition has been released every 4 years coincident with the year of the Olympic Games. The newest edition was released in 1992 and the next one is planned to be published in 1996.

The chart has the size of 2 m x 29.2 cm and are folded 20 cm x 29.2 cm for easy carrying. The limit of the size forces the data contained in the chart to be minimal. The data on the chart are following:

(1) Natural abundance,
(2) Half-life, and
(3) Decay mode.

The branching ratio of each decay mode is not explicitly given, but indicated symbolically for a categorized group. For the half-life, it is given not only for nuclides with measured data, but also for ones without measured data even if they are not synthesized yet. These half-lives are estimated by a model calculation[6].

On the back of the chart, a periodic table, conversion tables for time and energy, fundamental constants, physical constants of elements and gamma-ray intensity standards for important nuclides are listed as a form of table.

3. Data Necessary for Reference Chart of the Nuclides

Needless to say the data expected to be contained in a chart depend on what kind of chart we want to make. At least the above mentioned data are considered to be essential even if whatever chart we choose. Though the JNDC chart does not give numerical branching ratios even if more than two decay modes exist, they should be given numerically. In addition to those data, cross section data are also helpful for a person who wants to use a chart as a quick-reference to look for a way producing a nuclide. Above all the neutron cross section data, especially at thermal region, which is important for nuclear reactor technology, are useful. For a person interested in the reactor technology, fission yield data are also useful. The yield data are given in the GE chart[7]. However, the field of persons interested in the chart seems to be more extended. So it is better, if possible, to include the data not only for neutron induced reactions but also for proton, deuteron, alpha induced reactions and so on. In this case it seems to be rather difficult to determine what reaction types are included and at what energies the cross sections are given.

In conclusion, the following data should be considered to be contained in the chart.

(1) Natural abundance,
(2) Spin-parity
(3) Half-life,
(4) Decay mode and branching ratios,
(5) Energies and intensities of main beta, gamma, and/or alpha rays (or average decay energies)
(6) Thermal neutron cross section (and g-factor, resonance integral),
(7) Fission yield (cumulative yield), and
(8) Cross section of proton, deuteron, etc.

Of these data the items (1) through (4) might have high priority over the others. The item (8) is less important than the others.

4. Summary

As mentioned above, the JAERI Nuclear Data Center has maintained the activities in the evaluation of decay data of radioactive isotopes and neutron cross sections. For the work of the database the JAERI/NDC can contribute to the items (1) through (6) given in the above section. However, as there would be lots of nuclides in the chart, suitable division of the covered nuclides is needed and a part of it can be taken charge by Japan. The fission product region is suitable for us.

In order to make the cooperation effective, we propose to establish a Coordinate Research Program.

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Chart of the Nuclides for Windows©

A Brief Information

Introduction

The "Chart of the Nuclides" is a Microsoft (MS) Windows® PC (IBM-compatible) software package. It presents/searches some of the fundamental nuclides' properties in a graphical, "user-friedly" way. The Chart of the Nuclide data base has been formed from the NUDAT data files.

Brief History

The "Chart of the Nuclides" was conceived, mainly as a complementary software to the nuclear analytical softwares **GANAAS** (gamma spectrum analysis and neutron activation analysis software), **QXAS** (Quantitative XRF analysis software), etc. available from the Physics Section. It has also been developed with the purpose of using it for the IAEA Technical Cooperation programme (TC projects and TC Training courses).

It was designed for small laboratories or individual persons in developing countries, having mostly PCs available and performing nuclear analytical calculations, commonly in need of reliable nuclear data.

It was written, using the "Chart of the Nuclides" wall-chart, released by Karlsruhe Kernforschungszentrum in 1981 (the amount of displayed nuclides and their colour representations are the same), as an example.

The nuclear data shown on it was retrieved from NUDAT data library available at IAEA NDS. It is intended to continue to be consistent with NUDAT, which at the same time is consistent with ENSDF data base.

What is the "Chart of the Nuclides" software?

The software presents, in a graphical way, all the nuclides (according to the Karlsruhe wall-chart edition).

The normal way to look for an information is based on a "point-and-click" mode using a pointer device (e.g PC mouse).

Three main modes are available for presentation/search of data:

1.  Nuclear properties of the nuclides
2.  Decay radiations
3.  Gamma rays adopted properties

Nuclear Properties Mode

This is the default mode. The following nuclear properties are shown:

- Abundance, in %
- Mass excess, as M-A in MeV
- Decay mode
- Half live
- Decay brach, in %
- Decay Q, in MeV

Decay Radiations Mode

The following nuclear properties for each radiation decay record are shown, while working on this mode

- Decay mode
- Half live
- Radiation type
- Radiation energy, in KeV (End-point energy for β-)
- Radiation intesinty, in %
- Dose, in GrRad/μCi-h

Adopted Gammas Mode

The following nuclear properties for a selected nuclide are shown, while working on this mode

- Energy of the gamma-ray, in KeV
- Intensity of the transition (Branching Ratio), in %

- Energy level of the origin, in KeV
- Year of publication in Nuclear Data Sheets

There are two search modes:

- by Nuclide
- by Energy for Adopted Gammas mode

Some Technical details

The "Chart of the Nuclides" has been written in MS Visual Basic with some modules in MS C. It runs under MS Windows version 3.00 or a later version.

Minimum hardware requirements:

An IBM compatible PC with 386 or later microprocessor (486DX microprocessor at 33 MhZ with 4 Mbytes RAM and up, is recommended for reasonable speed), Colour (SVGA) display terminal and 6 Mbytes free of hard disk space.

Contact Person:

V. Osorio
Physics Section, IAEA
Room: A2310, ext.1706
Email: OSORIOFE@RIPO1.IAEA.OR.AT
RIO@IAEA1.IAEA.OR.AT

☞ **Important Note:** This software is not yet finished. It is still under development.

2. Decay Data

Page

A U.S. decay-data evaluation project and how it can relate to the IAEA plans

R. G. Helmer (INEL), E. Browne (LBL), and M. R. Schmorak (ORNL)

As a bit of introduction, Eddie Browne, Marcel Schmorak, and I do evaluations of nuclear structure data for ENSDF and the Nuclear Data Sheets. During the last year, we have obtained approval of the US Nuclear Data Network and the IAEA Advisory Group on the Coordination of the Nuclear Structure and Decay Data Evaluators' Network to carry out a special project to provide high-quality decay-data evaluations for about 250 radionuclides that are of interest to applied users. It is our plan to do these evaluations on a cooperative basis with two or three groups outside of the United States.

Two of the features of this effort will be the explicit definition of policies on which the choices of supporting information are based and the inclusion of detailed comments with each radionuclide stating the assumptions used and the decisions made. We hope that this will allow the other evaluators to accept our results or to make specific suggestions that would make the evaluations acceptable.

To date we have initiated a survey of users to determine what radionuclides they considered important. We have also created some partial evaluations to generate dialogue among ourselves concerning our methodology and policies.

In those cases where we are treating the same radionuclides, our project can support this IAEA effort by providing our results to it.

DECAY DATA EVALUATIONS AND UNCERTAINTIES

A L Nichols[1] and T D MacMahon[2]

[1] AEA Technology, 353 Harwell, Didcot, Oxfordshire OX11 0RA, UK

[2] Centre for Analytical Research in the Environment, Imperial College at Silwood Park, Ascot, Berks SL5 7TE, UK

ABSTRACT

A number of radioactive decay data libraries have been assembled in the UK for use in the nuclear power industry:

(i) Fission Product Decay Data (UKFPDD-2),
(ii) Activation Product Decay Data (UKPADD-3),
(iii) Heavy Element and Actinide Decay Data (UKHEDD-2).

Some of these libraries continue to be maintained, and are used to underpin the multinational data files to be found within JEF 2.2 (Joint Evaluated File based at the NEA Data Bank). The UK evaluations in recent years are reviewed, along with exploratory studies on the handling of data uncertainties.

1 INTRODUCTION

Within the UK nuclear power industry, radionuclide decay data libraries are required for a wide range of reactor-related calculations. The broad definition of such data requirements includes:

(i) fission product yields,
(ii) decay data for fission products, activation products, heavy elements and actinides,
(iii) delayed neutron data,
(iv) (α, n) production rates,
(v) (n, x) production rates.

Focus has been placed in this review on the decay data needed to assist in the design and operation of reactors, fuel transport and reprocessing, and waste disposal. Reactor fuel cycle calculations require such data to quantify decay heat, shielding requirements and address waste disposal issues. Requests can be made in the UK for the evaluation and recommendation of specific decay data, and authoritative libraries have been assembled and are being maintained. The preparation of accessible data files permits users to concentrate on the particular technical problems associated with their modelling calculations, without needing to become concerned about or involved in any time-consuming accumulation of the relevant decay data.

2 DECAY DATA FILES

The UK decay data libraries used over the previous 15 years are documented in the open literature and various accessible laboratory reports (1-4). Some of these evaluated data files have subsequently been incorporated into the Joint Evaluated File (JEF 2.2(5)). While UK evaluation effort has not been expended to update the fission product decay data library, both the activation product and heavy element/actinide decay data libraries have been developed further in the 1990s, as reported below.

2.1 Activation Product Decay Data (UKPADD-3)

The UK Activation Product Decay Data Library (UKPADD-2) was established in 1993, and ENDF-6 format was adopted (3). Significant improvements were made in the recommended data as a consequence of a wide range of relevant decay-data measurements, including a multinational programme during the late 1980s which was carried out under the auspices of the IAEA Coordinated Research Programme on the Measurement and Evaluation of X-ray and Gamma-ray Standards for Detector Calibration (6). It was judged appropriate to undertake a comprehensive evaluation of the decay data for 236 radionuclides as requested by various specialists within the UK nuclear industry (7), including calibrant standards as well as reactor-based activation products. UKPADD-2 has been extended to include a further 91 radionuclides from specific (n, x) reactions in the core region, as identified by Yamamuro and Iijima (8), along with Rn-223. The full contents of this new library (UKPADD-3) are listed in Table 1, with the completion dates of the individual evaluations (month/year). Work continues on these data files as indicated in the table (i.e. no entry for "Date of Evaluation" means evaluation is on-going, and some re-evaluations will also be made for specific radionuclides of low mass number).

2.2 Heavy Element and Actinide Decay Data (UKHEDD-2)

The UK Heavy Element and Actinide Decay Data Library (UKHEDD-2) was assembled in 1991, and ENDF-6 format was adopted (4). New evaluations for this library occurred after a multinational measurement exercise undertaken during the early 1980s, as formulated by an IAEA Coordinated Research Programme on the Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data. A series of laboratory studies were carried out under the auspices of this Coordinated Research Programme, resulting in significant improvements in the quality of specific decay data. This multinational effort and equivalent work undertaken by other specialists over the same period of time was reviewed and published in 1986 (9). It was judged appropriate to undertake a comprehensive re-assessment of the decay data on the basis of these improvements, and this work was completed in 1991. The contents of UKHEDD-2 are listed in Table 2, along with the completion dates of the various evaluations (month/year).

3 DECAY DATA EVALUATIONS

Evaluation efforts involved assessments of data for the following parameters:

(i) half-life,
(ii) total decay energies (Q-values),
(iii) branching fractions,

(iv) alpha-particle energies and emission probabilities,
(v) beta-particle energies, emission probabilities and transition types,
(vi) electron capture energies, electron capture transition and positron emission probabilities, and transition types,
(vii) gamma-ray energies, emission probabilities and internal conversion coefficients,
(viii) spontaneous fission data including prompt and gamma-ray spectra.

The spin and parity of the decaying nuclide were also defined, and uncertainties were assigned to all of the evaluated data. Other data in the files (mean energies, discrete electrons and mean x-rays) were calculated from the above data by using the processing code COGEND (10, 11). The component contributions to the average energies (beta, electromagnetic and heavy particle) were also derived from the evaluated input data by COGEND, which contains libraries of fluorescence yields, Auger-electron energies, mean x-ray energies and electron-wave-function ratios from which capture ratios can be calculated.

A semi-automatic evaluation strategy was adopted which also included a general series of data manipulations:

(i) all decay modes of each radioactive nuclide were specified in terms of both the branching fractions and Q-values;

(ii) sum of all α, β^-, β^+/electron-capture and isomeric gamma-ray emission probabilities were consistent with the corresponding branching fractions;

(iii) gamma-ray emission probabilities must be the photon probabilities per disintegration;

(iv) when the internal conversion of a gamma-ray transition was significant, theoretical internal conversion coefficients were adopted if experimental data were unavailable;

(v) internal-conversion coefficients for gamma-ray transitions were consistent with both the photon and total transition probabilities, i.e. (photon + conversion electron) emission probabilities = total transition probability;

(vi) every effort was made to ensure that there was a reasonable balance between the population and de-population of all excited levels in the decay schemes;

(vii) type of beta transition had to be taken into account when calculating the mean beta energies from the evaluated end points;

(viii) energies and emission probabilities of conversion electrons, Auger electrons, x-rays and annihilation radiation were derived in a consistent manner.

Both the UKPADD-3 and UKHEDD-2 libraries have been generated in ENDF-6 format (12). There is a general information section for each nuclide which contains:

(i) name of the evaluator and date of the evaluation (month and year),
(ii) list of references used to construct the recommended data set,

(iii) detailed comments associated with the evaluation,
(iv) consistency check of the evaluated data.

Any serious problems encountered during an evaluation are described in the comments section associated with each nuclide in the library. If the resulting decay scheme has any outstanding problems, a statement can be made to the effect that further measurements are required.

The recommended decay data are contained within the main data section. Every effort has been made to produce consistent and comprehensive data sets. When necessary, the theoretical internal conversion coefficients tabulated by Band et al (13), Hager and Seltzer (14), and Rösel et al (15) have been used in conjunction with the evaluated gamma-ray data. Nuclear binding energies and Q-values can be obtained from the tabulations of Wapstra et al ((16) and unpublished tabulations), while x-ray data are derived from energy and emission probability data (17, 18). It should also be noted that the evolution of a consistent and reasonably comprehensive decay scheme may involve the postulation of some transitions that have not been experimentally observed. This is particularly the situation for beta-particle and electron-capture transitions that have been calculated from the gamma-ray transition probabilities and normalisation factor, since these 'missing' data can be important in estimating both the beta and gamma energies per decay.

The consistency of the recommended data in all of decay schemes has been determined by calculating the percentage deviation between the effective Q-value and the calculated Q-value:

(i) effective Q-value $= \sum_{i=1}^{\text{all BF}} Q_i \, BF_i$

where Q_i and BF_i are the Q-value and branching faction of the i-th decay mode (i.e. weighted sum of the evaluated Q-values of the radionuclide),

(ii) calculated Q- value

$$= \sum_{i}^{\text{all } \alpha} E_{\alpha_i} P_{\alpha_i} + \sum_{j}^{\text{all } \beta} E_{\beta_j} P_{\beta_j} + \sum_{k}^{\text{all } \gamma} E_{\gamma_k} P_{\gamma_k} + \sum_{l}^{\text{all x-rays}} E_{x_l} P_{x_l} + \text{etc}$$

where E_{α_i}, E_{β_j}, E_{γ_k}, E_{x_l}, etc and P_{α_i}, P_{β_j}, P_{γ_k}, P_{x_l} etc are the energies and emission probabilities of the i-th alpha particle, j-th beta particle, k-th gamma ray, l-th x-ray etc of the individual decay process.

Percentage deviations above 5% are regarded as high and imply a poorly defined decay scheme; a value of less than 5% indicates the construction of a reasonably consistent decay scheme. The consistency of the decay data incorporated into the UKPADD-3 and UKHEDD-2 libraries to date are listed in Tables 3 and 4. Some of the most recently evaluated data sets await processing by the end of 1994, and therefore consistency values are unavailable.

4 DATA UNCERTAINTIES

Initial decay schemes are constructed for each radionuclide from a suitable combination of the various data sources. The normal evaluation procedure is as follows:

(i) assess the status of the existing data,
(ii) identify data discrepancies,
(iii) evaluate and recommend decay data.

All available measurements are generally taken into account during an evaluation, including experimental data from journals, laboratory reports and even private communications. Comprehensive statements of the precise evaluation procedure are prepared after each assessment, as well as details of any changes made to the data reported in the original references. Such an exercise requires a detailed consideration of the uncertainties in the measured data.

Specific notations are used below to quantify the various forms of uncertainty that can be adopted to quantify the accuracy of the decay data. Relevant formulae are listed in the appendix at the end of the paper.

4.1 Limitation of the relative statistical weight

The data-handling procedure adopted for UKPADD-3 and UKHEDD-2 is based on the methodology which was used to calculate the half-life and gamma-ray emission probability data and their uncertainties during the IAEA Coordinated Research Programme on the Measurement and Evaluation of X-ray and Gamma-ray Standards for Detector Calibration (6). If possible, no individual measurement is allowed to contribute more than 50% to the sum of weights when more than one value of the same parameter is reported, and the uncertainty of the datum is increased if necessary. A flow diagram for this method of analysis is shown in Fig 1. If the set of accepted experimental data proves to be inconsistent, one of several possibilities can be adopted:

(i) recommend the unweighted mean,

(ii) reject some measured values on the basis of objective or subjective judgements (e.g. inappropriate calibration procedure or ill-defined measurement techniques employed by the metrologist),

(iii) change the weights.

An appropriate method of changing weights is preferred rather than outright rejection of data. If the reduced χ^2 is within the acceptable range (i.e. $\chi^2/(N-1) \leq 2$), the weighted mean is recommended as the evaluated value. However, if the data set reveals inconsistencies after adjustment (i.e. $\chi^2/(N-1) > 2$), the choice of either the weighted or unweighted mean will depend on whether or not the error bars (expressed as one standard deviation) on each mean encompasses the other. This method was proposed by Zijp (19), and is defined as the "limitation of the relative statistical weight".

Several other procedures have been assessed and tested by Kafala et al (20), and are summarised below.

4.2 Outlier rejection using Chauvenet's criteria (21)

The limiting value p of the deviation from the unweighted mean of a single observation (in units of s) is given as a function of the number of experiments performed. When this limiting value is exceeded, the relevant measurement is considered as an outlier, i.e. any value outside the range $x_u \pm ps$ is rejected, where p is given by:

$$p = 0.91772 + 1.0168 \log N.$$

4.3 Uniform chi-square inflation

For a given set of data, a weighted mean and "internal error" σ_w are calculated if the data pass a chi-square test at the 5% significance level. If the chi-square test fails, the final uncertainty is estimated by multiplying σ_w by a factor equal to $\sqrt{\chi^2/(N-1)}$ so that the final uncertainty becomes the external error.

4.4 Iterative extensive weighting

Zijp (19) introduced the concept of the extensive weighting approach to deal with discrepant data sets. When the value of χ^2/(N-1) > 1, the total variance for the result from the i-th laboratory is increased to the sum of the external variance (σ_e^2) and the internal variance (σ_i^2). The modified statistical weight (w_i') becomes:

$$w_i' = \frac{1}{(\sigma_e^2 + \sigma_i^2)}.$$

The procedure can be repeated in iterative mode until χ^2 falls within the acceptable range.

4.5 Bayesian technique

A Bayesian procedure has been proposed by Gray et al (22). Nothing is assumed to be known about the extent to which the experimentalists estimated their uncertainties incorrectly, and therefore an uninformative prior density is used as an error probability density function. The recommended value is the weighted mean ($\bar{x}$) with a standard deviation given by:

$$\sqrt{\frac{\chi^2}{N-3}}\,\sigma_w.$$

4.6 Normalised residuals method

The normalised residuals method was introduced by James et al (23) in which only the uncertainties of the discrepant data are adjusted. Any such discrepant values are identified on the basis of the normalised residual (R_i) which is defined as:

$$R_i = \sqrt{w_i W / (W - w_i)} \cdot (x_i - \bar{x}).$$

A limiting value of the normalised residual (R_o) for a set of N values is defined as:

$$R_o = \sqrt{1.8 \ln N + 2.6} \quad \text{for } 2 \leq N \leq 100.$$

If any value in the data set has $|R_i| > R_o$, the weight of the value with the largest R_i is reduced until its normalised residual falls to R_o. This procedure is repeated until no normalised residual is greater than R_o.

4.7 Rajeval technique

Rajput and MacMahon (24) proposed a technique which shares the same basic principle as that of James et al (23) in that only the more discrepant data are adjusted. This procedure is divided into three stages.

(a) Population test stage-outliers are detected in the data set by calculating the quantity y_i:

$$y_i = \frac{x_i - x_{ui}}{\sqrt{\sigma_i^2 - \sigma_{ui}^2}}.$$

x_{ui} is the unweighted mean of all the data set excluding x_i, and σ_{ui} is the standard deviation associated with x_{ui}. The critical value of $|y_i|$ is 1.96 at the 5% significance level for a two-tailed test. Measurements with $|y_i| > 3 \times 1.96$ are considered as outliers and may be excluded from further stages in the evaluation.

(b) Inconsistent measurements that remain in the data set after the population test are revealed by calculating a standardized Z_i:

$$Z_i = \frac{x_i - \bar{x}}{\sqrt{\sigma_i^2 - \sigma_w^2}}.$$

For each Z_i the probability integral

$$P(z) = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} \exp\left(\frac{-t^2}{2}\right) dt.$$

is determined (values of P(z) may be obtained from normal distribution tables). The absolute difference between P(z) and 0.5 is a measure of the central deviation (CD). A critical value of the central deviation (cv) can be determined from the following expression:

$$cv = \left[(0.5)^{N/(N-1)}\right] \text{ for } N \geq 2;$$

(c) If the central deviation of any value is greater than the critical value, that value is regarded as inconsistent. The uncertainties of the inconsistent values are adjusted to σ_i':

$$\sigma_i' = \sqrt{\sigma_i^2 + \sigma_w^2}\,.$$

This requires an iteration procedure; each time σ_w is recalculated and added in quadrature to the uncertainties of those values with CD > cv. The iteration process is terminated when all CD < cv.

4.8 Additional Comments

Co-variance analysis techniques have been recommended to assist in the evaluation of decay scheme data. However, there is insufficient expertise and effort available to produce and maintain evaluated decay-day files, and the concept of producing co-variance matrices for individual parameters would exceed world-wide man-power capabilities. While the necessary correlations could be developed to assist greatly in assessing uncertainties at the measurement stage, the adoption of co-variance matrices in a complex evaluation of a multi-parameter decay scheme can only be viewed as questionable.

Kafala et al (20) tested all of the above procedures defined in Sections 4.1 to 4.7, using computer-generated data sets containing various types of inconsistency. Altogether 36,000 data sets were generated and subjected to analysis by each of the procedures. Overall, the authors found that the most reliable method was a modification of the Bayesian procedure where the standard deviation of the weighted mean was adjusted to

$$\sqrt{\frac{\chi^2}{N-2}} \cdot \sigma_w$$

Although this procedure produced the best overall results with the computer-generated data sets, the application of this method of analysis to half-life data showed that difficulties could arise in particular cases. The main problem is the use of the weighted mean as the recommended value. In certain data sets, the weighted mean can be heavily influenced by one or a few discrepant values, making it necessary to return to one of the other methods outlined above, such as the Rajeval or normalised residuals methods which deal specifically with such discrepancies. It is essential therefore that each data set is critically examined by the evaluator and that the results of applying various evaluation techniques are investigated and assessed. Only then can confidence be placed on a recommended value and the associated uncertainty.

5 CONCLUSIONS

The evaluation of a consistent set of data for a specific parameter to give a weighted mean and standard deviation is straightforward. However, an inconsistent data set poses a number of significant difficulties. Several manipulatory procedures have been suggested, and these methods have been applied to representative sets of data (20). It is stressed that the judgement and discretion of the evaluator continue to play an important role in the final recommended data. This judgement involves an understanding and appreciation of the limitations in the various experimental techniques. While decisions on the validity of the

measured data are subjective, statistical techniques are being developed and implemented to assist and speed-up this process of assessment. There is also an important advantage in agreeing on a common method of analysis and assessment: greater consistency can be achieved between disparate evaluations as attempted in specific IAEA Coordinated Research Programmes (6, 9).

Libraries of recommended decay data have been prepared in the UK that are based on subjective assessments of the published experimental and theoretical data, coupled with calculations of the recommended values using limited statistical weights ($\leq 50\%$) as adopted for the IAEA Coordinated Research Programme on the Measurement and Evaluation of X-ray and Gamma-ray Standards for Detector Calibration (6). The UK files are primarily for application in the nuclear power and processing industries and have been prepared in ENDF-6 format for over 320 activation products and 126 heavy elements and actinides. The resulting evaluated data sets represent significant improvements in the quality of the recommended decay parameters. Several inconsistencies have been identified in the decay data, and further efforts are required to resolve these difficulties. Such detailed evaluations require extensive efforts, and hence the recommended files have been submitted to the NEA Data Bank for possible international usage in JEF (Joint Evaluated File).

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Table 1: Summary of Activation Product Decay Data in UKPADD-3 Library

Nuclide	Decay Modes	Date of Evaluation (month/year)
1-H-3	β^-	October 1982
2-He-6	β^-	October 1982
2-He-8	β^-, β^- n (0.12)	October 1982
3-Li-8	$\beta^-\alpha$	April 1992
3-Li-9	β^-, β^- n (0.495)	April 1992
4-Be-7	EC	October 1982
4-Be-8	α	April 1992
4-Be-10	β^-	October 1982
4-Be-11	β^-, $\beta^-\alpha$ (0.030)	October 1982
5-B-12	β^-, $\beta^-\alpha$ (0.0158)	October 1982
5-B-13	β^-, β^- n (0.00276)	October 1982
6-C-14	β^-	October 1982
6-C-15	β^-	October 1982
7-N-13	EC	October 1982*
7-N-16	β^-, $\beta^-\alpha$ (0.0000120)	October 1982
8-O-19	β^-	October 1982
9-F-18	EC	October 1982*
9-F-20	β^-	October 1982
10-Ne-23	β^-	October 1982
11-Na-22	EC	November 1982
11-Na-24	β^-	November 1982
11-Na-24m	IT, β^- (0.005)	November 1982
11-Na-25	β^-	October 1982
11-Na-26	β^-	November 1982
12-Mg-27	β^-	November 1982
12-Mg-28	β^-	November 1982
13-Al-26	EC	November 1982*
13-Al-26m	EC	November 1982*
13-Al-28	β^-	November 1982
13-Al-29	β^-	November 1982
13-Al-30	β^-	November 1982
14-Si-31	β^-	November 1982
14-Si-32	β^-	November 1982
15-P-32	β^-	November 1982
15-P-33	β^-	November 1982

Nuclide	Decay Modes	Date of Evaluation (month/year)
15-P-34	β^-	November 1982
16-S-35	β^-	November 1982
16-S-37	β^-	November 1982
17-Cl-34	EC	November 1982*
17-Cl-34m	EC (0.52), IT (0.48)	December 1982*
17-Cl-36	β^-, EC (0.019)	December 1982
17-Cl-38	β^-	December 1982
17-Cl-38m	IT	November 1982
18-Ar-37	EC	December 1982
18-Ar-39	β^-	December 1982
18-Ar-41	β^-	January 1983
18-Ar-42	β^-	December 1982
19-K-38	EC	December 1982*
19-K-38m	EC	December 1982*
19-K-40	β^-, EC (0.107)	December 1982
19-K-42	β^-	February 1983
19-K-43	β^-	December 1982
19-K-44	β^-	March 1990
20-Ca-41	EC	December 1982
20-Ca-45	β^-	January 1992
20-Ca-47	β^-	April 1992
20-Ca-49	β^-	December 1982
21-Sc-44	EC	January 1983
21-Sc-44m	IT, EC (0.0123)	January 1983
21-Sc-46	β^-	February 1983
21-Sc-46m	IT	February 1983
21-Sc-47	β^-	December 1991
21-Sc-48	β^-	February 1983
21-Sc-49	β^-	December 1982
21-Sc-50	β^-	January 1992
21-Sc-50m	IT, β^- (0.0125)	January 1992
22-Ti-45	EC	April 1992
22-Ti-51	β^-	January 1992
23-V-48	EC	February 1983
23-V-49	EC	February 1983
23-V-52	β^-	January 1992

Nuclide	Decay Modes	Date of Evaluation (month/year)
23-V-53	β^-	April 1992
23-V-54	β^-	April 1992
24-Cr-49	EC	January 1983
24-Cr-51	EC	August 1989
24-Cr-55	β^-	February 1992
25-Mn-53	EC	November 1993
25-Mn-54	EC	December 1991
25-Mn-56	β^-	January 1992
26-Fe-53	EC	January 1992
26-Fe-53m	IT	January 1992
26-Fe-55	EC	January 1992
26-Fe-59	β^-	December 1991
26-Fe-60	β^-	January 1994
27-Co-55	EC	February 1992
27-Co-56	EC	April 1992
27-Co-57	EC	January 1992
27-Co-58	EC	July 1991
27-Co-58m	IT	July 1991
27-Co-60	β^-	December 1991
27-Co-60m	IT, β^- (0.0025)	January 1994
28-Ni-57	EC	January 1992
28-Ni-59	EC	December 1991
28-Ni-63	β^-	July 1990
28-Ni-65	β^-	December 1991
28-Ni-66	β^-	August 1993
29-Cu-62	EC	February 1992
29-Cu-64	EC, β^- (0.3886)	January 1992
29-Cu-66	β^-	January 1992
29-Cu-67	β^-	August 1993
30-Zn-63	EC	March 1991
30-Zn-65	EC	January 1990
33-As-74	EC (0.66), β^- (0.34)	October 1990
34-Se-75	EC	January 1990
35-Br-79m	IT	February 1990
35-Br-80	β^-, EC (0.083)	September 1990
35-Br-80m	IT	September 1990

Nuclide	Decay Modes	Date of Evaluation (month/year)
35-Br-82	β^-	December 1989
35-Br-82m	IT, β^- (0.024)	December 1989
36-Kr-79	EC	January 1990
36-Kr-79m	IT	January 1990
36-Kr-81	EC	May 1994
36-Kr-81m	IT, EC (0.000025)	May 1994
36-Kr-83m	IT	October 1993
36-Kr-85	β^-	April 1994
36-Kr-85m	β^-, IT (0.211)	April 1994
37-Rb-83	EC	October 1993
37-Rb-84	EC, β^- (0.032)	February 1994
37-Rb-84m	IT	August 1993
37-Rb-86	β^-, EC (0.000052)	April 1994
37-Rb-86m	IT	April 1994
38-Sr-83	EC	October 1993
38-Sr-83m	IT	October 1993
38-Sr-85	EC	February 1992
38-Sr-85m	IT, EC (0.134)	February 1992
38-Sr-89	β^-	January 1991
38-Sr-90	β^-	May 1994
39-Y-88	EC	March 1990
39-Y-89m	IT	January 1991
39-Y-90	β^-	February 1992
39-Y-90m	IT	February 1992
39-Y-91	β^-	April 1994
39-Y-91m	IT	April 1994
40-Zr-88	EC	May 1994
40-Zr-89	EC	January 1991
40-Zr-89m	IT, EC (0.0666)	January 1991
40-Zr-93	β^-	April 1990
40-Zr-95	β^-	November 1990
41-Nb-91	EC	April 1994
41-Nb-91m	IT, EC (0.024)	April 1994
41-Nb-92	EC	September 1993
41-Nb-92m	EC	September 1993
41-Nb-93m	IT	April 1990

Nuclide	Decay Modes	Date of Evaluation (month/year)
41-Nb-94	β^-	January 1990
41-Nb-94m	IT, β^- (0.0050)	January 1990
41-Nb-95	β^-	November 1990
41-Nb-95m	IT, β^- (0.034)	November 1990
42-Mo-93	EC	March 1990
42-Mo-93m	IT, EC (0.0012)	March 1990
42-Mo-99	β^-	October 1990
43-Tc-99	β^-	July 1990
43-Tc-99m	IT, β^- (0.000037)	July 1990
44-Ru-103	β^-	May 1990
45-Rh-102	EC	December 1990
45-Rh-102m	EC (0.75), β^- (0.20), IT (0.05)	December 1990
45-Rh-103m	IT	May 1994
45-Rh-104	β^-, EC (0.0045)	June 1990
45-Rh-104m	IT, β^- (0.0013)	June 1990
45-Rh-105	β^-	January 1994
45-Rh-105m	IT	January 1994
46-Pd-103	EC	May 1994
46-Pd-107	β^-	November 1993
46-Pd-107m	IT	November 1993
47-Ag-105	EC	January 1994
47-Ag-105m	IT, EC (0.0034)	January 1994
47-Ag-106	EC, β^- (0.005)	January 1994
47-Ag-106m	EC	January 1994
47-Ag-107m	IT	July 1990
47-Ag-108	β^-, EC (0.029)	October 1990
47-Ag-108m	EC, IT (0.087)	January 1992
47-Ag-109m	IT	March 1990
47-Ag-110	β^-, EC (0.0030)	November 1991
47-Ag-110m	β^-, IT (0.0127)	November 1991
47-Ag-111	β^-	July 1994
47-Ag-111m	IT, β^- (0.005)	July 1994
48-Cd-109	EC	March 1990
48-Cd-111m	IT	January 1991
48-Cd-113	β^-	January 1991
48-Cd-113m	β^-, IT (0.0012)	January 1991

Nuclide	Decay Modes	Date of Evaluation (month/year)
48-Cd-115	β^-	May 1994
48-Cd-115m	β^-	May 1994
49-In-111	EC	January 1991
49-In-111m	IT	January 1991
49-In-113m	IT	February 1991
49-In-114	β^-, EC (0.0050)	February 1992
49-In-114m	IT, EC (0.035)	February 1992
49-In-114n	IT	February 1992
49-In-115	β^-	March 1990
49-In-115m	IT, β^- (0.050)	May 1994
49-In-116	β^-	January 1992
49-In-116m	β^-	January 1992
49-In-116n	IT	January 1992
50-Sn-113	EC	February 1991
50-Sn-113m	IT, EC (0.089)	February 1991
50-Sn-117m	IT	January 1990
50-Sn-119m	IT	January 1992
50-Sn-121	β^-	January 1992
50-Sn-121m	IT, β^- (0.224)	January 1992
50-Sn-123	β^-	April 1991
50-Sn-123m	β^-	April 1991
50-Sn-125	β^-	October 1991
50-Sn-125m	β^-	October 1991
50-Sn-126	β^-	September 1990
51-Sb-119	EC	November 1993
51-Sb-120	EC	November 1993
51-Sb-120m	EC	November 1993
51-Sb-122	β^-, EC (0.0237)	July 1991
51-Sb-122m	IT	July 1991
51-Sb-124	β^-	November 1990
51-Sb-124m	IT, β^- (0.25)	December 1990
51-Sb-124n	IT	December 1990
51-Sb-125	β^-	January 1992
51-Sb-129	β^-	March 1992
51-Sb-129m	β^-, IT (0.15)	March 1992
52-Te-125m	IT	July 1991

Nuclide	Decay Modes	Date of Evaluation (month/year)
52-Te-129	β^-	June 1992
52-Te-129m	IT, β^- (0.31)	June 1992
53-I-125	EC	January 1992
53-I-126	EC (0.563), β^- (0.437)	October 1990
54-Xe-125	EC	October 1991
54-Xe-125m	IT	October 1991
54-Xe-127	EC	March 1991
54-Xe-127m	IT	March 1991
54-Xe-129m	IT	September 1994
54-Xe-131m	IT	September 1994
54-Xe-133	β^-	September 1993
54-Xe-133m	IT	September 1993
55-Cs-129	EC	September 1994
55-Cs-131	EC	September 1994
55-Cs-132	EC, β^- (0.018)	August 1994
55-Cs-134	β^-, EC (0.000003)	March 1992
55-Cs-134m	IT	March 1992
55-Cs-135	β^-	July 1991
55-Cs-135m	IT	July 1991
55-Cs-136	β^-	October 1991
55-Cs-136m	β^- (0.5), IT (0.5)	October 1991
55-Cs-137	β^-	November 1990
56-Ba-131	to be evaluated	
56-Ba-131m	to be evaluated	
56-Ba-133	EC	January 1992
56-Ba-133m	IT, EC (0.000101)	March 1992
56-Ba-137m	IT	November 1990
58-Ce-139	EC	May 1992
58-Ce-139m	IT	May 1992
60-Nd-140	EC	November 1993
60-Nd-147	β^-	June 1994
61-Pm-143	EC	November 1993
61-Pm-144	EC	August 1993
61-Pm-145	EC, α (2.8×10^{-9})	July 1991
61-Pm-146	EC (0.66), β^- (0.34)	July 1994
61-Pm-147	β^-	June 1994

Nuclide	Decay Modes	Date of Evaluation (month/year)
61-Pm-148	β^-	October 1993
61-Pm-148m	β^-, IT (0.05)	October 1993
61-Pm-149	β^-	February 1994
61-Pm-151	β^-	August 1994
62-Sm-145	EC	July 1991
62-Sm-146	α	July 1990
62-Sm-151	β^-	February 1994
62-Sm-153	β^-	August 1994
63-Eu-149	EC	February 1994
63-Eu-150	to be evaluated	
63-Eu-150m	to be evaluated	
63-Eu-152	EC, β^- (0.280)	July 1992
63-Eu-152m	β^-, EC (0.28)	July 1992
63-Eu-152n	IT	July 1992
63-Eu-154	β^-, EC (0.0002)	May 1992
63-Eu-154m	IT	May 1992
63-Eu-155	β^-	December 1991
63-Eu-156	β^-	October 1994
64-Gd-150	to be evaluated	
64-Gd-151	EC, α (10^{-8})	February 1994
64-Gd-153	EC	August 1994
65-Tb-157	EC	March 1991
66-Dy-157	EC	October 1991
66-Dy-159	EC	April 1991
70-Yb-175	β^-	December 1993
71-Lu-171	EC	March 1994
71-Lu-171m	IT	November 1993
71-Lu-172	EC	December 1993
71-Lu-172m	IT	December 1993
71-Lu-173	EC	July 1994
71-Lu-174	EC	November 1993
71-Lu-174m	IT, EC (0.0058)	November 1993
71-Lu-177	β^-	February 1994
71-Lu-177m	β^-, IT (0.226)	February 1994
72-Hf-173	EC	July 1994
72-Hf-174	α	July 1991

Nuclide	Decay Modes	Date of Evaluation (month/year)
72-Hf-175	EC	February 1992
72-Hf-177m	IT	February 1994
72-Hf-177n	IT	February 1994
72-Hf-181	β^-	January 1992
73-Ta-177	EC	September 1994
73-Ta-179	EC	March 1991
73-Ta-180	EC, β^- (0.181)	March 1991
73-Ta-180m	EC, β^- (0.20)	March 1991
73-Ta-182	β^-	December 1991
73-Ta-182m	IT	December 1991
73-Ta-182n	IT	December 1991
73-Ta-183	β^-	June 1994
74-W-178	EC	September 1994
74-W-181	EC	August 1991
74-W-183m	IT	June 1994
74-W-185	β^-	January 1991
74-W-185m	IT	January 1991
74-W-187	β^-	October 1991
79-Au-198	β^-	December 1987
79-Au-198m	IT	April 1992
80-Hg-197	EC	March 1992
80-Hg-197m	IT, EC (0.069)	March 1992
80-Hg-203	β^-	March 1991
81-Tl-201	EC	September 1993
81-Tl-202	EC	April 1994
81-Tl-204	β^-, EC (0.022)	November 1991
82-Pb-202	EC	December 1993
82-Pb-202m	IT, EC (0.091)	December 1993
82-Pb-203	EC	March 1994
82-Pb-203m	IT	March 1994
82-Pb-203n	IT	March 1994
82-Pb-204	α	November 1991
82-Pb-204m	IT	November 1991
82-Pb-205	EC	December 1993
83-Bi-207	EC	August 1991
86-Rn-223	β^-	December 1992

Nuclide	Decay Modes	Date of Evaluation (month/year)
90-Th-228	α	June 1989
90-Th-231	β^-	April 1991
93-Np-239	β^-	May 1991
95-Am-241	α, SF (3.77×10^{-12})	May 1991
95-Am-243	α, SF (3.7×10^{-11})	December 1989

* decay data to be re-evaluated, 1995.

Table 2: Summary of Heavy Element and Actinide Decay Data in UKHEDD-2 Library

Nuclide	Decay Modes	Date of Evaluation (month/year)
80-Hg-206	β^-	April 1991
81-Tl-206	β^-	April 1991
81-Tl-206m	IT	April 1991
81-Tl-207	β^-	April 1991
81-Tl-207m	IT	April 1991
81-Tl-208	β^-	April 1991
81-Tl-209	β^-	April 1991
81-Tl-210	β^-, β^- n (0.00007)	April 1991
82-Pb-205	EC	April 1991
82-Pb-209	β^-	April 1991
82-Pb-210	β^-, α (1.9×10^{-8})	April 1991
82-Pb-211	β^-	April 1991
82-Pb-212	β^-	August 1989
82-Pb-214	β^-	April 1991
83-Bi-210	β^-, α (1.32×10^{-6})	April 1991
83-Bi-210m	α	April 1991
83-Bi-211	α, β^- (0.00273)	April 1991
83-Bi-212	β^-(0.6405), α(0.3594), $\beta^-\alpha$ (0.00014)	December 1989
83-Bi-212m	α, β^- (0.10)	July 1989
83-Bi-212n	β^-	July 1989
83-Bi-213	β^-, α (0.0216)	April 1991
83-Bi-214	β^-, α (0.00021)	April 1991
83-Bi-215	β^-	April 1991
84-Po-209	α, EC (0.0026)	April 1991
84-Po-210	α	April 1991
84-Po-211	α	April 1991
84-Po-211m	α	April 1991
84-Po-212	α	May 1989
84-Po-212m	IT, ITα (0.07), α (0.06)	May 1989
84-Po-212n	α	May 1989
84-Po-213	α	April 1991
84-Po-214	α	April 1991
84-Po-215	α, β^- (0.000004)	April 1991
84-Po-216	α	August 1989
84-Po-218	α, β^- (0.0002)	April 1991

Nuclide	Decay Modes	Date of Evaluation (month/year)
85-At-215	α	April 1991
85-At-217	α, β^- (0.00012)	April 1991
85-At-218	α, β^- (0.001)	April 1991
85-At-219	α, β^- (0.03)	April 1991
86-Rn-217	α	April 1991
86-Rn-218	α	April 1991
86-Rn-219	α	April 1991
86-Rn-220	α	August 1989
86-Rn-222	α	April 1991
87-Fr-221	α	April 1991
87-Fr-223	β^-, α (0.00006)	April 1991
88-Ra-223	α	April 1991
88-Ra-224	α	July 1989
88-Ra-225	β^-	April 1991
88-Ra-226	α	April 1991
88-Ra-228	β^-	April 1991
89-Ac-225	α	April 1991
89-Ac-227	β^-, α (0.0138)	April 1991
89-Ac-228	β^-	April 1991
90-Th-227	α	April 1991
90-Th-228	α	June 1989
90-Th-229	α	April 1991
90-Th-230	α, SF (2.5×10^{-13})	April 1991
90-Th-231	β^-	April 1991
90-Th-232	α, SF (1.4×10^{-11})	April 1991
90-Th-233	β^-	April 1991
90-Th-234	β^-	April 1991
90-Th-235	β^-	April 1991
91-Pa-231	α, SF (3.0×10^{-12})	February 1986
91-Pa-232	β^-, EC (0.00003)	April 1991
91-Pa-233	β^-	April 1991
91-Pa-234	β^-	April 1993
91-Pa-234m	β^-, IT (0.0015)	April 1993
91-Pa-235	β^-	April 1991
92-U-232	α, SF (9×10^{-13})	May 1989
92-U-233	α	April 1991

Nuclide	Decay Modes	Date of Evaluation (month/year)
92-U-234	α, SF (1.7×10^{-11})	January 1986
92-U-235	α, SF (2×10^{-10})	April 1991
92-U-235m	IT	April 1991
92-U-236	α, SF (1.2×10^{-9})	April 1991
92-U-237	β^-	April 1991
92-U-238	α, SF (5.4×10^{-7})	April 1991
92-U-239	β^-	January 1991
92-U-240	β^-	April 1991
93-Np-236	EC, β^- (0.118), α (0.0016)	February 1990
93-Np-236m	EC (0.50), β^- (0.50)	February 1990
93-Np-237	α	October 1988
93-Np-238	β^-	May 1991
93-Np-239	β^-	May 1991
93-Np-240	β^-	May 1991
93-Np-240m	β^-, IT (0.0011)	May 1991
93-Np-241	β^-	October 1989
94-Pu-236	α, SF (8.5×10^{-10})	May 1989
94-Pu-237	EC, α (0.000042)	May 1991
94-Pu-238	α, SF (1.86×10^{-9})	May 1991
94-Pu-239	α, SF (4.4×10^{-12})	May 1991
94-Pu-240	α, SF (5.7×10^{-8})	May 1991
94-Pu-241	β^-, α (0.0000245)	May 1991
94-Pu-242	α, SF (5.5×10^{-6})	May 1991
94-Pu-243	β^-	May 1991
94-Pu-244	α, SF (0.00125)	May 1991
94-Pu-245	β^-	May 1991
94-Pu-246	β^-	May 1991
95-Am-240	EC, α (0.0000019)	May 1991
95-Am-241	α, SF (3.77×10^{-12})	May 1991
95-Am-242	β^-, EC (0.173)	May 1991
95-Am-242m	IT, α (0.0045), SF (1.6×10^{-10})	May 1991
95-Am-243	α, SF (3.7×10^{-11})	January 1991
95-Am-244	β^-	May 1991
95-Am-244m	β^-, EC (0.00041)	May 1991
95-Am-245	β^-	May 1991
95-Am-246	β^-	May 1991

Nuclide	Decay Modes	Date of Evaluation (month/year)
95-Am-246m	β^-	May 1991
96-Cm-241	EC, α (0.010)	May 1991
96-Cm-242	α, SF (6.33×10^{-8})	May 1991
96-Cm-243	α, EC (0.0024)	May 1991
96-Cm-244	α, SF (1.347×10^{-6})	April 1989
96-Cm-245	α	May 1989
96-Cm-246	α, SF (0.0002614)	May 1991
96-Cm-247	α	May 1991
96-Cm-248	α, SF (0.0826)	May 1991
96-Cm-249	β^-	May 1991
96-Cm-250	SF (0.70), α (0.30)	May 1991
97-Bk-249	β^-, α (0.0000145), SF (4.69×10^{-10})	May 1991
97-Bk-250	β^-	May 1991
98-Cf-249	α, SF (5.2×10^{-9})	May 1991
98-Cf-250	α, SF (0.00077)	May 1991
98-Cf-251	α	May 1991
98-Cf-252	α, SF (0.03092)	May 1991
98-Cf-253	β^-, α (0.0031)	May 1991
99-Es-253	α, SF (8.7×10^{-8})	May 1991

Table 3: Data Consistency (%) in UKPADD-3

Nuclide	UKPADD-3	Nuclide	UKPADD-3	Nuclide	UKPADD-3
1-H-3	0.0000	15-P-32	0.0000	22-Ti-45	0.0022
2-He-6	0.0000	15-P-33	0.0000	22-Ti-51	0.0073
2-He-8	incomplete	15-P-34	-0.0065	23-V-48	-0.2125
3-Li-8	0.0419	16-S-35	0.0000	23-V-49	0.0029
3-Li-9	incomplete	16-S-37	-0.0801	23-V-52	-0.0006
4-Be-7	0.0111	17-Cl-34	0.0000	23-V-53	-0.2563
4-Be-8	-0.0092	17-Cl-34m	-0.0441	23-V-54	incomplete
4-Be-10	0.0000	17-Cl-36	0.0006	24-Cr-49	-0.0171
4-Be-11	0.0915	17-Cl-38	-0.0079	24-Cr-51	0.0053
5-B-12	0.0002	17-Cl-38m	-0.0640	24-Cr-55	0.0000
5-B-13	-0.0238	18-Ar-37	-0.0007	25-Mn-53^{+}	
6-C-14	0.0000	18-Ar-39	0.0000	25-Mn-54	-0.0001
6-C-15	-0.0733	18-Ar-41	-0.0384	25-Mn-56	-0.0179
7-N-13	0.0000	18-Ar-42	0.0000	26-Fe-53	-0.2021
7-N-16	0.0589	19-K-38	0.0000	26-Fe-53m	0.1882
8-O-19	-0.1655	19-K-38m	0.0000	26-Fe-55	-0.0020
9-F-18	0.0000	19-K-40	-0.0011	26-Fe-59	-0.0172
9-F-20	0.0051	19-K-42	0.0066	26-Fe-60^{+}	
10-Ne-23	0.0183	19-K-43	-0.0474	27-Co-55	0.0305
11-Na-22	0.0018	19-K-44	0.1283	27-Co-56	0.5072
11-Na-24	0.0068	20-Ca-41	0.0035	27-Co-57	0.0020
11-Na-24m	0.0003	20-Ca-45	0.0000	27-Co-58	-0.0023
11-Na-25	0.1602	20-Ca-47	0.1213	27-Co-58m	-0.3171
11-Na-26	-0.0077	20-Ca-49	-0.0229	27-Co-60	0.0053
12-Mg-27	0.0001	21-Sc-44	0.0171	27-Co-60m^{+}	
12-Mg-28	0.1597	21-Sc-44m	0.0391	28-Ni-57	-0.0314
13-Al-26	0.0250	21-Sc-46	-0.0028	28-Ni-59	-0.0056
13-Al-26m	0.0000	21-Sc-46m	0.4710	28-Ni-63	0.0000
13-Al-28	0.0022	21-Sc-47	0.0017	28-Ni-65	0.0352
13-Al-29	-0.0207	21-Sc-48	0.0226	28-Ni-66^{+}	
13-Al-30	-0.0638	21-Sc-49	0.0000	29-Cu-62	0.0001
14-Si-31	-0.0014	21-Sc-50	-0.0075	29-Cu-64	-0.0007
14-Si-32	0.0000	21-Sc-50m	-0.0276	29-Cu-66	0.0166

Nuclide	UKPADD-3	Nuclide	UKPADD-3	Nuclide	UKPADD-3
29-Cu-67+		40-Zr-88+		47-Ag-107m	-0.0525
30-Zn-63	0.0286	40-Zr-89	0.0513	47-Ag-108	0.0204
30-Zn-65	-0.0075	40-Zr-89m	-0.0317	47-Ag-108m	-0.0190
33-As-74	-0.2919	40-Zr-93	0.0000	47-Ag-109m	-0.1873
34-Se-75	-0.1033	40-Zr-95	-0.0121	47-Ag-110	-0.0009
35-Br-79m	-0.0283	41-Nb-91+		47-Ag-110m	-0.3356
35-Br-80	-0.0134	41-Nb-91m+		47-Ag-111+	
35-Br-80m	-0.1960	41-Nb-92+		47-Ag-111m+	
35-Br-82	0.0729	41-Nb-92m+		48-Cd-109	0.0330
35-Br-82m	0.5001	41-Nb-93m	-0.3676	48-Cd-111m	-0.0834
36-Kr-79	-0.0466	41-Nb-94	-0.0014	48-Cd-113	0.0000
36-Kr-79m	-0.0728	41-Nb-94m	-0.0290	48-Cd-113m	0.0012
36-Kr-81+		41-Nb-95	0.0025	48-Cd-115+	
36-Kr-81m+		41-Nb-95m	-0.0661	48-Cd-115m+	
36-Kr-83m+		42-Mo-93	-0.0074	49-In-111	0.0372
36-Kr-85+		42-Mo-93m	0.0162	49-In-111m	-0.0507
36-Kr-85m+		42-Mo-99	-0.0098	49-In-113m	0.0014
37-Rb-83+		43-Tc-99	0.0000	49-In-114	-0.0031
37-Rb-84+		43-Tc-99m	0.0470	49-In-114m	-0.1894
37-Rb-84m+		44-Ru-103	-0.0914	49-In-114n	-0.0062
37-Rb-86+		45-Rh-102	-0.4531	49-In-115	0.0000
37-Rb-86m+		45-Rh-102m	0.0748	49-In-115m+	
38-Sr-83+		45-Rh-103m+		49-In-116	0.6261
38-Sr-83m+		45-Rh-104	0.0233	49-In-116m	0.1921
38-Sr-85	-0.0051	45-Rh-104m	-0.1843	49-In-116n	0.0632
38-Sr-85m	0.0031	45-Rh-105+		50-Sn-113	0.0204
38-Sr-89	0.0000	45-Rh-105m+		50-Sn-113m	-0.2109
38-Sr-90+		46-Pd-103+		50-Sn-117m	-0.0006
39-Y-88	0.0531	46-Pd-107+		50-Sn-119m	-0.1028
39-Y-89m	0.0024	46-Pd-107m+		50-Sn-121	0.0000
39-Y-90	0.0000	47-Ag-105+		50-Sn-121m	-0.0800
39-Y-90m	-0.0151	47-Ag-105m+		50-Sn-123	-0.0042
39-Y-91+		47-Ag-106+		50-Sn-123m	-0.0694
39-Y-91m+		47-Ag-106m+		50-Sn-125	-0.0725

Table 3 (Cont)

Nuclide	UKPADD-3	Nuclide	UKPADD-3	Nuclide	UKPADD-3
50-Sn-125m	0.1417	55-Cs-137	0.0000	64-Gd-153+	
50-Sn-126	0.0784	56-Ba-131+		65-Tb-157	1.2277
51-Sb-119+		56-Ba-131m+		66-Dy-157	-0.0226
51-Sb-120+		56-Ba-133	0.0810	66-Dy-159	0.0906
51-Sb-120m+		56-Ba-133m	-0.0816	70-Yb-175+	
51-Sb-122	0.0041	56-Ba-137m	0.0176	71-Lu-171+	
51-Sb-122m	-0.0135	58-Ce-139	0.1622	71-Lu-171m+	
51-Sb-124	-0.0495	58-Ce-139m	0.0029	71-Lu-172+	
51-Sb-124m	-0.3407	60-Nd-140+		71-Lu-172m+	
51-Sb-124n	-0.4979	60-Nd-147+		71-Lu-173+	
51-Sb-125	0.0434	61-Pm-143+		71-Lu-174+	
51-Sb-129	-0.6673	61-Pm-144+		71-Lu-174m+	
51-Sb-129m	incomplete	61-Pm-145	0.1990	71-Lu-177+	
52-Te-125m	-0.0051	61-Pm-146+		71-Lu-177m+	
52-Te-129	-0.0619	61-Pm-147+		72-Hf-173+	
52-Te-129m	-0.2257	61-Pm-148+		72-Hf-174	0.0155
53-I-125	0.0709	61-Pm-148m+		72-Hf-175	0.0337
53-I-126	0.0678	61-Pm-149+		72-Hf-177m+	
54-Xe-125	-0.0292	61-Pm-151+		72-Hf-177n+	
54-Xe-125m	0.0606	62-Sm-145	0.0659	72-Hf-181	0.0975
54-Xe-127	-0.1451	62-Sm-146	-0.0199	73-Ta-177+	
54-Xe-127m	-0.0383	62-Sm-151+		73-Ta-179	0.8418
54-Xe-129m+		62-Sm-153+		73-Ta-180	0.0321
54-Xe-131m+		63-Eu-149+		73-Ta-180m	0.1639
54-Xe-133+		63-Eu-150+		73-Ta-182	-0.0057
54-Xe-133m+		63-Eu-150m+		73-Ta-182m	0.1654
55-Cs-129+		63-Eu-152	-0.1502	73-Ta-182n	0.8531
55-Cs-131+		63-Eu-152m	-0.6753	73-Ta-183+	
55-Cs-132+		63-Eu-152n	0.0207	74-W-178+	
55-Cs-134	0.0823	63-Eu-154	0.0416	74-W-181	0.0684
55-Cs-134m	-0.0812	63-Eu-154m	0.0927	74-W-183m+	
55-Cs-135	0.0000	63-Eu-155	0.1705	74-W-185	0.0001
55-Cs-135m	-0.0280	63-Eu-156+		74-W-185m	-0.1514
55-Cs-136	-0.2422	64-Gd-150+		74-W-187	0.0631
55-Cs-136m	incomplete	64-Gd-151+		79-Au-198	0.0018

Nuclide	UKPADD-3	Nuclide	UKPADD-3	Nuclide	UKPADD-3
79-Au-198m	incomplete	82-Pb-202m+		86-Rn-223	-0.3329
80-Hg-197	0.1285	82-Pb-203+		90-Th-228	0.0122
80-Hg-197m	0.6335	82-Pb-203m+		90-Th-231	-0.7156
80-Hg-203	0.0271	82-Pb-203n+		93-Np-239	-0.1364
81-Tl-201+		82-Pb-204	-0.0097	95-Am-241	-0.0220
81-Tl-202+		82-Pb-204m	0.0780	95-Am-243	-0.0217
81-Tl-204	0.0033	82-Pb-205+			
82-Pb-202+		83-Bi-207	0.1833		

+ Evaluated or re-evaluated recently, and awaiting consistency check

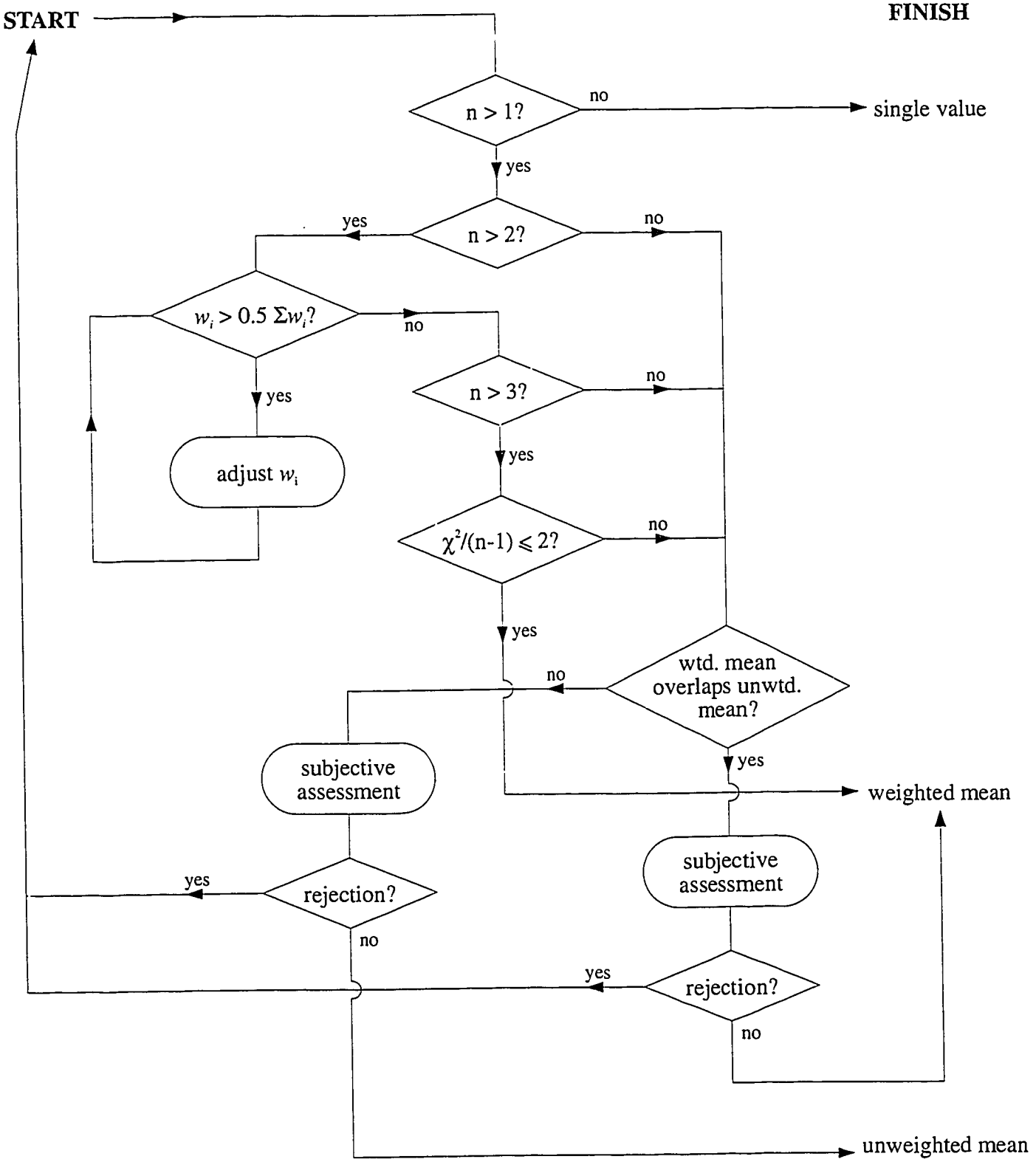
Table 4: Data Consistency (%) in UKHEDD-2

Nuclide	UKHEDD-2	Nuclide	UKHEDD-2	Nuclide	UKHEDD-2
80-Hg-206	-0.1156	84-Po-218	0.0010	91-Pa-235	incomplete
81-Tl-206	0.0004	85-At-215	-0.0031	92-U-232	-0.0360
81-Tl-206m	0.0090	85-At-217	-0.0083	92-U-233	-0.0825
81-Tl-207	-0.0009	85-At-218	0 .0109	92-U-234	0.0067
81-Tl-207m	-0.0084	85-At-219	0.0043	92-U-235	0.0143
81-Tl-208	-0.1087	86-Rn-217	-0.0053	92-U-235m	0.0000
81-Tl-209	0.0429	86-Rn-218	0.0025	92-U-236	-0.0452
81-Tl-210	incomplete	86-Rn-219	-0.0078	92-U-237	0.1157
82-Pb-205	2.0507	86-Rn-220	-0.0011	92-U-238	-0.0319
82-Pb-209	0.0000	86-Rn-222	0.0010	92-U-239	-0.0099
82-Pb-210	-0.7073	87-Fr-221	-0.8061	92-U-240	-0.0670
82-Pb-211	0.0003	87-Fr-223	0.5535	93-Np-236	0.0464
82-Pb-212	0.1212	88-Ra-223	-0.1938	93-Np-236m	0.0723
82-Pb-214	-0.1591	88-Ra-224	0.0020	93-Np-237	-0.1777
83-Bi-210	0.0000	88-Ra-225	-0.0137	93-Np-238	-0.0900
83-Bi-210m	-0.1748	88-Ra-226	-0.0786	93-Np-239	-0.1364
83-Bi-211	0.0025	88-Ra-228	0.3213	93-Np-240	incomplete
83-Bi-212	-0.0049	89-Ac-225	0.3742	93-Np-240m	-0.4641
83-Bi-212m	0.0052	89-Ac-227	0.2773	93-Np-241	-0.1891
83-Bi-212n	0.0000	89-Ac-228	-0.7282	94-Pu-236	0.0153
83-Bi-213	0.0758	90-Th-227	-0.4859	94-Pu-237	1.2389
83-Bi-214	0.0675	90-Th-228	0.0122	94-Pu-238	0.0130
83-Bi-215	Q/3	90-Th-229	0.2975	94-Pu-239	-0.0281
84-Po-209	incomplete	90-Th-230	0.1990	94-Pu-240	0.0077
84-Po-210	-0.0025	90-Th-231	-0.7156	94-Pu-241	0.0093
84-Po-211	-0.0006	90-Th-232	-0.2622	94-Pu-242	0.0024
84-Po-211m	0.0784	90-Th-233	0.2179	94-Pu-243	0.0346
84-Po-212	-0.0008	90-Th-234	0.2141	94-Pu-244	0.0048
84-Po-212m	0.0245	90-Th-235	Q/3	94-Pu-245	incomplete
84-Po-212n	-0.0010	91-Pa-231	-0.0803	94-Pu-246	0.4786
84-Po-213	-0.0049	91-Pa-232	-0.3333	95-Am-240	0.0825
84-Po-214	0.0016	91-Pa-233	-0.0793	95-Am-241	-0.0220
84-Po-215	0.0037	91-Pa-234	-0.7946	95-Am-242	0.0356
84-Po-216	-0.0012	91-Pa-234m	0.0348	95-Am-242m	4.1068

Nuclide	UKHEDD-2	Nuclide	UKHEDD-2	Nuclide	UKHEDD-2
95-Am-243	-0.0218	96-Cm-243	-0.9741	97-Bk-249	-0.4970
95-Am-244	0.0002	96-Cm-244	0.0004	97-Bk-250	-0.0287
95-Am-244m	-0.0363	96-Cm-245	-0.0024	98-Cf-249	0.1430
95-Am-245	0.0470	96-Cm-246	-0.0174	98-Cf-250	-0.0045
95-Am-246	incomplete	96-Cm-247	-0.0068	98-Cf-251	-0.1201
95-Am-246m	-0.4708	96-Cm-248	0.0057	98-Cf-252	-0.0710
96-Cm-241	-0.5680	96-Cm-249	0.0430	98-Cf-253	-0.9361
96-Cm-242	0.0629	96-Cm-250	-0.0005	99-Es-253	0.0053

Figure 1: Calculation of Recommended Data - Method of Limited Statistical Weights ($\leqslant 50\%$)

For n experimental data



APPENDIX

Nomenclature and Formulae

The uncertainty studies involved manipulations of the terms x_i and σ_i which refer to individual values and their uncertainties respectively. It is useful to list the relevant notations and formulae:

$x_u = \frac{\sum x_i}{N}$ unweighted mean for N observations;

$s_u^2 = \frac{\sum (x_i - x_u)^2}{N(N-1)}$ variance of the unweighted mean;

$s^2 = \frac{\sum (x_i - x_u)^2}{N-1}$ sample variance;

$\bar{x} = \frac{\sum x_i w_i}{W}$ weighted mean;

$w_i = 1/\sigma_i^2$ weight of the i-th value;

$W = \sum w_i$ total weight;

$\sigma_w = \sqrt{1/W}$ standard deviation of the weighted mean (internal error);

$\sigma_e = \sqrt{\frac{\chi^2}{(N-1)}}\,\sigma_w$ external error;

$\chi^2 = \sum \chi_i^2$ where $\chi_i^2 = (x_i - \bar{x})^2/\sigma_i^2$ is a measure of the consistency of the whole data set.

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Short remarks for

IAEA Specialists Meeting on the
Development of an International Nuclear Decay Data
and Cross-Section Database
Vienna, 24-28 October 1994

F.E. Chukreev

I should like to remember that the first proposals regarding this cooperation were discussed during the Jülich Conference on Nuclear Data for Science and Technology.

Our objections were based on one question:

"Why must a new cooperation be created? We have the ENSDF cooperation and all needed data could be produced by the ENSDF community. If anybody would like to publish a handbook or nuclear wall-chart, he can use ENSDF data." But our opinion is changed now. Why?

1. The ENSD File is a total collection of Nuclear Structure and Decay Data and the data evaluation for it is a long-time procedure. We conserve our opinion that ENSDF data are the most reliable data. But the needed time for a new data evaluation for ENSDF is very long because the financial support of this activity is not sufficient. Practical needs request some half-life data with high accuracy and quickly.

   Let me take your attention for this subject.

   All nuclides could be divided into four sections:

   1.1 The most important nuclides. These are fissionable nuclides, and Pu-239 is the most interesting. Why? All humanity is alarmed by the possible plundering of fissionable elements by criminals. As long as fissionable materials are contained in head parts of the missiles the Army guards it. But the disarmament process will open path to these materials. Exact counting of fissionable materials is needed. The accuracy of this counting cannot be more accurate than our knowledge of the Pu-239 half-life. NDS recommend for Pu-239 24110 $\pm$30 years. Of course, I do not know the reserve size Pu-239 inside modern weapons, but I can believe that tens of tons of Pu-239 exist in our world. Let us assume 80 tons for Pu-239. Then our accuracy for this quantity is not better than 100 kilograms! One A-bomb needs 8 kg of Pu! Correct counting of Pu requests to increase the half-life accuracy by a factor of 10 at least.

   1.2 Important nuclides. These are metrological nuclides which are used for important measurements in Science and Technology. Medical Radioisotopes must be included in this group.

   1.3 Fission products.

   1.4 All nuclides which have not been included in the first three groups.

2. The ENSD File does not answer the question: "Is our information about some nuclides trustworthy?"

Sure knowledge of the border of nuclear stability is needed to predict possible paths for nuclear energy development and to eliminate the speculations on this subject.

3. What must we do in order that the future database will be acknowledged? This database must have an elegant shell which could be installed (without any special education) on a cheap and little computer. As a good example of similar solution I would like to take your attention to the first version of NUC code of OECD Nuclear Data Bank, but nuclear data which have been included in this database must be checked and corrected. Another form for a representation of decay-data could be a Chart of Nuclides. Charts of Nuclides which had been published by Selinov, Karlsruhe group, Knoll's Laboratory are the examples of different Charts for different communities.

Therefore I would like to propose the structure for envisaged cooperation.

1. A little group of volunteers must study existing "computer Charts of Nuclides" and recommend suitable code for little cheap computer.

2. We could use ENSDF data to fill the selected computer code and another volunteer group must check these data because computer codes to transform ENSDF data to the needed form may have unavoidable mistakes. As a suitable example of a similar mistake I mention the NUC code again. I have the impression that first version of this code included two times the gamma-rays, which have the ENSDF label "disposal twice".

3. A special group must be organized to solve the problem of the Pu-239 half-life. I see that this group must include the experimenters and evaluators. The task for this group would be to prepare an international program of measurements.

   This program will be very difficult and expensive, but I have no doubt that the IAEA can convince the governments of developed countries to find the needed funding. I am sure that the public opinion will provide the needed support for this program.

4. A special group for methodology of data evaluation and uncertainties assessment will be needed. I am ready to participate in the meetings of this group.

5. A special subgroup to evaluate the nuclear stability border must include experimenters from several scientific centers, which have suitable experience for new elements and isotopes.

After these first steps we will know the community response and we will have a base to correct our future actions in the needed direction.

Evaluation of Absolute Gamma-Ray Intensities

Edgardo Browne
Lawrence Berkeley Laboratory
Berkeley, California 94720
September 1994

1. Introduction

Absolute gamma-ray intensities, that is, the percentage of photons emitted in a nuclear transformation, are quantities needed in basic research for normalizing decay schemes and testing nuclear models. These quantities are also used in applied research for the analysis of samples irradiated with neutrons, measurement of radioactive tracer elements in biology and nuclear medicine, analysis of radioactive pollutants in environmental samples, calculation of reactor decay heat, analysis of radioactive elements for reactor decommissioning, and more. Hence it is important, particularly for those radionuclides studied in applied research or used as calibration standards, to obtain *accurate* values for their absolute gamma-ray intensities and uncertainties. I describe here some typical methods used for measuring or deducing absolute gamma-ray intensities and uncertainties, and stress the importance of agreement among evaluators on specific topics that require a uniform methodology of evaluation.

2. Measurement of Absolute Gamma-Ray Intensities

The usual methods are:

- **Singles Measurements at a Known Geometry**

These measurements include the various types of experiments where particles and gamma rays from a source placed at a well-determined geometry are measured with calibrated detectors of known counting efficiencies.

- **Coincidence Measurements** (typically $4\pi\alpha\gamma$ or $4\pi\beta\gamma$ coincidence experiments)

These are typical coincidence measurements between particles and gamma rays. The measurement, by Gehrke *et al.* [1], of the absolute intensity (38.6±0.5%) for the 312-keV gamma ray in the β^- decay of ^{233}Pa is an example of a $4\pi\beta^-\gamma$ coincidence measurement. This value gives a normalization factor with a fractional uncertainty of 1.3%. The uncertainty in the absolute intensity of each of the other gamma rays can be obtained by combining in quadrature this value with the fractional uncertainty in its relative intensity.

- **Measurement of Relative Equilibrium Intensities**

Absolute intensities in the decay of a chain of radionuclides can often be deduced from equilibrium-intensity measurements of relative gamma-ray intensities, where the absolute intensitiy of at least one gamma ray in the decay chain is known. Results from this type of measurement usually require a correction due to the half-life of the isotope(s) in equilibrium. The measurement of relative gamma-

ray intensities in the electron-capture decay of ^{100}Pd (3.6 days) in transient equilibrium with ^{100}Rh (20.8 hours) is a good example. Singh *et al.* [2] measured the following relative intensities: I(84)=100±6, I(539)=19 ±10, where the 84-keV and 539-keV gamma rays are from the electron-capture decay of ^{100}Pd and ^{100}Rh, respectively. The 539-keV gamma ray has a known absolute intensity of 78.4±1.7% [3]. The correction factor for the half-life is

$$F=[1 - T_{1/2}(^{100}Rh)/T_{1/2}(^{110}Pd)]=0.761\pm0.006.$$

Finally, the absolute intensity of the 84-keV gamma ray is

$$\gamma_{84}(\%)=(100\pm6)x(78.4\pm1.7)/(196\pm10)x(0.761\pm0.006)= 53\pm4.$$

All fractional uncertainties have been combined in quadrature.

3. Absolute Gamma-Ray Intensities Deduced from Decay Scheme

The usual procedure here is to normalize the decay scheme using the sum of the transition intensities (photons plus conversion electrons) to the ground state, and possibly, to low-lying levels not directly populated by particle or electron-capture decay. The normalization factor is:

$$N= 100/\Sigma_i I_i(1 + \alpha_i), \qquad (1)$$

where I_i is the relative intensity of the i-th gamma ray, and α_i, its total conversion coefficient. Recommended values for these quantities should be used in equation (1). I discuss this topic next.

- **Recommended Relative Gamma-Ray Intensities**

The intensities to be used in equation (1) are values from a single measurement, or values combined from several measurements and adopted by an evaluator. A question is *how to combine* several experimental results to produce an adopted set of recommended relative intensities. Here are two possibilities:

- Normalizing all measurements to the intensity of a strong gamma ray, and then calculating weighted averages (and corresponding uncertainties), or
- Assuming the scales of the various measurements to be linearly related by factors b_j (procedure of Tepel [4] and Lederer [5] used in the *Table of Radioactive Isotopes* [6]) and minimizing the quantity

$$Q=\Sigma_{ij}\ \omega_{ij}\ (I_{ij} - b_jJ_i)^2 \qquad (2)$$

to obtain the recommended intensities J_i and the factors b_j. I_{ij} is the relative intensity of the i-th gamma ray in the j-th measurement; $\omega_{ij}=(\Delta I_{ij})^{-2}$, where ΔI_{ij} is the uncertainty in I_{ij}, and b_j, the factor that normalizes the scale of the j-th measurement. The uncertainty in J_i can be calculated using a procedure that takes into account the covariances.

This is a matter that requires agreement among evaluators.

- **Recommended Total Conversion Coefficients**

A usual procedure to obtain a total conversion coefficient consists of determining first the gamma-ray multipolarity and mixing ratio (using a single-shell experimental conversion coefficient, sub-shell ratios, or angular correlation results with the additional knowledge of spins and parities of the states involved), and then, calculating the *total conversion coefficient* using theory (Hager and Seltzer [7], or Rösel *et al.* [8]). For pure multipolarities the difference between experiment and theory is usually no more than 3%. For mixed transitions, however, this deviation could be significantly larger. The procedure to deduce mixing ratios from a single-shell conversion coefficient (e.g., α_k) or from a sub-shell ratio (e.g., L_1/L_2) is generally straightforward, whereas deducing a mixing ratio by using *all* measured conversion coefficients and sub-shell ratios *simultaneously* requires a complex minimization procedure, such as that developed by Rysavy *et al.* [9]

This is a matter that requires agreement among evaluators.

The mixing ratio of the 24.4-keV gamma ray from the electron-capture decay of ^{191}Au illustrates a case where each of these procedures gives a different multipolaritiy and mixing ratio. The measured sub-shell ratio L_1/L_2=1.7±0.4 is consistent with M1+2%E2 or with E1, whereas the other measured value, L_2/L_3=0.65±0.15, is consistent with *pure* E2 or E1. Using this argument, Johansson *et al.* [10] assigned an E1 multipolarity. This multipolarity, however, is *inconsistent* with the placement (11/2+ to 13/2+) of this transition in the decay scheme. Figure 1 shows the theoretical ratio L_2/L_3 as a function of the E2 mixing. Notice that, because of the extremely large values of α(L2) and α(L3) for an E2 multipolarity (1390 and 1630, respectively), the subshell ratio L_2/L_3 for an M1+E2 transition is not sensitive to the amount of E2 (above ≈2%) mixed with M1. The experimental sub-shell ratio L_2/L_3=0.65±0.15 is essentially consistent within two standard deviations with a value of 1.0 expected for an M1+2%E2 transition, and this multipolarity is consistent with the placement of the 24.4-keV transition in the decay scheme. Rysavy's minimization procedure using the L_1/L_2 and L_2/L_3 sub-shell ratios simultaneously gives a mixing ratio δ=0.15±0.06, that is, an M1+2%E2 multipolarity.

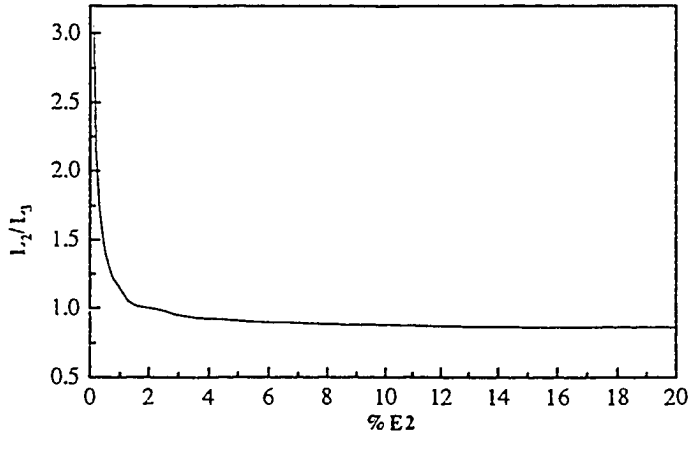

Figure 1. Theoretical L_2/L_3 ratio as a function of the E2 mixing for the 24.4-keV gamma ray.

- **Nuclear Penetration Effects**

Another topic that requires special attention is the effect of nuclear penetration on conversion coefficients. Such an effect may be significant for M1 or E1 gamma rays with transition probabilities much smaller than the corresponding single-particle Weisskopf [11] estimates. The Nilsson-Rasmussen [12] selection rules for the asymptotic quantum numbers are useful to predict nuclear penetration in deformed nuclei.

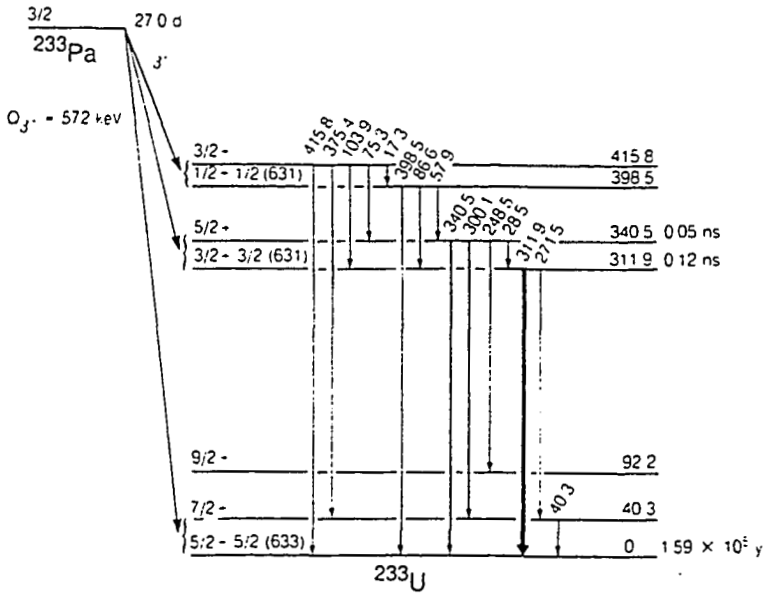

Figure 2. Simplified ^{233}Pa decay scheme

The β^- decay of ^{233}Pa shown in Figure 2 illustrates a case where the use of theoretical conversion coefficients could lead to incorrect results. Using a value of 38.6±0.5% [1] for the absolute intensity of the 312-keV gamma ray, relative gamma-ray intensities also from Gehrke *et al.* [1], and *theoretical* conversion coefficients [7] (which do not include nuclear penetration effects) for normalizing the decay scheme, a value of 102±2% can be deduced for the total photon plus conversion electron intensity to the ground-state rotational band. This result implies that there is no direct β^- population of this band, and hence is in disagreement with the measured intensities of 12% [13] or 5% [14, 15] for the combined β^- transitions to the ground and first excited states. An additional inconsistency, between measured [1] and calculated K x-ray intensities, implied conversion coefficients smaller than those from theory. Browne *et al.* [16] later measured the K conversion coefficients for the 300-, 312-, and 340-keV gamma rays and obtained values ≈18% smaller than those from theory. This result removed the inconsistency in the transition-intensity balance, allowing a 6±2% β^- branch to the ground and first-excited state.

- **Uncertainties and Covariances**

The absolute intensity of the l-th gamma ray deduced from a decay scheme is given by

$$\gamma_l(\%) = 100\, I_l / \Sigma_i\, I_i\,(1+\alpha_i)\,, \qquad (3)$$

where I_i and α_i are best values deduced as described before.

Propagating the uncertainties in I_i and α_i is straightforward, although it requires taking into account the effect of covariant terms. For example, consider a hypothetical decay scheme with a single gamma ray and negligible total conversion coefficient, as shown in Figure 3. The absolute intensity is

$$\gamma(\%) = 100\, I/I = 100.$$

Notice that the precision in this value is independent of the intensity I.

For other cases, this effect may be distributed among several gamma rays, as in the hypothetical decay scheme shown in Figure 4. The relative intensities of γ_1 and γ_2 are $I_1 = 110 \pm 5$ and $I_2 = 100 \pm 5$, respectively. Assuming negligible total conversion coefficients, the normalization factor is

$$N = 100/I_1 = 100/110 \pm 5,$$

and the absolute intensities are

$$\gamma_1(\%) = 100 \times (110 \pm 5)/(110 \pm 5) = 100, \text{ and } \gamma_2(\%) = 100 \times (100 \pm 5)/(110 \pm 5) = 91 \pm 6.$$

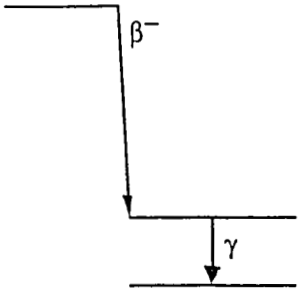

Figure 3

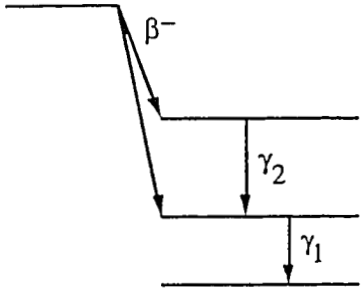

Figure 4

Notice that the normalization procedure produced absolute intensities with precisions significantly different from those in the relative intensities.

The general expression for the fractional uncertainty of the l-th gamma ray associated with the i-th decay mode is [17]:

$$\frac{d\gamma_{li}(\%)}{\gamma_{li}(\%)} = \frac{dY_{li}}{Y_{li}} = \left[D_l^2 + C_l^2 \left(\frac{dI_{li}}{I_{li}} \right)^2 + \left(\frac{\frac{1}{G_t} d\alpha_{li}}{\sum_{j,t} \frac{1}{G_t} T_{jt}} I_{li} \right)^2 + \frac{\sum_t \frac{\left(\sum_j T_{jt} \right)^2}{G_t^2} \left(\frac{dG_t}{G_t} \right)^2}{\left(\sum_{j,t} \frac{1}{G_t} T_{jt} \right)^2} \right]^{1/2} . \qquad (4)$$

All the quantities in equation (4) are described in reference [17].

Although the scales between relative and absolute intensities are linearly related through a normalization factor, equation (4) shows that, because of the covariances, the relation between the corresponding uncertainties may not be simple. Consequently, presenting a table of relative intensities and a normalization factor (with their respective uncertainties) is *not sufficient.* Tables of absolute gamma-ray intensities should include the uncertainty in each individual transition.

The electron-capture decay of ^{56}Ni is a good example. Figure 5 shows the ^{56}Ni decay scheme of Sur *et al.* [18]. Using relative gamma-ray intensities from Sur *et al.* [18] and a total conversion coefficient of 0.012±0.001 [19] for the 158-keV *normalizing* transition, one obtains a decay-scheme normalization factor N=0.99±0.01. Table 1 shows relative and the deduced absolute gamma-ray intensities. Both N and most of the relative gamma-ray intensities have fractional uncertainties of 1%. Notice, however, that due to the covariances, the fractional uncertainty in the absolute intensity of the 158-keV gamma ray is only 0.1%.

Energy (keV)	Rel. Int. (I)	Abs. Int. (%)
158.4	100±1	99.00±0.10
269.5	38.70±0.39	38.31±0.54
480.4	38.64±0.39	38.25±0.54
749.9	50.58±0.50	50.07±0.71
811.8	88.40±0.90	87.5±1.2
1561.8	12.77±0.41	12.64±0.42

Table 1. Gamma-ray intensities from ^{56}Ni electron-capture decay.

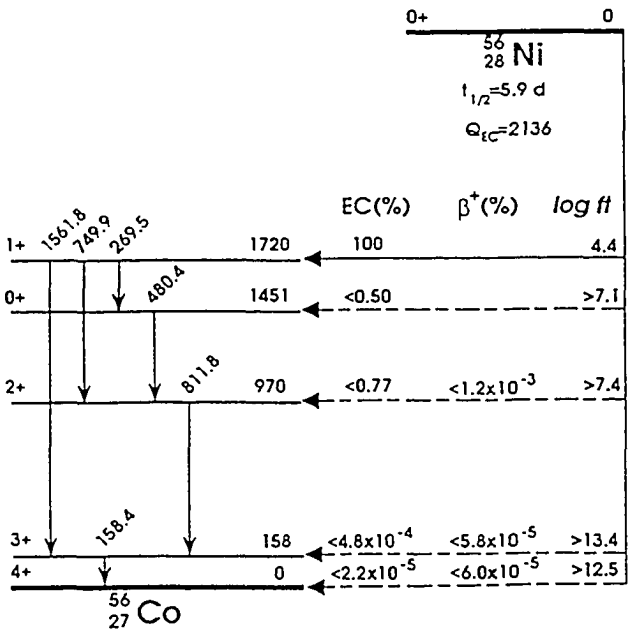

Figure 5. ^{56}Ni decay scheme

4. X-Ray Intensities

Relative x-ray intensities emitted by isotopes that decay by electron capture may provide a useful source of data for normalizing a decay scheme and deducing absolute gamma-ray intensities.

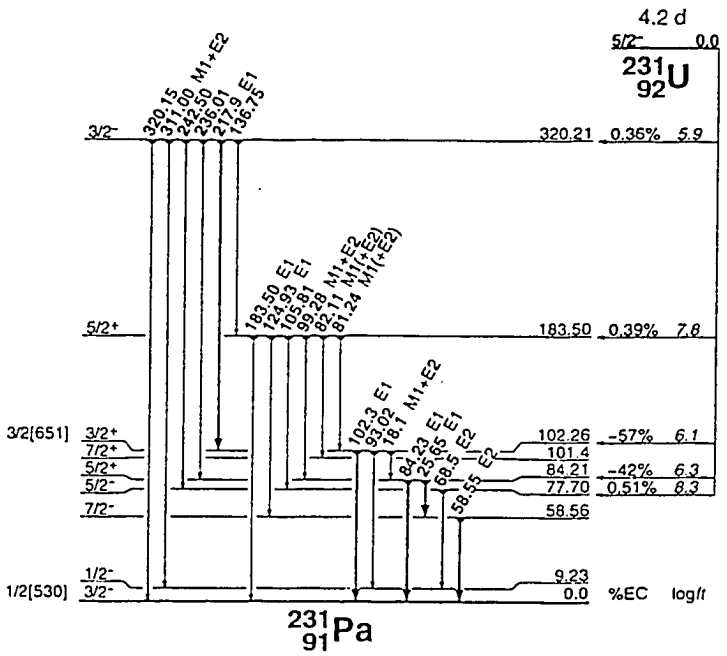

Figure 6. ^{231}U decay scheme

The electron-capture decay of ^{231}U illustrates this type of measurement. Figure 6 shows the ^{231}U decay scheme of Browne *et al.* [20] who measured the relative intensities of the two most intense gamma rays, $I(25)=100\pm6$ and $I(84)=50\pm3$. Using their value of 390 ± 14 for the measured relative Pa K x-ray intensity, theoretical values for the K-to-total electron-capture ratios, and a K-fluorescence yield of 0.972 [21], they deduced a value of 680 ± 33 for the total number of atomic vacancies created by the electron-capture process. The normalization factor to convert relative to absolute intensities is $N=100/680\pm33=0.147\pm0.007$, and the absolute intensities of the 25- and 84-keV gamma rays are $\gamma_{25}(\%)=14.7\pm1.1$ and $\gamma_{84}(\%)=7.3\pm0.6$ [20].

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Some remarks concerning nuclear decay data.

V. Manokhin.

Several very important applications in nuclear science and technology (calculations of activation and gas production in nuclear facility materials, transmutation of fission product and actinide in reactors and on accelerators, production of medical radionuclides) expanded greatly requirements in nuclear data cross sections both on stable and radioactive nuclei, including also nuclei in isomer state. The data are needed for several thousand nuclides and in very wide energy range (up to ~ 100 MeV for neutrons and ~ 1 GeV - for protons).

The main sources such data are nuclear reaction model calculations using decay data. That is why the importance of reliable knowledge of decay data for practical applications increased greatly.

As far as the most cross sections are measured by activation method, the role of reliability and accuracy of half-lives for cross sections being measured is evident.In the procedure of cross section measurement of the short-lived nuclei the uncertainty in in half-lives affects the results strongly.

The applications mentioned stimulated simultaneous analysis, measurements and evaluation of cross sections of nuclear reactions and decay data of reaction products in order to obtain consistent values. As a result in some cases unpleasant discrepancies in half-lives were revealed.

For example, for the problem of fission reactor decommissioning it is necessary to calculate reactor material activation because of the ^{108m}Ag production. The recommended half-life value for this isomer was (127+7) years. The results of measurements by U.Schotzig et al /1/ differ greatly.They obtained the value, which is equal to (418+15) years. Simultaneous analysis of production cross section and half-life of isomer state, made in the work /2/, gives the value (310+132) years.

The similar situation was analyzed in the work /3/ concerning the half-life of ^{59}Ni. The experimental values of five authors lie within order of magnitude ($7,58*10^4$y - $7,58*10^5$y). An activation gives (104+25)mb at 14,8 MeV for the reaction $^{60}Ni(n,2n)^{59}Ni$ under the assumption of the presently accepted half-life of $7,58*10^4$y for ^{59}Ni. But there are other values which 4-5 times more. It is so, the half-life of ^{59}Ni must be 4-5 times longer. The $^{60}Ni(n,2n)$ cross section measured by the AMS method, which does not require the knowledge of the half-life, gives (410+120)mb. The half-life of ^{59}Ni measured in the work /3/ is equal (9,5+2,5)810^4y and close to the presently accepted value.It seems that further analysis and measurements are needed.

The works /2,3/ are interesting from methodological point of view as far as contain simultaneous analysis data for cross sections and half-lives. It gives possibility to make both types of data more consistent and reliable.

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2.6

V.P. Chechev

Laboratory of Applied Nuclear Spectroscopy -
Radionuclide Data Center

V.G. Khlopin Radium Institute, St. Petersburg, Russia

Brief information

1. Laboratory

This research laboratory has been acting at St. Peterburg Radium Institute since 1964. Now the main field of its activity is a radionuclide metrology, a metrological support of the production of different radionuclide sources which are produced under the auspieces of the Russian Ministry of Atomic Energy.

The laboratory has got detectors and instrumentation for nuclear spectrometry works, mainly for A- and X-, G-spectrometry.

In 1993 the laboratory was transformed into the Radionuclide Data Center in order to intensify activity on the formation of databases on radiation parameters of Russian standard and reference sources and also on the development of a database for decay data of widely applied radionuclides /1/.

2. Decay data measurement activity

Apparatus: 4πB(ppc) - G(NaI) coincidence system,
Ge(Li), HPGe, Si(Li), Si(Au)-detectors.

In 1986-1990 years the absolute and relative emission probabilities of gamma- and X-rays in the decays of ^{75}Se, ^{109}Cd, ^{119m}Sn, ^{125m}Te, ^{133}Ba, ^{145}Sm, ^{170}Tm, ^{238}Pu, ^{239}Pu, ^{243}Am have been measured /2-5/.

In recent years (1992-1994) measurements of $P_{x,\gamma}$ in the decays of ^{153}Gd and ^{155}Eu have been made /6,7/.

3. Decay data evaluation activity

Since 1980 the decays of 300 radionuclides have been evaluated. The results of this work are presented in Russian reference books of evaluated data /8-11/. Many of those evaluations, especially refs /8,9/, require revision on account of the publications of new measurement results. Such a work has been fulfilled for many long-lived radionuclides /12/.

In last years the decay data revised evaluations have made for ^{22}Na, ^{24}Na, ^{44}Ti+^{44}Sc, ^{46}Sc, ^{49}V, ^{51}Cr, ^{54}Mn, ^{57}Co, ^{60}Co, ^{109}Cd, ^{113}Sn, ^{125}Sb, ^{129}I, ^{137}Cs, ^{145}Sm, ^{152}Eu, ^{153}Sm, ^{153}Gd, ^{155}Eu, ^{160}Tb, ^{170}Tm /6,7,13-21/.

4. Near future plans

Measurements for making precise the value of absolute emission probability of the 186 keV gamma-ray in the decay of 226Ra and the values of absolute emission probability of some gamma-rays in the decays of ^{244}Cm and ^{241}Am.

Evaluation of decay data for ^{85}Kr, ^{85}Sr, ^{94}Nb, ^{95}Nb, ^{111}In, ^{169}Yb, ^{182}Ta, ^{192}Ir.

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V.P. Chechev

Comments on evaluation procedure

The evaluation rules assume usually a calculation of the weighted mean using as weights the inverses of the squares of author's measurement uncertainties in the form of standard deviations (σ_i). An analysis of data consistency can be done using a chi-square test at 5 % significance level /1,2/ and for discrepant data set the magnitude of the uncertainty in the evaluated value can be changed in comparison with the "internal error" of the weighted mean (σ_{int}) if we use one or another rule of uncertainty assessment /3,4/, e.g. $\sigma_{int} \times \sqrt{\chi^2/(n-2)}$ /4/ However we have not to forget the following aspects:

(a) the χ^2 can be abnormally low value for the data set,

(b) the only lowest uncertainty in the data set which can influence the weighted mean very much can be incorrect,

(c) the presence of a great constant component of systematic error in measurement results makes incorrect a calculation of the weighted mean deduced from the total author's uncertainties,

(d) it is difficult to use statistical criteria for the number of measurements $n<4$.

In order to take into account these aspects it can be suggested:

(a) to use for discrepant data set the $\sigma_{external}$ or $\sigma_{int} \times \sqrt{\chi^2/(n-2)}$ only for $\chi^2/(n-1)>1$,

(b) in all cases to use the rule of limitation of relative statistical weight /5/ before statistical processing the final data set,

(c) to use the rule that the uncertainty of the evaluated value should not be smaller than the minimum measurement error (σ_{min}) possible at the modern experimental level /1,3,6/,

(d) to use the "student's" factor to increase the evaluated uncertainty when the number of measurements is small /1,3,6/,

(e) in some special (rare) cases to give possibility for evaluator to take the unweighted mean or to reject some values on the basis of objective or subjective reasons or to adopt one of the experimental values as the evaluated magnitude.

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V.P. Chechev

Proposals on the Chart of Nuclides

1. Main ordinary characteristics should be presented in the wall-chart:
   - charge of nucleus (proton number),
   - symbol of element,
   - mass number,
   - spin of nucleus ground state,
   - atomic mass or decay energy,
   - absence or presence of nuclear isomers.

2. Nuclear isomers can be presented in a separate table.

3. Addition main ordinary characteristics should be presented:
   for stable nuclides:
   - isotopic yield,
   - cross section for the radiative thermal neutron capture,
   - natural (solar) abundance (in 10^6 Si atoms),

   for radioactive nuclides:
   - half-life,
   - modes of radioactive decay,
   - decay branching for one decay mode.

4. For radiations of radioactive nuclides it is suggested to present "practical" characteristics taken from the Table of Radioactive Isotopes by E. Browne and R.B. Firestone:

for A-, B^+-, p-, n-particles - one value of the energy of the most intensive group and the mean energy per decay,

for B^--particles - the mean energy or one-two values of the energy of the most intensive groups,

for e^--particles (B^-+ce) - the mean energy per decay,

for G-, X-radiations one or two or three values of the most intensive G-rays plus the mean energy of (G+X)-rays per decay.

VALIDITY OF INFORMATION, EXACTNESS OF DATA PRESENTATION, CONVENIENCE OF USE

RADIONUCLIDE DATA CENTER

V.G. Khlopin Radium Institute,
St. Petersburg, Russia

In progress

A COMPUTER NUCLIDE GUIDE

containing evaluated nuclear data

The Electronic Notebook of the *GUIDE* contains data of 3,000 nuclides known by 1994.

Each nuclide is characterized with the charge of nucleus, mass number and absence or presence of nuclear isomers. All nuclides are divided into three kinds: stable nuclides, artificial radioactive nuclides and natural long-lived radionuclides.

1. Stable nuclides

Presented characteristics: cross section for the radiative thermal neutron capture ("neutron cross section"), atomic mass, natural abundance (in 10E6 Si), isotopic yield (%), nucleus spin, magnetic moment of nucleus, quadrupole moment of nucleus.

2. Artificial radioactive nuclides

Presented characteristics: half-life, atomic mass, spin of decayed nucleus, modes of radioactive decay, decay branchings (%), decay energy for each branch (MeV), mean energy of beta-, gamma-, X- radiations (keV), energy of radiation components (alpha-, beta-, gamma- etc.), intensity of radiation components (% decays).

3. Natural long-lived radionuclides

For them the same characteristics are presented as for stable nuclides plus the half-life.

The recommended values of decay and radiation characteristics of radionuclides presented in the *COMPUTER NUCLIDE GUIDE* are EVALUATED ones including evaluated *UNCERTAINTIES* (errors). They are composed using the data in the Evaluated Nuclear Structure Data File (ENSDF) and the Table of Radioactive Isotopes by E. Browne and R.B. Firestone and the own evaluations made by specialists of the Radionuclide Data Center.

The *GUIDE* is provided with the *COLOURED CHARTS OF NUCLIDES* (proton number Z is given on the ordinate, neutron number N or neutron excess N-Z or mass number N+Z is on the abscissa, respectively).

The software of the *COMPUTER NUCLIDE GUIDE* is made in BORLAND PASCAL using the record size of PARADOX 4.0. The convenient user's interface of pseudoWindows and conditions of work in English and Russian are present.

The *COMPUTER NUCLIDE GUIDE* runs on the *IBM PC* family of computers, including the *AT* and the *PS/2* series and all true IBM compatibles. *MS DOS 5.0* or higher is required and at least *3.5M* of hard disk space. It runs on *EGA, VGA, SVGA* monitors.

```
NN      NN   UU     UU   BBBBBBB     AAAAA     SSSSSS   EEEEEEE
NN      NN   UU     UU   BBBBBBBB   AAAAAAA   SSSSSSS   EEEEEEE
NNN     NN   UU     UU   BB     BB   AA   AA   SS        EE
NNNN    NN   UU     UU   BB     BB   AA   AA   SS        EE
NN NN   NN   UU     UU   BBBBBBB    AAAAAAA   SSSSSS    EEEEE
NN  NN  NN   UU     UU   BBBBBBB    AAAAAAA    SSSSSS   EEEEE
NN   NNNN   UU     UU   BB     BB   AA   AA        SS   EE
NN    NNN   UU     UU   BB     BB   AA   AA        SS   EE
NN      NN   UUUUUUUU   BBBBBBBB   AA   AA   SSSSSSS   EEEEEEE
NN      NN    UUUUUU    BBBBBBB    AA   AA   SSSSSS    EEEEEEE
```

G. Audi, O. Bersillon, J. Blachot and A.H. Wapstra

(October 21, 1994)

INTRODUCTION

NUBASE is a ''horizontal'' nuclear database.

NUBASE is a critical compilation of 2 evaluations:

a) The Atomic Mass Evaluation;
b) The ENSDF (Evaluated Nuclear Structure Data File)

updated on the basis of recent literature. However, new information on half-lives from literature are used only if their precision is at least 3 times better than the accepted ENSDF values.

Full references are given for all experimental information.

NUBASE gives experimentaly known nuclear properties and some that have been estimated from extrapolation (marked ''#'') for more than 2855 nuclides in ground-state, 623 first and 60 second isomers: mass, isomeric excitation energy, half-life, spin, parity, decay modes and branching ratios.

MASS EXCESS

[M(in u) - A], in keV, and its one standard deviation error.

In cases where the furthest-left significant digit in the error was larger than 3, values and errors were rounded off, but not to more than tens of keV.

: in place of decimal point: values and error estimated from systematic trends.

Asymmetric errors:

the probability distribution is (roughly) symmetrized (cf 93Au05, p.205):

central value: mid-value between upper and lower 1 sigma-equivalent limits;
error: average of the two errors.

ISOMER

Definition of isomer:

excited state with half-life > 1ms.

Isomers are given in the order of increasing energy and named by successively appending "m" and "n" to nuclidic name.

e.g. 122Cs for ground state
122Csm for first excited state
122Csn for second excited state

If it is not known which isomer is lowest (from experiments or from theory): the one with the LARGEST uncertainty is taken as lowest

Excitation Energy:

Energy difference between levels adopted as higher level and ground-state, and its one standard deviation error.

In cases where the furthest-left significant digit in the error was larger than 3, values and errors were rounded off, but not to more than tens of keV.

: in place of decimal point: values and error estimated from systematic trends.

Assignment of isomer to gs or excited state is declared "uncertain", if :

Exc.En. < 2*error

flagged by * in col. 96

Origins of Excitation Energy (weakest connection):

MD	Mass Doublet
RQ	Reaction energy difference
AD	Alpha energy difference
BD	Beta energy difference
p	proton decay
2p	2 proton decay
XL	L X-rays
EU	Existence Uncertain
Nm	Nilsson Model systematics
blanc	from gamma-ray energy measurements

HALF-LIFE

units :

s=second m=minute h=hour d=day y=year

1 y (tropical year 1900) = 31 556 925.974 7 s
= 365.242 198 78 d

sub-units:

ms : E- 3s	(milli)-seconds	ky= E+ 3 y	(kilo)-year
us : E- 6s	(micro)	My= E+ 6 y	(mega)
ns : E- 9s	(nano)	Gy= E+ 9 y	(giga)
ps : E-12s	(pico)	Ty= E+12 y	(tera)
fs : E-15s	(femto)	Py= E+15 y	(peta)
as : E-18s	(atto)	Ey= E+18 y	(exa)
bs : E-21s	(----)	Sy= E+21 y	(---)
		Hy= E+24 y	(---)

Asymmetric errors:

the probability distribution is (roughly) symmetrized (cf 93Au05, p.205):

central value: mid-value between upper and lower 1 sigma-equivalent limits;

error: average of the two errors.

Particle Stability:

p-unst n-unst : proton or neutron unstable
p-stbl n-stbl : proton or neutron stable

followed by #: deduced from mass systematics

? in place of uncertainty : statement is not certain (Sep.En. < 2*error)

Unused data:

New information on half-lives from literature are used only if their precision is at least 3 times better than the accepted ENSDF values

SPIN and PARITY

Spin and parity assignments without and with parentheses are based upon strong and weak arguments, respectively (cf. 90Tuli).

Followed by #: estimated from systematic trends in nuclides of same N and Z parities.

low : low spin

high : high spin

am : same spin as alpha-decay parent

DECAY MODES and BRANCHING RATIOS

B-	beta - decay
2B-	double beta - decay
B+	beta + decay
EC	electron capture
EC+B+	electron capture and beta + decay
IT	internal transition
N	neutron emission
B-N	beta delayed neutron emission
B-2N	beta delayed 2-neutron emission
P	proton emission
B+P	beta delayed proton emission
B+2P	beta delayed 2-proton emission
ECP	electron capture delayed proton emission
2P	2-proton emission
A	alpha emission
B-A	beta - delayed alpha emission
B-3A	beta - delayed 3-alpha emission
B+A	beta + delayed alpha emission
ECA	electron capture delayed alpha emission
SF	spontaneous fission
24Ne	heavy cluster emission
IS	Isotopic Abundance
?	Decay mode energetically allowed but not observed
=?	Decay mode observed but intensity not measured
AP	approximatively
GT,GE	greater than, greater or equal
LT,LE	lower than, lower or equal

REFERENCES

MASSTAB= "The 1993 Atomic Mass Evaluation"
G. Audi and A.H. Wapstra
Nuclear Physics A565 (1993) 1.

ENSDF = "Evaluated Nuclear Structure Data File"
computer file of evaluated experimental
nuclear structure data maintained by the
National Nuclear Data Center
Brookhaven National Laboratory
(including ENSDF-'continuous updates')

NUBRA = ENSDF updated by
J.Blachot and O.Bersillon

1) Masses:

from MASSTAB, plus updates by G. Audi and A.H. Wapstra.

2) Excitation Energies:

from ENSDF+NUBRA when resulting from gamma-ray energy measurements;
Origin in 94:95 = " "

from MASSTAB when resulting from other than gamma-ray energy measurements.
Origin in 94:95 = non blank

3) Half-life, Spin, Parity, Branching
from ENSDF + NUBRA updates.
Reference in col 102:109
'89 ' = ENSDF of year 1989
including ENSDF-'continuous updates'
'89 92Aa10TJ' = ENSDF 1989 + NUBRA updates
for half-life T according to 92Aa10
for spin and or parity according to reference
given in supplementary reference file

Code for References:

I	Identification
M	Mass
E	Energy (isomer)
T	Half-life
B	Branching
J	Spin and parity

Reference in col 88:93 are for data not yet present in ENSDF+NUBRA
or, if flag in cols 97-100, for data not identical in NUBASE
and in ENSDF + NUBRA updates

4) Isotopic Abundances:
by N.E. Holden CRC Handbook of Chemistry and Physics
71st edition (1990) 11-33.

APPENDIX: FORMAT

from MassTab:

	Nubase file		creation from Nubra	
1: 8	AAA_ZZZi a8	l	a8	calculated
9: 9	W a1	c	a1	"W"
10: 10	" " a1	c	a1	" "
11: 21	Mass f11.4	l	a11	"-10000# "
22: 30	dMass f9.4	l	a9	"9000# "
31: 36	A El m a6	l	a6	calculated
37: 46	Exc f10.4	.	a10	13: 22
47: 54	dE f8.4	.	a2	23: 24 + 4 bl(l) + 2 bl (r)
55: 63	T f9.4	.	a9	44: 52
64: 65	ut a2	r	a2	62: 63
66: 66	" " a1	c	a1	64: 64
67: 73	dT a7	l	a7	54: 60
74: 87	Jpi a14	l	a14	26: 39
88: 93	Ref a6	l	a6	"Nubra "
94: 95	Orig a2	l	a2	" "
96:100	Discrp. a5		a5	" "
101:101	" " a1		a1	" "

from NUBRA

	Nubase file		from Nubra	
102:103	Ensdf a2	r	107:108	Ensdf Reference Year
104:109	Ref a6	r	109:114	Reference
110:112	code a3	r	115:117	Code for reference TBEIJ
113:154	Bra a42	l	65:106	Branching Ratio + unc. (or Isotopic Abundance)
155:172	Jpi a18	l	26: 43	Spin and Parity
173:182	T a10	l	44: 53	Half-life
183:190	dT a8	l	54: 61	Half-life unc.
191:192	unit a2	l	62: 63	Half-life unit
193:193	" " a1	c	64: 64	bl
194:203	Exc f10.4	c	13: 22	Excit. Energy of Isomer
204:205	dE a2	r	23: 24	Excit. unc.

Remark: if dE is missing in Nubra, decimal point replaced by "?"

Laboratoire Primaire des Rayonnements Ionisants
Département des Applications et de la Métrologie des Rayonnements Ionisants
Commissariat à l'Energie Atomique.
CE Saclay, BP52, 91193 Gif-sur-Yvette, France.
Tel : (33) 1.69.08.52.88 - Fax : (33) 1.69.08.47.73

2.8

Evaluation of Nuclear Decay Data - a brief report on work and projects at LPRI,
by N. Coursol.

The Primary Ionizing Radiation Laboratory (LPRI) is one of the primary laboratories affiliated with the French National Bureau of Metrology (BNM), which is responsible for organizing scientific and technical metrology in France. In this capacity, LPRI is in charge of the establishment, preservation and improvement of national standards for quantities and units of measurement of ionizing radiation. It insures national metrological coordination and traceability. It maintains relations with other national laboratories and participates in international comparisons, particularly in relation with the Bureau International des Poids et Mesures (BIPM). It also insures national metrological coordination with associated laboratories as part of accreditation service (FRETAC) or of special networks.

Owing to its know-how in radiation measurements and to its position within the national agency in charge of nuclear research and development (CEA), LPRI carries out applied research, e.g., for providing special standard sources of radioactivity and for setting up dosimetry systems or methods for testing or radioisotope analysis.

In the framework of its capacity, LPRI staff includes specialists in the evaluation of non-neutron nuclear data for radionuclides most frequently applied in science and technology : radiation protection, nuclear industry, brachytherapy, nuclear medicine, environmental monitoring, ...

The results of this evaluation work have been the source for extensive sets of recommended data published in the "Table de Radionucléides" (LMRI, 1974-1980; re-edited and continued on 1982-1986)[1], or in the decay data library LARA [2]. The evaluation work is based on available (literature) experimental and partly also theoretical data. The resulting evaluated (and recommended) data are presented in a distinct and easily readable form (printed material or computer-based files).

Amongst these evaluated radionuclides (over 180 nuclides), 38 have been chosen for their importance in nuclear medicine, and published as a "medical selection" [3] which gives, in addition to the decay data , values of the mean energy emitted per nuclear transformation for the main emissions. All recommended data (half-life, total energy decay, branching fractions, energies and emission probabilities and so on), are given with their associated uncertainties. The data status and evaluation procedures used by LPRI are given in the introduction of the "Table de Radionucléides".

A new version written in English and containing some minor modifications with respect to the former one is now being undertaken by LPRI and the Nuclear Data Group of the Physikalisch-Technische Bundesanstalt (PTB, Germany) in the framework of a European-cooperation effort. These modifications incorporate international recommendations for presentation as for example, the use of the standard deviation instead of the uncertainty at 99,7 % confidence level which was used before 1986, or for the evaluation procedures used to obtain the recommended half-life values (see [6]).

In a parallel evaluation action, a specific computer file for electron emissions ("EME") is in preparation at LPRI.

In relation to its evaluation task, LPRI staff has participated to previous IAEA Advisory group meetings [4] or to Co-ordinated Research Programmes, which aims were to promote the improvement of the quality of the nuclear data used in science and technology as the CRP on Transactinium Nuclide Decay Data (1978-1985) [5] and those on the Measurements and Evaluation of X- and Gamma-Ray Standards for Detector Efficiency Calibration (1986-1990) [6]. LPRI is also member of the International Committee for Radionuclide Metrology (ICRM), and contributes to Joint Evaluated File (JEF) library on decay heat data.

REFERENCES

[1] F. Lagoutine, N. Coursol and J. Legrand, Table de Radionucléides, ISBN-2-7272-0078-1, LMRI, 1974-1987

[2] LARA, Bibliothèque de Données Nucléaires pour la Spectrométrie Gamma et Alpha, LPRI, 1990

[3] F. Lagoutine, N. Coursol and J. Legrand, Table de Radionucléides - Sélection Médicale, LMRI, 1987

[4] IAEA Advisory Group Meeting , Uppsala (1984), IAEA TecDoc-336, 1985

[5] IAEA TecReports series n°261, (1986)

[6] IAEA TecDoc - 619, (1991)

1 - PRIMARY IONIZING RADIATION - LPRI

It is :

- a unit of the French Atomic Energy Commission (CEA)
- one of primary laboratories affiliated with the French National Bureau of Metrology (BNM).

It is in charge of :

- the establisment, preservation and improvement of national standards for quantities and units of measurement of ionizing radiation.
- the national metrological coordination and traceability.

2 - DECAY DATA

In general : evaluation of decay data for radionuclides applied in science and technology :

Radiation Protection, Nuclear Industry, Brachytherapy, Nuclear Medicine, Environmental monitoring, ...

At present : "Table de Radionucléides"
(over 180 nuclides).

"LARA" library
(over 300 nuclides, 11000 γ-ray transitions).

"Medical selection".

In the future : a LPRI - PTB Table
(a version written in English).

"EME" library
(electron emission probabilities).

3 - LPRI PARTICIPATION

On previous IAEA Co-ordinated Research Programmes such as :

- CRP on Transactinium Nuclide Decay Data (1978-1985)
(IAEA TecReports series n° 261, 1986).
- Advisory Group Meeting, Uppsala,
(IAEA TecDoc - 336, 1985).
- CRP on the Measurements and Evaluation of X- and Gamma-Ray Standards for Detector Efficiency Calibration (1986-1990),
(IAEA TecDoc - 619, 1991).

LPRI is a member of the International Committee for Radionuclide Metrology (ICRM) and contributes to JEF library (decay heat).

Decay Data Activities in Sweden

2.11

to the
IAEA Specialists' Meeting on the
Development of an International Nuclear Half-Life
and Cross-Section Database
IAEA Headquartes, Vienna, 24-28 October 1994

H Condé, Department of Neutron Research, Uppsala University, Sweden

Swedish activities of relevance for the proposed nuclear decay data and cross-section database are on the one hand work on the development of computer based nuclear reference data systems and on the other hand on measurements of nuclear decay data.

The status of the nuclear structure and decay data evaluation effort and the computer database development made at the Physics Department, Lund University in collaboration with the Isotope Project at Berkeley are presented in Appendix 1. Dr Peter Ekström, who is in charge of the work at the Lund University, has been appointed as the chairman ot the Task Force of the US Nuclear Data Committee for the development of computer programs for the handling of nuclear data basis.

Nuclear decay data (β, γ, $T_{1/2}$, $B(\Lambda)$) are measured for neutron-rich nuclei (fission products) at the OSIRIS facility of the Neutron Research Laboratory, Uppsala University, Studsvik. The OSIRIS facility contains a mass separator on-line a fission source placed in the 1 MW swimming-pool reactor R2-0. The present research is focused on decay data of nuclei in new doubly magic regions and on the development of a radioactive beam. Futhermore, fission yield measurements are underway for fast fission of ^{238}U and thermal fission of ^{233}U and is planned for fast fission of ^{232}Th

Status report: Sweden

Nuclear Structure and Decay Data Evaluation in Sweden

Peter Ekström, Department of Physics, Lund University,
Sölvegatan 14, S223 62 Lund, Sweden

Financial support and personnel

During the last two years, the funding for the project has been SEK 80000 (about $10000) per year. This is sufficient for updating and maintaining the on-line reference system and for some database development in collaboration with the Isotopes Project at Berkeley.

Mass-chain evaluation

Since the last meeting in 1992, the evaluation of A=90 has been published.

The NSR on-line

The local installation of the NSR database is continuously updated with updates from the NNDC. The last update was successfully performed by transferring the update file with FTP via Internet.

The database at present contains 49290 references (primary references from 1975 and secondary references from 1989). Although no marketing of the service has been done the last few years, the number of logins per year is still increasing (1990:278, 1991:200, 1992:385, 1993:440). This can only be interpreted as a confirmation that the users still find it a useful service.

Papyrus NSR

Papyrus NSR is a system for searching the literature database NSR on a PC. The system is based on a commercial bibliographic program, Papyrus. It contains more than 130000 references from 1910 to the present. Papyrus NSR allows indexed searches on keywords, authors, year of publication, journal, title, type of reference and keynumber, and un-indexed searches on the keyword abstract.

During the summer of 1993, Peter Ekström visited the Isotopes Project at Berkeley with funding from the US Department of Energy. During this visit the main part of the work to transfer the NSR to Papyrus was performed in collaboration with Edgardo Browne. Since December 1993, a test version of the system has been available on the Lund University local area network. The CD-ROM version will be released in May 1994.

3. Cross-sections

Page

Paper presented at the *IAEA Specialists Meeting on the Development of an International Nuclear Decay Data and Cross-Section Database*, Vienna, 24-28 October 1994

3.1

REACTOR-NEUTRON ACTIVATION ANALYSIS BASED ON A DEDICATED NUCLEAR DATA LIBRARY

(The definition of the k_0-standardization)

A. SIMONITS and F. DE CORTE*

KFKI Atomic Energy Research Institute, Nuclear Chemistry Dept. (RKL)
H-1525 Budapest 114, P.O. Box 49, Hungary

**Institute for Nuclear Sciences (INW), University of Gent*
Proeftuinstraat 86, B-9000 Gent, Belgium

A new standardization approach utilizing the so-called k_0 compound nuclear constants was suggested in 1975 for absolute reactor-neutron activation analysis to eliminate many inaccuracies introduced by using ambiguous nuclear data. In order that the new method could soon be applied competitively in actual analytical work, a cooperation between the Activation Analytical Laboratories of the KFKI-AEKI, Budapest and INW, Gent was established to determine the k_0 and essential related nuclear data (Q_0, $T_{1/2}$, $\overline{E}_r$, etc.) with a high accuracy, to develop procedures for monitoring irradiation and measuring parameters (Φ_s/Φ_e, α, ε_p, $\overline{\Omega}$, etc.) as well as to share experiences when applying the method. The two decade co-operative research has resulted in an expedient data library which now contains experimentally determined and/or evaluated nuclear data for more than 120 (n,γ) reactions. Reliability and accuracy of the method and its database have been checked by analyzing a number of standard reference materials. It is to be hoped, that while our effort continues to determine nuclear data for reactions not yet covered, the present k_0-library could serve as a useful source to an internationally agreed database.

DIRECT METHOD

$$N_p = \frac{N_{Av}}{M} \cdot W \cdot \Theta \cdot \gamma \cdot \hat{\sigma} \cdot \Phi_0 \cdot \varepsilon_p \cdot \left(1 - e^{-\lambda \cdot t_{irr}}\right) \cdot e^{-\lambda \cdot t_{cool}} \cdot \left[\frac{1 - e^{-\lambda \cdot t_{meas}}}{\lambda}\right]$$

where

- N_p - full-energy peak area of measured γ-line
- N_{av} - Avogadro's number
- M - molar mass
- W - element weight
- Θ - isotope abundance
- γ - absolute gamma-ray intensity
- $\hat{\sigma}$ - effective (n, γ) activation cross-section
- Φ_0 - Westcott's total flux
- λ - decay constant
- ε_p - absolute full-energy peak efficiency

SINGLE COMPARATOR METHOD

Principle:

$$W = k \cdot \frac{\frac{N_p}{t_{meas} \cdot S \cdot D \cdot C}}{\frac{N_p^*}{t_{meas}^* \cdot S^* \cdot D^* \cdot C^*}} \cdot W^*$$

Definition:

$$k = \frac{M}{M^*} \cdot \frac{\Theta}{\Theta^*} \cdot \frac{\gamma}{\gamma^*} \cdot \frac{\hat{\sigma}}{\hat{\sigma}^*} \cdot \frac{\varepsilon_p}{\varepsilon_p^*}$$

where

S, D and C are the saturation, decay and "measurement" factor and * stands for the comparator

Note:

$\hat{\sigma} = \sigma_0 (g + rs)$ [Westcott] - neutron spectrum dependent

REACTION RATE CALCULATION

(HØGDAHL CONVENTION)

$$R = \Phi_0 \cdot \hat{\sigma} = \Phi_s \cdot \sigma_0 + \Phi_e \cdot I_0$$

where

σ_0 - 2200 m/s cross-section,

$I_0 = \int_{E_{Cd}}^{\infty} \sigma(E) \cdot \frac{dE}{E}$, infinitely dilute resonance integral

$E_{cd} = 0.55$ eV, effective Cd cutoff

$\Phi_s = n(0,E_{Cd}) \cdot v_0$, conventional thermal (subcadmium) neutron flux with $n(0,E_{Cd}) = \int_0^{E_{Cd}} n(v)dv$, the neutron density integrated up to the Cd cutoff

$v_0 = 2200$ m/s

Φ_e - epithermal or intermediate neutron flux per unit lnE energy interval

Note: Valid for target isotopes obeying the "1/v-law" up to ~5 eV (90 % of the 150 analytically important n,γ reactions)

K_0-STANDARDIZATION

Principle:

$$k_{0,Au}(x) = \frac{M_{Au}}{M_x} \cdot \frac{\Theta_x}{\Theta_{Au}} \cdot \frac{\gamma_x}{\gamma_{Au}} \cdot \frac{\sigma_{0,x}}{\sigma_{0,Au}}$$

Measurement:

1) $$k_{0,Au}(x) = \frac{A_{sp,x}}{A_{sp,Au}} \cdot \frac{f + Q_{0,x}}{f + Q_{0,Au}} \cdot \frac{\varepsilon_{p,Au}}{\varepsilon_{p,x}}$$

2) $$k_{0,Au}(x) = \frac{A_{sp,x} - (A_{sp,x})_{Cd}}{A_{sp,Au} - (A_{sp,Au})_{Cd}} \cdot \frac{\varepsilon_{p,Au}}{\varepsilon_{p,x}}$$

Conversion:

$$k_{0,comp}(x) = \frac{k_{0,Au}(x)}{k_{0,Au}(comp)}$$

Application:

$$\rho(x) = \frac{\left[\frac{N_p(x)}{t_m \cdot S \cdot D \cdot C \cdot W}\right]_{sample}}{k_{0,Au}(x)} \cdot \frac{f + Q_{0,Au}}{f + Q_{0,x}} \cdot \frac{\varepsilon_{p,Au}}{\varepsilon_{p,x}}$$

where $f = \Phi_s/\Phi_e$; $Q_0 = I_0/\sigma_0$; $A_{sp} = N_p/(t_{meas} \cdot S \cdot D \cdot C \cdot W)$

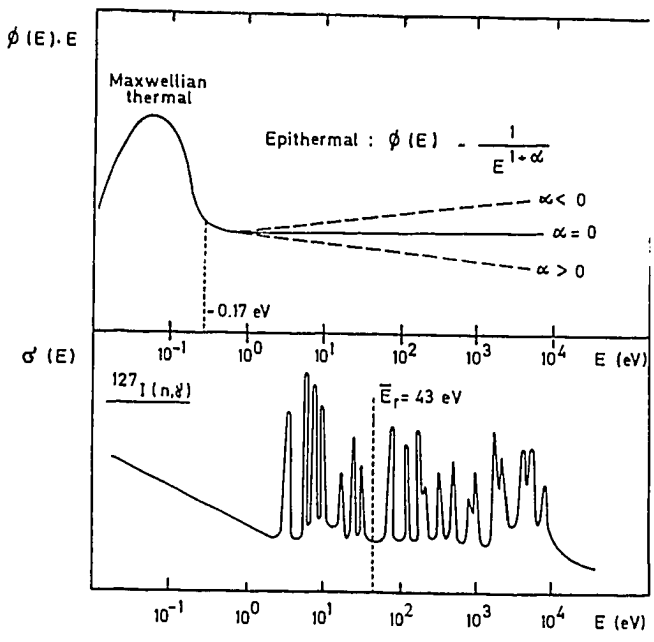
USE OF THE EFFECTIVE RESONANCE ENERGY

Definition (by RYVES):

$$\ln \bar{E}_r = \frac{\sum_i \frac{\sigma_{r,i}\Gamma_{r,i}}{E_{r,i}} \cdot \ln E_{r,i}}{\sum_i \frac{\sigma_{r,i}\Gamma_{r,i}}{E_{r,i}}}$$

Application:

$$Q_0(\alpha) = \frac{I_0(\alpha)}{\sigma_0} = \frac{\int_{E_{Cd}}^{\infty} \frac{\sigma(E)dE}{E^{1+\alpha}}}{\sigma_0} = \frac{Q(\alpha=0) - 0.429}{(\bar{E}_r)^{\alpha}} + \frac{0.429}{(2\alpha+1)E_{Cd}^{\alpha}}$$



Tabulation: Calculated $\bar{E}_r$- values for 127 isotopes

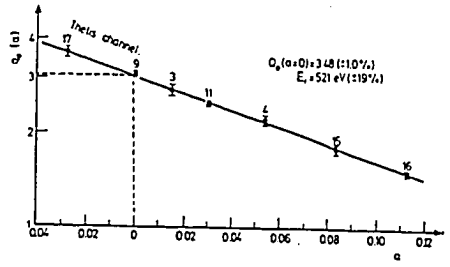
EXPERIMENTAL E_r-DETERMINATION Simonits (1984)

Principle:

$$q_0(\alpha) = \frac{q_0(0)}{(E_r)^{\alpha}} = \frac{f}{R_{Cd} - 1} - \frac{0.429}{(2\alpha + 1)(0.55)^{\alpha}}$$

$$\ln q_0(\alpha) = \ln q_0(0) - (\ln E_r)\,\alpha$$

Results:



Reaction	E_r, keV with rel err. (%) Calculation		Measurement		NOTE
$^{64}Zn(n,\gamma)^{65m}Zn$	515	(0.2)	521	(19)	One major resonance
$^{96}Ru(n,\gamma)^{97}Ru$	-		776	(16)	No resonance data
$^{180}Hf(n,\gamma)^{181}Hf$	-		65	(16)	-"-

EXPERIMENTAL α-DETERMINATION

Methods:

Cd-covered multi-monitor

Cd-ratio for multi-monitor

Bare multi-monitor

Application:

Reference channel calibration

^{197}Au - ^{238}U - ^{98}Mo - ^{100}Mo - ^{64}Zn monitor set

with „CD-RATIO FOR MULTI-MONITOR"-method

Routine analysis

„BARE TRIPLE MONITOR" -method with

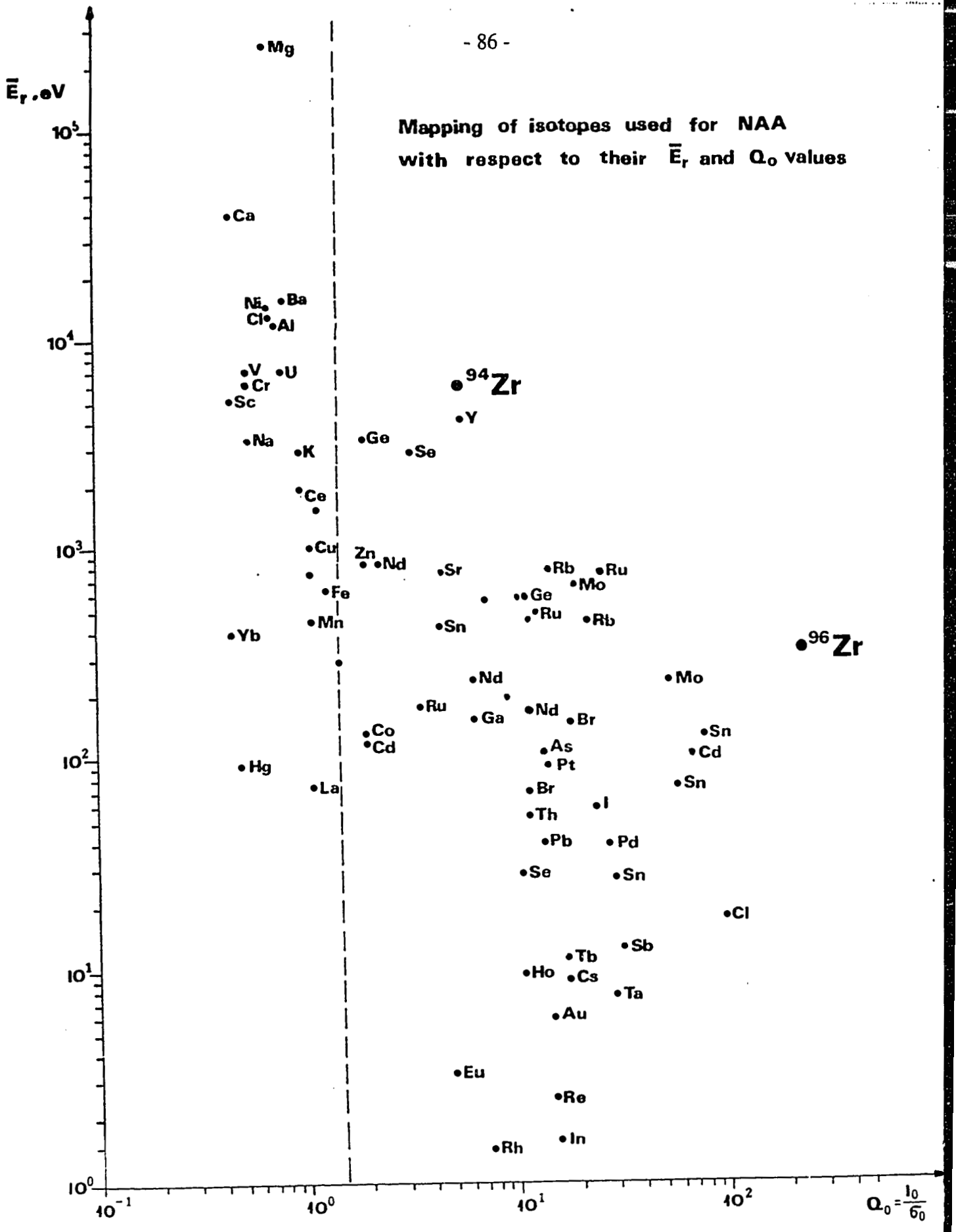
^{94}Zr - ^{96}Zr - ^{197}Au monitor set

$$(a-b)\cdot Q_{0,1}(\alpha) - a\cdot Q_{0,2}(\alpha) + b\cdot Q_{0,3}(\alpha) = 0$$

where

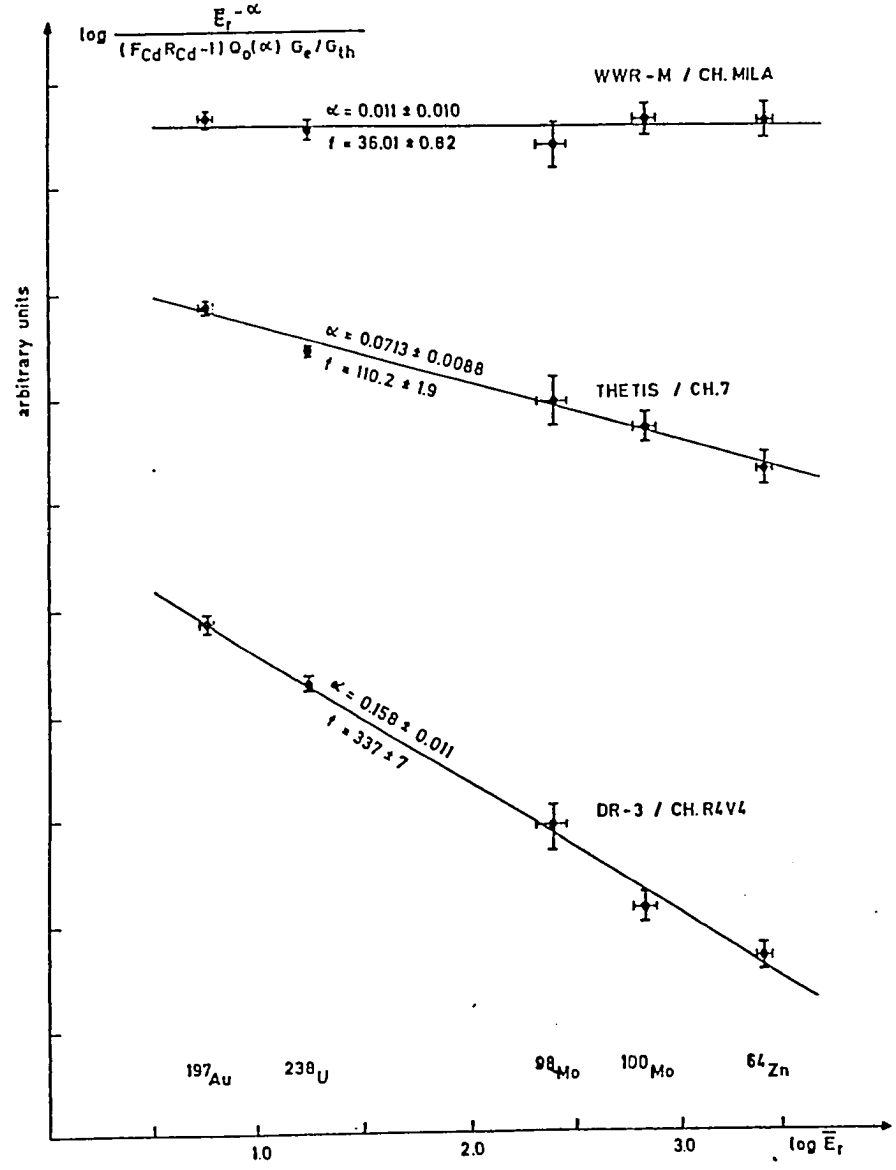
$$a = \left[1 - \frac{A_{sp,2}}{A_{sp,1}} \cdot \frac{k_{0,Au}(1)}{k_{0,Au}(2)} \cdot \frac{\varepsilon_{p,1}}{\varepsilon_{p,2}}\right]^{-1}$$

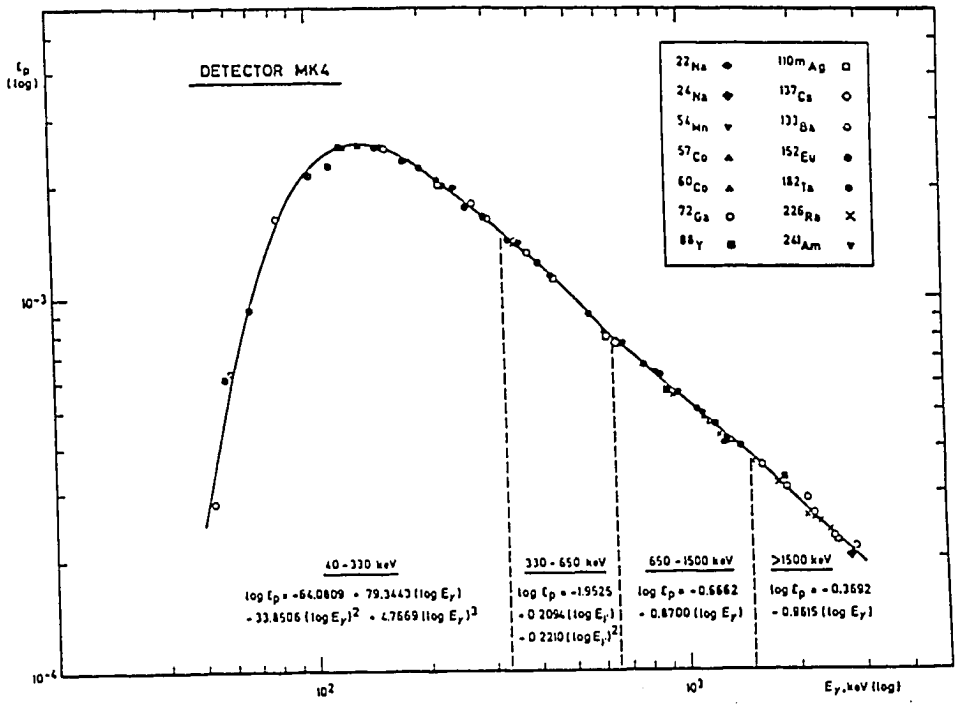
$$b = \left[1 - \frac{A_{sp,3}}{A_{sp,1}} \cdot \frac{k_{0,Au}(1)}{k_{0,Au}(3)} \cdot \frac{\varepsilon_{p,1}}{\varepsilon_{p,3}}\right]^{-1}$$

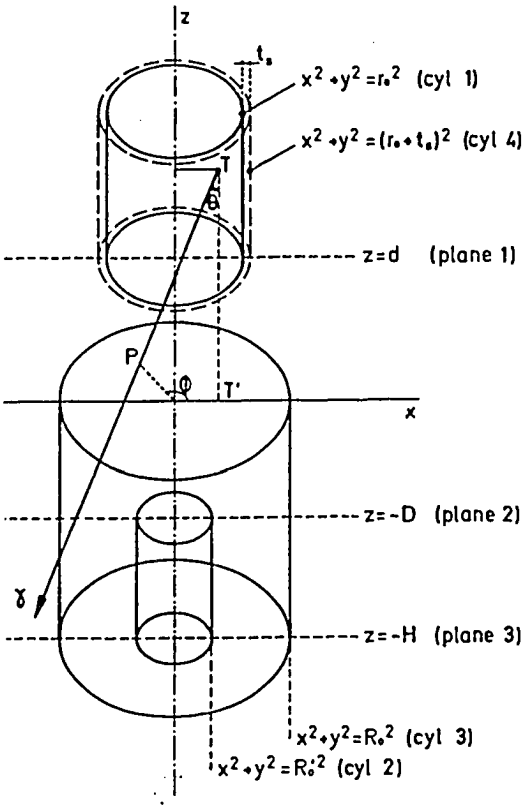

Mapping of isotopes used for NAA
with respect to their $\bar{E}_r$ and Q_o values
$\bar{E}_r$ .eV
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^0
10^1
10^2
$Q_0 = \frac{I_0}{\sigma_0}$
Mg
Ca
Ni
Ba
Cl
Al
V
U
Cr
Sc
^{94}Zr
Y
Na
Ge
K
Se
Ce
Cu
Zn
Nd
Sr
Rb
Ru
Mo
Fe
Ge
Ru
Rb
Mn
Sn
Yb
^{96}Zr
Nd
Mo
Ru
Nd
Br
Ga
Co
Cd
Sn
As
Cd
Hg
Pt
Sn
La
Br
I
Th
Pb
Pd
Se
Sn
Cl
Sb
Tb
Ho
Cs
Ta
Au
Eu
Re
In
Rh

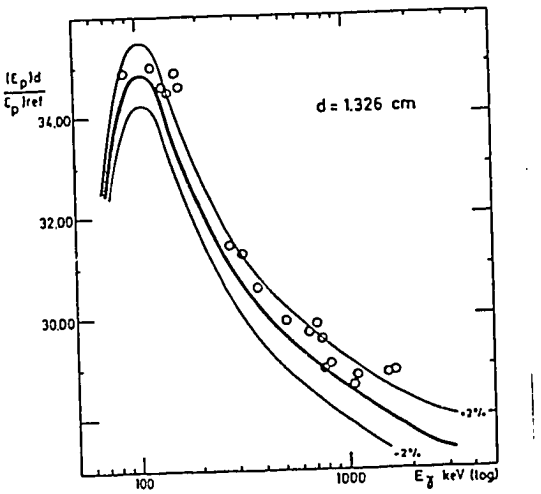
Q_0-VALUES FOR ^{94}ZR AND ^{96}ZR ISOTOPES

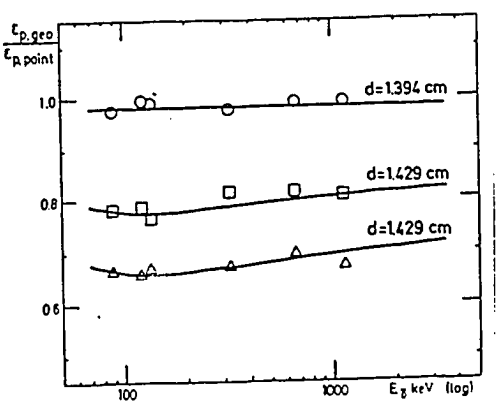
Author (Date)	Q_0's with relative error (%)			
	^{94}Zr		^{96}Zr	
RICABARRA (1970)	6.27	(0.8)	879	(10.9)
FULMER (1971)	5.77		250	(22.8)
CH. NUCL.(1972)	5.45		250	
V.D. LINDEN	7.64	(5.2)		
SANTRY (1973)	4.59	(8.7)	227	(15.0)
IAEA (1974)	5.1		100	
SIMONITS (1975)	6.5	(12.3)	260	(15.4)
Recommended (1989)	**5.05**	**(2.0)**	**248**	**(1.5)**




DETECTOR MK4
ε_p (log)
10^{-3}
10^{-4}
10^2
10^3
E_γ, keV (log)
^{22}Na
^{24}Na
^{54}Mn
^{57}Co
^{60}Co
^{72}Ga
^{88}Y
^{110m}Ag
^{137}Cs
^{133}Ba
^{152}Eu
^{182}Ta
^{226}Ra
^{241}Am
40 - 330 keV
$\log \varepsilon_p = -64.0809 + 79.3443 (\log E_\gamma) - 33.8506 (\log E_\gamma)^2 + 4.7669 (\log E_\gamma)^3$
330 - 650 keV
$\log \varepsilon_p = -1.9525 + 0.2094 (\log E_\gamma) - 0.2210 (\log E_\gamma)^2$
650 - 1500 keV
$\log \varepsilon_p = -0.6662 - 0.8700 (\log E_\gamma)$
>1500 keV
$\log \varepsilon_p = -0.3692 - 0.8615 (\log E_\gamma)$


z
t_s
$x^2+y^2=r_s^2$ (cyl 1)
$x^2+y^2=(r_s+t_s)^2$ (cyl 4)
T
θ
z=d (plane 1)
P
ϕ
T'
x
z=-D (plane 2)
γ
z=-H (plane 3)
$x^2+y^2=R_s^2$ (cyl 3)
$x^2+y^2=R_c^2$ (cyl 2)


$\frac{(\varepsilon_p)d}{\varepsilon_p)ref}$
34.00
32.00
30.00
d = 1.326 cm
+2%
-2%
100
1000
E_γ keV (log)


$\frac{\varepsilon_{p,geo}}{\varepsilon_{p,point}}$
1.0
0.8
0.6
d=1.394 cm
d=1.429 cm
d=1.429 cm
100
1000
E_γ keV (log)

KAYZERO

element concentration calculation using

the k_0 standardization method

Version 3.0

preliminary

Manual

june 1993

Software by DSM Research, Geleen (NL)
for NAA using the k_0 standardization technique
developed at the INW-RU, Gent (B) and the KFKI, Budapest (H).

THE MODIFIED WESTCOTT FORMALISM

Reaction rate calculations:

$$R = \Phi_0 \cdot \sigma_0 \cdot \left(g(T_n) + r\sqrt{T_n/T_0} \cdot s_0\right) \cdot$$

⇓ introducing α and f

$$R = \Phi_0 \cdot \sigma_0 \cdot \left[g(T_n) + r(\alpha) \cdot \sqrt{T_n/T_0} \cdot s_0(\alpha)\right] \cdot$$

where

$g(T_n)$ - Westcott's factor (≠ 1 for "non-1/v" isotopes)

T_n - neutron temperature

$$s_0(\alpha) = \frac{2}{\sqrt{\pi}} \cdot \frac{I'_0(\alpha)}{\sigma_0} \quad \text{with} \quad I'_0(\alpha) = I'_0(\bar{E}_r)^{-\alpha}$$

$I'_0(\alpha)$ = reduced resonance integral (1/v part subtracted)

$r(\alpha)\sqrt{T_n/T_0}$ - modified spectral index

Note: for 1/v reactions [$g(T_n) = 1$] $s_0 = (2/\sqrt{\pi}) \cdot Q_0 - 0.484$

THE MODIFIED WESTCOTT FORMALISM IN THE K_0-METHOD

Concentration calculation

HØGDAHL

$$\rho(x) = \frac{\left[\frac{N_p(x)}{t_m \cdot S \cdot D \cdot C \cdot W}\right]_{sample}}{k_{0,Au}(x)} \cdot \frac{f + Q_{0,Au}(\alpha)}{f + Q_{0,x}(\alpha)} \cdot \frac{\varepsilon_{p,Au}}{\varepsilon_{p,x}}$$

⇓

WESTCOTT (mod)

$$\rho(x) = \frac{\left[\frac{N_p(x)}{t_m \cdot S \cdot D \cdot C \cdot W}\right]_{sample}}{k_{0,Au}(x)} \cdot \frac{g_{Au}(T_n) + r(\alpha)\sqrt{T_n/T_0} \cdot s_{0,Au}(\alpha)}{g_x(T_n) + r(\alpha)\sqrt{T_n/T_0} \cdot s_{0,x}(\alpha)} \cdot \frac{\varepsilon_{p,A}}{\varepsilon_{p,x}}$$

NUCLEAR DATA FOR SOME ANALYTICALLY INTERESTING NON-1/V NUCLIDES

Reaction	Half life	$g(T_n)$ [20 °C]	E_r(eff.) eV	s_0	Notes
$^{103}Rh(n,\gamma)^{104}Rh$	42.3 s	1.025	1.45	7.26	
$^{115}In(n,\gamma)^{116m}In$	54.1 min	1.020	1.56	18.5	
$^{151}Eu(n,\gamma)^{152m}Eu$	9.32 h	0.901	0.448	1.2	
$^{164}Dy(n,\gamma)^{165m}Dy$	1.258 min	0.988	224	-0.2	
$^{168}Yb(n,\gamma)^{169}Yb$	32.02 d	1.050*	0.61	5.0	*only at 20 and 100 °C
$^{175}Lu(n,\gamma)^{176}Lu$	3.635 h	0.977	16.1	38.8	
$^{176}Lu(n,\gamma)^{177}Lu$	6.71 d	1.746	0.158	1.67	T_n monitor
$^{191}Ir(n,\gamma)^{192}Ir$	73.83 d	1.033	1.1	5.8	
$^{193}Ir(n,\gamma)^{194}Ir$	19.15 h	1.022	2.21	13.1	
$^{197}Au(n,\gamma)^{198}Au$	2.695 d	1.007	5.65	17.24	α, f monitor

PUBLISHED K_0-RELATED NUCLEAR DATA COMPILATIONS

- Q_0-measurements for **13** isotopes	Moens (1979)
- Calculated E_r-values for **96** isotopes	Moens (1979)
- k_0-measurements for **35** isotopes	Simonits (1980)
- k_0 and related nucl. data compilation for **80** isotopes	De Corte (1982)
- Q_0-measurements for **57** isotopes	Simonits (1984)
- k_0-measurements for **72** isotopes	Moens (1984)
- Calc. and measured E_r-values for **127** isotopes	Jovanović (1984)
- k_0 and related nucl. data comp. for **112** isotopes	De Corte (1989)
- k_0 and related nucl. data comp. for **122** isotopes	De Corte (1991)

IMPACT OF THE K_0-CONCEPT ON OTHER FIELDS

- Neutron metrology
  Φ_s/Φ_e and α determinations (De Corte 1979)

- Epicadmium activation analysis
  Converting k_0-factors into $k_{0,epi}$ (El Nimr 1981)

- $^{235}U(n,f)$ interference correction
  Introducing k_0^{fiss} values (Lin Xiley 1984)

- NAA with 14 MeV neutron generator
  k_0-values for (n,p), (n,α) reactions (Janczynszy 1985)

- Use of unresolved γ-peaks for analysis
  Introduction of k_i-values derived from γ_i and $k_{0,i}$ (Erdtmann 1988)

- **NAA using very short-lived isotopes**
  k_0-measurements for msec-living isotopes (Roth 1990)

- Quality assurance in classical NAA
  consistency check of standard sets by their calculated k_0-ratios (Heydorn 1992)

Paper presented at the *IAEA Specialists Meeting on the Development of an International Nuclear Decay Data and Cross-Section Database*, Vienna, 24-28 October 1994.

3.2

FROM k_0 TO A RELIABLE AND CONSISTENT DATA BASE OF σ_0 AND ESSENTIAL RELATED ACTIVATION AND DECAY CONSTANTS

F. DE CORTE[1)*] and A. SIMONITS[2)]

[1)] *Institute for Nuclear Sciences (INW), Laboratory of Analytical Chemistry, University of Gent, Proeftuinstraat 86, B-9000 Gent, Belgium*

* *Research Director of the National Fund of Scientific Research*

[2)] *KFKI-Atomic Energy Research Institute of the Hungarian Academy of Sciences, H-1525 Budapest 114, POB 49, Hungary*

As outlined at the present meeting by Dr. A. Simonits, k_0-factors are composite nuclear constants containing molar masses (M), isotopic abundances (θ), absolute gamma-intensities (γ) and 2200 ms^{-1} (n,γ) cross sections (σ_0), also including these data for the ultimate comparator $^{197}Au(n,\gamma)^{198}Au$ [411.8 keV]. Precise and accurate k_0-values for [the most prominent gamma lines of] 122 (n,γ) reactions were obtained as a result of measurements, mainly at the INW and the KFKI, via the activation method performed with various experimental setups (targets, reactors, Ge detectors, etc.).

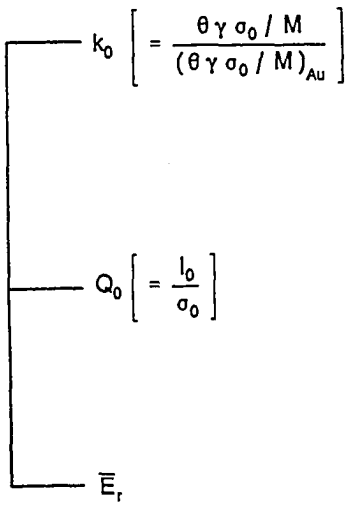
Evidently, k_0's can easily be converted to corresponding σ_0's by introducing values for M, θ and γ (and M, θ, γ and σ_0 for Au). With regard to the quality and applicability of the thus created σ_0 data set, it is strongly advisable that: i) the input for γ (and for θ, in case of less abundant isotopes) is based on an up-to-date and internationally recognized data base; and ii) the final σ_0 data base contains (or at least refers to) the input data as well, in order to guarantee consistency and traceability. Illustrative for this is our presentation given at the 1988 Conference on Nuclear Data for Science and Technology, Mito, Japan.

A data base of I_0(resonance integrals) can be obtained from this set of σ_0's by combination with the set of Q_0-values (I_0/σ_0 ratios), which are input data when determining and applying k_0-factors (so as to take into account the contribution of epithermal activation) and which were experimentally measured at the INW and the KFKI using the Cd-ratio method. At present, some of the data in our Q_0-library do not originate from experimental determination at the INW/KFKI but are taken from former compilations (often containing conflicting data). Updating and extension is highly desirable.

Determination and application of Q_0 requires correction for a non-1/E epithermal neutron flux distribution, and this can be based on the concept of the $1/E^{1+\alpha}$ approximation and the effective resonance energy $\bar{E}_r$. The presently available INW/KFKI E_r-library, as published in the 1987 IAEA Handbook on Nuclear Activation Data, was based on calculation using the resonance parameter data from BNL 1981/1984. For cases where these data were not available [e.g. $^{96}Ru(n,\gamma)$], a method was worked out for experimental $\bar{E}_r$-determination. In general, updating of the existing $\bar{E}_r$ data library is strongly advised and should be based on the most recent compilation of evaluated resonance parameter data.

Our existing data base of σ_0 and essential related activation and decay constants (M, θ, γ, I_0 and $\bar{E}_r$) dates from the mid-80's and was mainly released as compilations published in the Journal of Radioanalytical and Nuclear Chemistry. Upgrading and extension can be performed as outlined above.

k_0-NAA LIBRARY [122 (n,γ) REACTIONS]



σ_0 DATA BASE

-SHOULD BE DERIVED FROM UP-TO-DATE AND INTERNATIONALLY RECOGNIZED INPUT γ

M : GENERALLY NO PROBLEMS

θ : CAN BE PROBLEMATIC FOR MINOR ISOTOPES
[CF: P. DE BIÈVRE, F. DE CORTE, L. MOENS, A. SIMONITS, J. HOSTE, INT. J. MASS SPECTROM. ION PHYS., 1983]

EXPER. DETERMIN.

[INW, KFKI]

k_0

INPUT : M , θ , γ

[+ DATA FOR Au]

σ_0

σ_0 DATA BASE

- SHOULD ALSO CONTAIN (OR AT LEAST REFER TO) THE INPUT DATA, IN ORDER TO GUARANTEE CONSISTENCY AND TRACEABILITY

THE CASE ^{174}Yb (n,γ)^{175}Yb (m+g)

SITUATION MID 1980's

M_{Yb} = 173.04; θ_{174} = 31.8%; γ: BROWNE & FIRESTONE, 1986

^{175}Yb E_γ, keV	k_0 [EXP] INW / KFKI	γ, % * 1986	$\sigma_{0,\ BARN}$
113.8	9.42 10^{-3}	1.91	128
137.7	5.69 10^{-4}	0.117	126
144.9	1.59 10^{-3}	0.332	125
282.5	1.46 10^{-2}	3.05	125
396.3	3.12 10^{-2}	6.5	125

* 12% SYSTEMATIC UNCERTAINTY

THE CASE ^{174}Yb (n,γ)^{175}Yb (m+g)

SITUATION MID 1980's

* DE CORTE, SIMONITS ET AL., MID 1980's: 126 BARN

CF: * MUGHABGHAB & CHRIEN, 1968: 65 BARN

[TRANSMISSION METHOD;
98.97% ^{174}Yb;
$\sigma_{TOT.}$ = 142 BARN;
$\sigma_{SCATTER.}$ = 77 BARN]

* SIMS & JUHNKE, 1970: 141 BARN

[ACTIVATIN METHOD;
γ_{396} = 6.0%]

* HEFT, 1979: 108 BARN

[ACTIVATION METHOD;
γ_{396} = 6.98 %]

THE CASE ^{174}Yb (n,γ)^{175}Yb (m+g)

SITUATION 1994

γ's FROM MIYAHARA, MATUMOTO & MORI, IJARI, 1994

M_{Yb} = 173.04; θ_{174} = 31.8%

^{174}Yb E_γ, keV	[γ, % 1986]	γ, % 1994	σ_0, BARN
113.8	[1.91]	3.857	63.4
137.7	[0.117]	0.2188	67.5
144.9	[0.332]	0.6695	62.0
282.5	[3.05]	6.103	62.4
396.3	[6.5]	13.101	62.0

THE CASE ^{174}Yb (n,γ)^{175}Yb (m+g)

SITUATION 1994

* DE CORTE, SIMONITS ET AL., 1994: 63 BARN

CF: * MUGHABGHAB & CHRIEN, 1968: 65 BARN

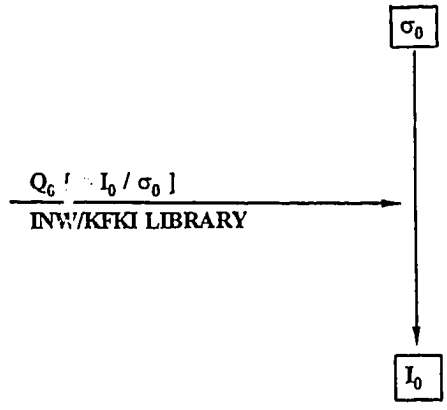
* SIMS & JUHNKE, 1970: 65 BARN

* HEFT, 1979: 58 BARN

σ_0 DATA BASE

INW/KFKI PUBLICATIONS

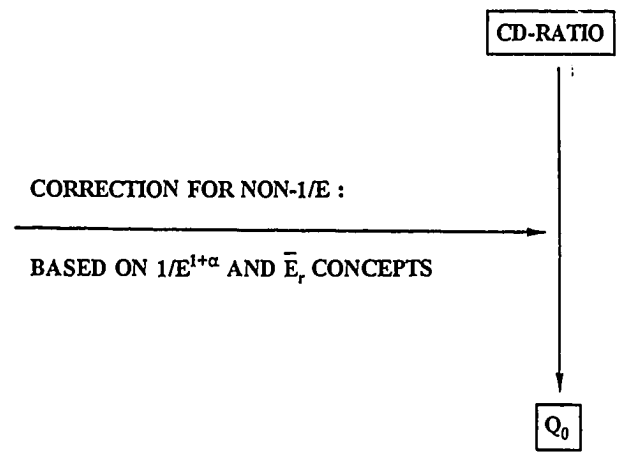
* JRNC, 1984 -1985 (SELECTED CASES)
* BULL.SOC.CHIM.BELGE, 1986 (ROLE OF INPUT DATA)
* PROCEED. MITO, JAPAN, 1988 (COMPILATION)
* PROCEED. MITO, JAPAN, 1988 (CONSISTENCY)
* JRNC, 1989 (COMPILATION)



INW / KFKI Q_0-LIBRARY

* JRNC, 1989 (2 PAPERS) (COMPILATION)
* DATA MOSTLY (BUT NOT ALWAYS) BASED ON CD-RATIO MEASUREMENTS (AT INW, KFKI, RISØ, LNETI, IJS, ETC.)

TO BE UPDATED AND EXTENDED



INW / KFKI $\bar{E}_r$ LIBRARY

* BASED ON CALCULATION USING THE RESONANCE PARAMETER DATA FROM BNL 1981/1984
* EXPERIMENTAL DETERMINATION METHOD DEVELOPED FOR CASES WHERE NO RESONANCE DATA ARE AVAILABLE [E.G. ^{96}Ru (n,γ)]
* JRNC, 1987 [CALCULATED $\bar{E}_r$'s]
  JRNC, 1984 / 1985 [EXP. DETERM.]

TO BE UPDATED, BASED ON
THE MOST RECENT COMPILATION OF
EVALUATED RESONANCE PARAMETER DATA

CONCLUSION

OUR EXISTING DATA BASE OF σ_0 AND ESSENTIAL RELATED ACTIVATION AND DECAY CONSTANTS (M, θ, γ, I_0 AND $\bar{E}_r$) DATES FROM THE MID-80's AND WAS MAINLY RELEASED AS COMPILATIONS PUBLISHED IN THE JOURNAL OF RADIOANALYTICAL AND NUCLEAR CHEMISTRY. UPGRADING AND EXTENSION CAN BE PERFORMED AS OUTLINED.

3.3

Report to the
IAEA Specialists' Meeting on the
Development of an International Nuclear Half-Life
and Cross-Section Database
IAEA Headquartes, Vienna, 24-28 October 1994

Nuclear Data Standards for Nuclear Measurements NEANDC/INDC Nuclear Standards File

H Condé, Dept of Neutron Research, Uppsala University, Sweden

Introduction

The NEANDC/INDC Standards File consists of status summaries for eighteen nuclear data standards and data tabulations. The narrative summaries describe the current status of each of the standards and include references to recent relevant work and areas of continuing uncertainties. These brief reviews were prepared under the auspicies of the OECD/Nuclear Energy Agency Nuclear Data Committee (NEANDC) and the IAEA/ International Nuclear Data Committee (INDC) by outstanding specialists in the respective fields. The NEANDC was terminated in November 1991. The responsibility at NEA for the Nuclear Standards File has subsequently been taken over by a Working Party on Experimental Activities under the new Committee on Nuclear Science at OECD/NEA.

The objective of the file is to provide concise and readily usable reference guidelines to essential nuclear standards quantities for a variety of basic and applied endeavours.

The large majority of the recommended numerical data for the standard cross sections is taken from ENDF/B-VI, produced by the United States Cross Section Evaluation Working Group. The reminder of the numerical data is from evaluations undertaken by individuals or groups closely connected with the nuclear data activities promoted by the NEANDC and INDC. Generally, the numerical data tables include quantitative definitions of the data uncertainties and some guidelines as to their appropriate usage.

The 1982 version of the Standards File was published as an IAEA document (Technical Reports Series No 227, IAEA, Vienna, 1983) and the 1991 updated version was published by OECD/NEA (NEANDC-311 "U", INDC(SEC)-101, OECD/NEA 1992).

Reference-Data-Types and Review Responsibilities

The standards file consists of tabulated reference values and a status summary for eighteen nuclear data standards. The narrative summaries consist of concise statements delineating nuclear reference standards judged of importance by the Committee.

These statements, prepared by selected specialists, outline the contemporary status (including shortcomings) and suggest possible avenues toward improvement. The statements explicitly support the accompanying numerical tabulations and set forth other important nuclear standards not amenable to straightforward numerical tabulation. The review responsibility distribution as of 1991/1992 was as follows.

	Responsibilty	
Standard	National	Specialist
H(n,n)H	USA	G Hale/P Young
$^{6}Li(n,t)^{4}He$	USA	P Young/G Hale
$^{10}B(n,\alpha)^{7}Li$	CBNM	E Wattecamps
C(n,n)C	USA	Y Fu/P Young
$^{197}Au(n,\gamma)^{198}Au$	CBNM	F Corvi
$^{235}U(n,f)$	UK/USSR	M Sowerby/V Konshin
^{235}U Fiss Fragm Anistropy	CBNM	F J Hambsch
$^{238}U(n,f)$	Japan	Y Nakayima/Y Kanda
$^{27}Al(n,\alpha)$	Austria	H Vonach
$^{59}Co(n,2n)^{58}Co$	Austria	H Vonach
$^{93}Nb(n,2n)^{92}Nb$	Austria	H Vonach
Neutron Energy Standards	Italy	C Coceva
Actinide Half-lives	CBNM/IAEA	W Bambynek/H Lemmel
Thermal parameters	France	H Tellier
Low Energy Cross Section Dependence	Belgium	C Wagemans
^{252}Cf Fission Spectrum	Germany/IAEA	W Mannhart/H Lemmel
	Russia	M Blinov
^{252}Cf nu-bar	Australia	J W Boldeman
Neutron Flux Comparison	France	E Fort/G Grenier
Gamma-ray Standards	France/IAEA	J Legrand/H Lemmel

Besides the recommended thermal cross-sections for the standard reactions involving light and medium weight nuclei the recommended values and the status summary for "Actinide Half-Lives", "Thermal Parameters for ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu" and "X-ray and Gamma-ray Standards" are of particular interest for this meeting. Thus, those three entries from the 1991 NEANDC/INDC Nuclear Standards File report (NEANDC-311 "U") are given below:

STATUS OF ACTINIDE HALF LIVES

W Bambynek
Commission of The European Communities, Joint Research Centre, Geel Establishment, Central Bureau for Nuclear Measurements, B-2440 Geel, Belgium

H Lemmel
International Atomic Energy Agency, A-1010 Vienna

The recommended reference half-life data for the major actinides, included in the 1985 revision of the 1983 INDC/NEANDC Standards File, resulted from an extensive international review of transactinium nuclide decay data performed by an IAEA Coordinated Research Programme (CRP) from 1978 to 1985. The results of this effort were published in the IAEA Technical Report Series No. 261 (1986). The complete listings, published in this IAEA report, include decay data for a wide range of heavy elements of broader interest than that of nuclear standards.

In the end of 1989, a Specialist's Meeting on the Status and the Requirements of Transactinium Isotope Decay Data reviewed the data in the light of new measurements and/or evaluations. In a number of cases, data have been supplemented or replaced by values measured or evaluated by members of the CRP and by other groups or inviduals.

The anticipated updating of the IAEA Technical Report 261 on Decay Data of Transactinium Nuclides is delayed. Among the half-life values, specifically ^{241}Pu requires updating, in view of recent experiments. A new evaluation may produce a value around 14.35 years compared to the presently recommended value of 14.4 ± 0.1 years.

ACTINIDE HALF-LIVES - Recommended Reference Data

Nuclide	Decay mode	Half-life and Uncertainty Years
U-233	Alpha	(1.592 ± 0.002) E05
	Spont. fission	> 2.7 E17
U-234	Alpha	(2.457 ± 0.003) E05
	Spont. fission	(1.42 ± 0.08) E16
U-235	Alpha	(7.037 ±0.007) E08
	Spont. fission	(1.0 ± 0.3) E19
U-238	Alpha	(4.47 ± 0.02) E09
	Spont. fission	(8.2 ± 0.1) E15
Np-237	Alpha	(2.14 ± 0.01) E06
	Spont. fission	> 1. E18
Pu-239	Alpha	(2.411 ± 0.003) E04
	Spont. fission	(8. ± 2.) E15
Pu-240	Alpha	(6.563 ± 0.007) E03
	Spont. fission	(1.16 ±0.02) E11
Pu-241	Alpha	(5.96 ± 0.04) E05
	Beta	(1.44 ± 0.01) E01
Pu-242	Alpha	(3.75 ± 0.02) E05
	Spont fission	(6.77 ± 0.07) E10
Pu-244	Alpha	(8.00 ± 0.09) E07
	Spont. fission	(6.6 ± 0.2) E10
Cf-252	Alpha	(2.73 ± 0.01) E00
	Spont. fission	(8.55 ± 0.03) E01
	Total	(2.645 ± 0.008) E00

THERMAL PARAMETERS FOR ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu

H Tellier
Centre d'Etudes de Saclay, France

The thermal cross sections of ^{235}U are considered as standard reference data for cross section measurements of other nuclides. The thermal neutron data of ^{233}U, ^{235}U, ^{239}Pu, and ^{241}Pu are correlated, because cross section ratios between these nuclides have been measured in addition to some accurate absolute values. The values for 2200 m/s neutrons (0.0253 eV) are used for normalization of cross section curves at thermal and higher energies.

The following table shows a comparison of the recommended values of ENDF/B-VI and the ones adopted in the recent file JEF-2

		ENDF/B-VI	JEF-2
^{235}U	σ_f	584.25 ± 1.11	582.5
	σ_γ	98.25 ± 0.74	98.8
	ν_t	2.4320 ± 0.0036	2.437
^{233}U	σ_f	531.14 ± 1.33	528.45
	σ_γ	45.51 ± 0.23	45.76
	ν_t	2.4946 ± 0.0040	2.4947
^{239}Pu	σ_f	747.99 ± 1.37	747.2
	σ_γ	271.43 ± 2.14	270.2
	ν_t	2.8815 ± 0.0052	2.877
^{241}Pu	σ_f	1012.68 ± 6.58	1011.88
	σ_γ	361.29 ± 4.95	362.95
	ν_t	2.9453 ± 0.0059	2.932
^{252}Cf	ν_t	3.7676 ± 0.0049	

The ENDF/B-VI values are based on Axton's evaluation. The JEF-2 values are the result of an important benchmarking of integral data (mainly k_{eff} measurements for a high number of thermal neutron critical experiments). That is why we can observe little differences between the ENDF/B-VI values and the JEF-2 ones.

For the nu-bar ratio data the insufficient knowledge of the fission neutron spectra of the fissile nuclides used to be a significant source of uncertainties. For ^{252}Cf the fission neutron spectrum shape is now better known from Mannhart's evaluation. It would now be essential to establish reliable spectrum shapes also for the other fissile nuclides. Thereafter one should investigate whether the improved spectrum shapes have a noticeable impact on the corrections for the nu-bar ratio experiments. As the recommended nu-bar values have errors of 0.15 to 0.2 percent, even small changes in nu-bar ratio corrections may have an impact on the thermal parameters.

X-RAY AND GAMMA-RAY STANDARDS

J Legrand, A Lorenz
France/IAEA
June 1988

Updated by H D Lemmel, IAEA, Vienna, August 1992

The efficiency calibration of gamma-ray detectors requires a precise knowledge of the gamma-ray energies and emission probabilities of the calibrant radionuclides. The need for an universally accepted base of radionuclide decay data to serve as a standard for the efficiency calibration of gamma-ray detectors has become increasingly apparent in the course of nuclear measurement intercomparison programmes performed over the past few years. A variety of reference data sets has been developed for this purpose in many gamma spectroscopy laboratories. The formulation and use of a single internationally produced and accepted file of carefully evaluated decay data would eliminate inconsistencies and improve the accuracy of detector efficiency calibrations.

In 1986, the IAEA initiated a Coordinated Research Programme (CRP) aimed specifically at the production of a single internationally accepted set of x-ray and gamma-ray detector calibration data of improved quality to meet the needs of radioactivity measurements in fields such as safeguards, dosimetry and fuel management. In particular, this programme examines the current status and adequacy of radionuclide decay data used for detector efficiency calibration, identifies additional nuclides which could be appropriate as calibration standards, and initiates appropriate actions, (i.e.

required measurements and/or evaluations) to produce the required file of calibration data.

The conclusions of this CRP have been published in IAEA-TECDOC-619 (Sept 1991). The recommended values from this report are listed on the following pages. These data are also available on a PC diskette by Hartmut Lemmel which can be obtained from the IAEA Nuclear Data Section, costfree upon request.

References

Work referred to in the lists of Recommended Reference Data was performed in the context of the IAEA Coordinated Research Programme on X- and Gamma-ray Standards for Detector Efficiency Calibration (1986 - 1989)

1. M J Woods, A S Munster, National Physical Laboratory (NPL), Teddington, Middelsex, UK and K Debertin, Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Geramany
2. K Debertin, Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany and M J Woods, A S Munster, National Physical Laboratory (NPL), Teddington, Middelsex, UK
3. W Bambynek, CEC-JRC, Central Bureau for Nuclear Measurements (CBNM), Geel, Belgium
4. F J Schima, National Institute of Standards and Technology (NIST), Gaithersburg, Mayland, USA
5. Y Yoshizawa, Faculty of Sciences, Hiroshima University, Hiroshima-Shi, Japan
6. A L Nichols, AEA Technology, Winfrith Technology Centre, Dorchester, Dorset, UK
7. T Barta, R Jedlovszky, National Office of Measures (OMH), Budapest, Hungary
8. N Coursol, Laboratoire de Métrologie des Rayonnements Ionisants (LMRI), Gif-sur-Yvette, France
9. R G Helmer, Idaho National Engineering Laboratory (INEL), Idaho Falls, Idaho, USA
10. F Lagoutine, Laboratoire de Métrologie des Rayonnements Ionisants (LMRI), Gif-sur-Yvette, France

X-RAY AND GAMMA-RAY STANDARDS - Recommended Reference Data

Table 1: Half-Lives of Radionuclides Used for Detector Calibration

Nuclide	Decay Mode	Half-life (days) Value	Uncertainty	Exponent	Reference
11-Na-022	EC	950.8	± 0.9		(1)
11-Na-024	β-	0.62356	± 0.00017		(1)
21-Sc-046	β-	83.79	± 0.04		(1)
24-Cr-051	EC	27.706	± 0.007		(1)
25-Mn-054	EC	312.3	± 0.4		(1)
26-Fe-055	EC	999	± 8		(1)
27-Co-056	EC	77.31	± 0.19		(1)
27-Co-057	EC	271.79	± 0.09		(1)
27-Co-058	EC	70.86	± 0.07		(1)
27-Co-060	β-	1925.5	± 0.5		(1)
30-Zn-065	EC	244.26	± 0.26		(1)
34-Se-075	EC	119.64	± 0.24		(1)
38-Sr-085	EC	64.849	± 0.004		(1)
39-Y-088	EC	106.630	± 0.025		(1)
41-Nb-093m	IT	5890	± 50		(2)
41-Nb--094	β-	7.3	± 0.9	E+06	(2)
41-Nb-095	β-	34.975	± 0.007		(2)
48-Cd-109	EC	462.6	± 0.7		(2)
49-In-111	EC	2.8047	± 0.0005		(2)
50-Sn-113	EC	115.09	± 0.04		(2)
51-Sb-125	β-	1007.7	± 0.6		(2)
53-I-125	EC	59.43	± 0.06		(2)
55-Cs-134	β-	754.28	± 0.22		(2)
55-Cs-137	β-	1.102	± 0.006	E+04	(2)
56-Ba-133	EC	3862	± 15		(2)
58-Ce-139	EC	137.640	± 0.023		(2)
63-Eu-152	EC	4933	± 11		(2)
63-Eu-154	β-	3136.8	± 2.9		(2)
63-Eu-155	β-	1770	± 50		(2)
79-Au-198	β-	2.6943	± 0.0008		(2)
80-Hg-203	β-	46.595	± 0.013		(2)
83-Bi-207	EC	1.16	± 0.07	E+04	(2)
90-Th-228	α	698.2	± 0.6		(1)

Table 1 (cont)

Nuclide	Decay Mode	Half-life (days) Value	Uncertainty	Exponent	Reference
93-Np-239	β-	2.350	± 0.004		(2)
95-Am-241	α	1.5785	± 0.0024	E+05	(2)
95-Am-243	α	2.690	± 0.008	E+06	(1)

X-RAY AND GAMMA-RAY STANDARDS - Recommended Reference Data

Table 2: X-Ray Standards, Energies and Emission Probabilities

The data uncertainties are standard deviations. For the emission probabilities uncertainties are noted as last digit uncertainties, i.e. 12.3(4) means 12.3 ± 0.4 and 12.3(14) means 12.3 ± 1.4

Nuclide	Trans	Energy (keV)	Probability
24-Cr-051	VKα	4.95	0.201(3)
24-Cr-051	VKβ	5.43	0.027(1)
24-Cr-051	VKx	4.95-5.43	0.228(3)
25-Mn-054	CrKα	5.41	0.226(7)
25-Mn-054	CrKβ	5.95	0.030(1)
25-Mn-054	CrKx	5.41-5.95	0.256(8)
26-Fe-055	MnKα	5.89	0.249(9)
26-Fe-055	MnKβ	6.49	0.034(1)
26-Fe-055	MnKx	5.89-6.49	0.283(10)
27-Co-057	FeKα	6.40	0.510(7)
27-Co-057	FeKβ	7.06	0.069(1)
27-Co-057	FeKx	6.40-7.06	0.579(8)
27-Co-058	FeKα	6.40	0.235(3)
27-Co-058	FeKβ	7.06	0.032(1)
27-Co-058	FeKx	6.40-7.06	0.267(3)
30-Zn-065	CuKα	8.03-8.05	0.341(6)
30-Zn-065	CuKβ	8.91	0.046(1)
30-Zn-065	CuKx	8.03-8.91	0.387(6)
34-Se-075	AsKα	10.51-10.54	0.493(11)
34-Se-075	AsKβ	11.72-11.95	0.075(2)
34-Se-075	AsKx	10.51-11.95	0.568(13)
38-Sr-085	RbKα	13.34-13.40	0.500(3)
38-Sr-085	RbKβ	14.96-15.29	0.087(2)
38-Sr-085	RbKx	13.34-15.29	0.587(4)

Table 2 (cont)

Nuclide	Trans	Energy (keV)	Probability
39-Y-088	SrKα	14.10-14.17	0.522(6)
39-Y-088	SrKβ	15.83-16.19	0.094(2)
39-Y-088	SrKx	14.10-16.19	0.616(7)
41-Nb-093m	NbKα	16.52-16.62	0.0925(30)
41-Nb-093m	NbKβ	18.62-19.07	0.0179(7)
41-Nb-093m	NbKx	16.52-19.07	0.1104(35)
48-Cd-109	AgKα	21.99-22.16	0.821(9)
48-Cd-109	AgKβ	24.93-25.60	0.173(3)
48-Cd-109	AgKx	21.99-25.60	0.994(10)
49-In-111	CdKα	22.98-23.17	0.684(5)
49-In-111	CdKβ	26.09-26.80	0.146(3)
49-In-111	CdKx	22.98-26.80	0.830(5)
50-Sn-113	InKα	24.00-24.21	0.796(6)
50-Sn-113	InKβ	27.27-28.02	0.172(3)
50-Sn-113	InKx	24.00-28.02	0.968(6)
53-I-125	TeKα	27.20-27.47	1.135(21)
53-I-125	TeKβ	30.98-31.88	0.255(6)
53-I-125	TeKx	27.20-31.88	1.390(25)
55-Cs-137	BaKα	31.82-32.19	0.0566(16)
55-Cs-137	BaKβ	36.36-37.45	0.0134(5)
55-Cs-137	BaKx	31.82-37.45	0.0700(20)
56-Ba-133	CsKα	30.63-30.97	0.980(14)
56-Ba-133	CsKβ	34.97-36.01	0.230(5)
56-Ba-133	CsKx	30.63-36.01	1.210(16)
58-Ce-139	LaKα	33.03-33.44	0.643(18)
58-Ce-139	LaKβ	37.78-38.93	0.154(5)
58-Ce-139	LaKx	33.03-38.93	0.797(22)

Table 2 (cont)

Nuclide	Trans	Energy (keV)	Probability
63-Eu-152	SmKα	39.52-40.12	0.591(12)
63-Eu-152	GdKα	42.31-43.00	0.00648(22)
63-Eu-152	SmKβ	45.38-46.82	0.149(3)
63-Eu-152	GdKβ	48.65-50.21	0.00176(18)
63-Eu-152	SmKx	39.52-46.82	0.740(12)
63-Eu-152	GdKx	42.31-50.21	0.00824(28)
63-Eu-154	GdKα	42.31-43.00	0.205(6)
63-Eu-154	GdKβ	48.65-50.21	0.051(2)
63-Eu-154	GdKx	42.31-50.21	0.256(6)
79-Au-198	HgKα	68.89-70.82	0.0219(8)
79-Au-198	HgKβ	80.12-82.78	0.0061(3)
79-Au-198	HgKx	68.89-82.78	0.0280(10)
80-Hg-203	TlLx	8.95-14.40	0.060(12)
80-Hg-203	TlKα2	70.83	0.038(2)
80-Hg-203	TlKα1	72.87	0.064(2)
80-Hg-203	TlKβ1	82.43	0.022(1)
80-Hg-203	TlKβ2	85.19	0.0063(3)
80-Hg-203	TlKx	70.83-85.19	0.130(4)
83-Bi-207	PbLx	9.19-14.91	0.325(13)
83-Bi-207	PbKα2	72.80	0.226(12)
83-Bi-207	PbKα1	74.97	0.382(20)
83-Bi-207	PbKβ1	84.79	0.130(10)
83-Bi-207	PbKβ2	87.63	0.039(3)
83-Bi-207	PbKx	72.80-87.63	0.777(26)
95-Am-241	NpLl	11.871	0.0085(3)
95-Am-241	NpLα	13.927	0.132(4)
95-Am-241	NpLβη	17.611	0.194(6)
95-Am-241	NpLγ	20.997	0.049(2)

X-RAY AND GAMMA-RAY STANDARDS - Recommended Reference Data

Table 3: Gamma Ray Standards, Energies and Emission Probabilites

The data uncertainties are standard deviations. For the emission probabilities uncertainties are noted as last digit uncertainties, i.e. 12.3(4) means 12.3 ± 0.4 and 12.3(14) means 12.3 ± 1.4

Nuclide	Energy (keV)	Probability	Reference
11-Na-022	1274.542(7)	0.99935(15)	(4)
11-Na-024	1368.633(6)	0.999936(15)	(4)
11-Na-024	2754.030(14)	0.00855(5)	
21-Sc-046	889.277(3)	0.999844(16)	(5)
21-Sc-046	1120.545(4)	0.999874(11)	
24-Cr-051	320.0842(9)	0.0986(5)	(6)
25-Mn-054	834.843(6)	0.999758(24)	(5)
27-Co-056	846.764(6)	0.99933(7)	(5)
27-Co-056	1037.844(4)	0.1413(5)	
27-Co-056	1175.099(8)	0.02239(11)	
27-Co-056	1238.287(6)	0.6607(19)	
27-Co-056	1360.206(6)	0.04256(15)	
27-Co-056	1771.350(15)	0.1549(5)	
27-Co-056	2015.179(11)	0.03029(13)	
27-Co-056	2034.759(11)	0.07771(27)	
27-Co-056	2598.460(10)	0.1696(6)	
27-Co-056	3201.954(14)	0.0313(9)	
27-Co-056	3253.417(14)	0.0762(24)	
27-Co-056	3272.998(14)	0.0178(6)	
27-Co-056	3451.154(13)	0.0093(4)	
27-Co-056	3548.27(10)	0.00178(9)	
27-Co-057	14.4127(4)	0.0916(15)	(7)
27-Co-057	122.0614(3)	0.8560(17)	
27-Co-057	136.4743(5)	0.1068(8)	
27-Co-058	810.775(9)	0.9945(1)	(7)
27-Co-060	1173.238(4)	0.99857(22)	(4)

Table 3 (cont)

Nuclide	Energy (keV)	Probability	Reference
27-Co-060	1332.502(5)	0.99983(6)	
30-Zn-065	1115.546(4)	0.5060(24)	(6)
34-Se-075	96.7344(10)	0.0341(4)	(6)
34-Se-075	121.1171(14)	0.171(1)	
34-Se-075	136.0008(6)	0.588(3)	
34-Se-075	264.6580(17)	0.590(2)	
34-Se-075	279.5431(22)	0.250(1)	
34-Se-075	400.6593(13)	0.115(1)	
38-Sr-085	514.0076(22)	0.984(4)	(5)
39-Y-088	898.042(4)	0.940(3)	(8)
39-Y-088	1836.063(13)	0.9936(3)	
41-Nb-094	702.645(6)	0.9979(5)	(9)
41-Nb-094	871.119(4)	0.9986(5)	
41-Nb-095	765.807(6)	0.9981(3)	(9)
48-Cd-109	88.0341(11)	0.0363(2)	(8)
49-In-111	171.28(3)	0.9078(10)	(5)
49-In-111	245.35(4)	0.9416(6)	
50-Sn-113	391.702(4)	0.6489(13)	(9)
51-Sb-125	176.313(1)	0.0685(7)	(8)
51-Sb-125	380.452(8)	0.01518(16)	
51-Sb-125	427.875(6)	0.297(3)	
51-Sb-125	463.365(5)	0.1048(11)	
51-Sb-125	600.600(4)	0.1773(18)	
51-Sb-125	606.718(3)	0.0500(5)	
51-Sb-125	635.954(5)	0.1121(12)	
53-I-125	35.4919(5)	0.0658(8)	(8)
55-Cs-134	475.364(3)	0.0149(2)	(5)
55-Cs-134	563.240(4)	0.0836(3)	

Table 3 (cont)

Nuclide	Energy (keV)	Probability	Reference
55-Cs-134	569.328(3)	0.1539(6)	
55-Cs-134	604.720(3)	0.9763(6)	
55-Cs-134	795.859(5)	0.854(3)	
55-Cs-134	801.948(5)	0.0869(3)	
55-Cs-134	1038.610(7)	0.00990(5)	
55-Cs-134	1167.968(5)	0.01792(7)	
55-Cs-134	1365.185(7)	0.03016(11)	
55-Cs-137	661.660(3)	0.851(2)	(8)
56-Ba-133	80.998(5)	0.3411(28)	(7)
56-Ba-133	276.398(1)	0.07147(30)	
56-Ba-133	302.853(1)	0.1830(6)	
56-Ba-133	356.017(2)	0.6194(14)	
56-Ba-133	383.851(3)	0.08905(29)	
58-Ce-139	165.857(6)	0.7987(6)	(8)
63-Eu-152	121.7824(4)	0.2837(13)	(9)
63-Eu-152	244.6989(10)	0.0753(4)	
63-Eu-152	344.2811(19)	0.2657(11)	
63-Eu-152	411.126(3)	0.02238(10)	
63-Eu-152	443.965(4)	0.03125(14)	
63-Eu-152	778.903(6)	0.1297(6)	
63-Eu-152	867.390(6)	0.04214(25)	
63-Eu-152	964.055(4)	0.1463(6)	
63-Eu-152	1085.842(4)	0.1013(5)	
63-Eu-152	1089.767(14)	0.01731(9)	
63-Eu-152	1112.087(6)	0.1354(6)	
63-Eu-152	1212.970(13)	0.01412(8)	
63-Eu-152	1299.152(9)	0.01626(11)	
63-Eu-152	1408.022(4)	0.2085(9)	
63-Eu-154	123.071(1)	0.412(5)	(5)
63-Eu-154	247.930(1)	0.0695(9)	
63-Eu-154	591.762(5)	0.0499(6)	
63-Eu-154	692.425(4)	0.0180(3)	
63-Eu-154	723.305(5)	0.202(2)	
63-Eu-154	756.804(5)	0.0458(6)	
63-Eu-154	873.190(5)	0.1224(15)	

Table 3 (cont)

Nuclide		Energy (keV)		Probability	Reference
63-Eu-154		996.262(6)		0.1048(13)	
63-Eu-154		1004.725(7)		0.182(2)	
63-Eu-154		1274.436(6)		0.350(4)	
63-Eu-154		1494.048(9)		0.0071(2)	
63-Eu-154		1596.495(18)		0.0181(2)	
79-Au-198		411.8044(11)		0.9557(47)	(6)
80-Hg-203		279.1967(12)		0.8148(8)	(9)
83-Bi-207		569.702(2)		0.9774(3)	(5)
83-Bi-207		1063.662(4)		0.745(2)	
83-Bi-207		1770.237(9)		0.0687(4)	
90-Th-228		84.373(3)		0.0122(2)	(8)
90-Th-228	*	238.632(2)		0.435(4)	
90-Th-228	*	240.987(6)		0.0410(5)	
90-Th-228	*	277.358(10)		0.0230(3)	
90-Th-228	*	300.094(10)		0.0325(3)	
90-Th-228	*	510.77(10)	+	0.0818(10)	
90-Th-228	*	583.191(2)		0.306(2)	
90-Th-228	*	727.330(9)		0.0669(9)	
90-Th-228	*	860.564(5)		0.0450(4)	
90-Th-228	*	1620.735(10)		0.0149(5)	
90-Th-228	*	2614.533(13)		0.3586(6)	
93-Np-239		106.123(2)		0.267(4)	(10)
93-Np-239		228.183(1)		0.1112(15)	
93-Np-239		277.599(2)		0.1431(20)	
95-Am-241		26.345(1)		0.024(1)	(3)
95-Am-241		59.537(1)		0.360(4)	
95-Am-243		43.53(1)		0.0594(11)	(6)
95-Am-243		74.66(1)		0.674(10)	

* Indicates daughter in equilibrium with parent radionuclide

\+ Note the close distance to 511.003 keV annihilation radiation

Contribute to SM on Development of an International Nuclear Half-Life an Cross-Section Database.

Obtained results and present or future activities, on reference data of interest for the present SM, in the framework of ENEA Nuclear Data Programme.

(E. Menapace)

A. The initiatives are related to the international collaboration, namely:

i) **JEF (NEA) Project** for a **General Purpose File** (present version JEF - 2.2) including **cross section** and **decay** data for all relevant nuclides for the applications.

Role of the **Scientific Coordination Group** (SCG) and **ENEA participation** for the critical selection of "best" evaluated data from the internally or internationally available evaluations.

Participation to **NEA Working Party** for the **International Evaluation Comparison** and benefits for the JEF SCG work.

ii) **ENEA-CEA Cooperation for the Innovative and Future Reactors,** with main regard to nuclear parameters for safety, and including fuel cycle items with particular regard to nuclear burning or transmutation programme in advanced reactors for Pu and Minor Actinides and long-lived Fission Products.

In this context nuclear data of **interest for the present SM** were evaluated or critically selected with the contributes by **E N E A Nuclear Data Programme** and Laboratory specifically for:

B. **Thermal cross section** and **r e s o n a n c e integrals** (capture and fission data) evaluated values with main regard to:

i) **Fission Products;**

ii) **Burnable Poisons as control a b s o r b e r s:**

iii) **Major actinides;**

iv) **Minor actinides;**

v) **Structural material** natural isotopes, with main regard to **Fe, Ni, Cr, Zr, Mo, Cu.**

C. **Specific evaluations** performed within the **ENEA Nuclear Data Programme** including **thermal cross sections** and **resonance integrals** (radiative **capture and fission** data) concern:

i) **Gd**, and **Hf** natural isotopes:

ii) **Fission Products:**

$^{37}Rb_{85}$
$^{39}Y_{91}$
$^{40}Zr_{93}$
$^{41}Zr_{95}$
$^{41}Nb_{95}$
$^{42}Mo_{100}$
$^{43}Tc_{99}$
$^{44}Ru_{100}$
$^{44}Ru_{101}$
$^{44}Ru_{102}$
$^{44}Ru_{103}$
$^{44}Ru_{104}$
$^{44}Ru_{106}$
$^{45}Ru_{103}$
$^{46}Pd_{103}$
$^{46}Pd_{104}$
$^{46}Pd_{105}$
$^{46}Pd_{106}$
$^{46}Pd_{107}$
$^{46}Pd_{108}$
$^{46}Pd_{110}$
$^{47}Ag_{109}$
$^{48}Cd_{111}$
$^{49}In_{115}$
$^{52}Te_{128}$
$^{55}Cs_{133}$
$^{55}Cs_{135}$
$^{55}Cs_{137}$
$^{56}Bl_{138}$
$^{56}Bl_{140}$
$^{57}La_{139}$
$^{58}Ce_{140}$
$^{58}Ce_{141}$
$^{58}Ce_{142}$
$^{58}Ce_{144}$
$^{59}Pr_{141}$
$^{59}Pr_{143}$
$^{60}Nd_{143}$
$^{60}Nd_{144}$
$^{60}Nd_{145}$
$^{60}Nd_{146}$
$^{60}Nd_{147}$
$^{60}Nd_{148}$
$^{60}Nd_{150}$
$^{61}Pm_{147}$
$^{62}Sm_{147}$
$^{62}Sm_{149}$
$^{62}Sm_{150}$
$^{62}Sm_{151}$
$^{62}Sm_{152}$
$^{62}Sm_{154}$
$^{63}Eu_{153}$
$^{63}Eu_{154}$
$^{63}Eu_{155}$
$^{65}Tb_{159}$

iii) Fe and Cr natural isotopes,

$^{42}Mo_{95,97,98}$; $^{29}Cu_{63,65}$; $^{40}Zr_{91,92,94,96}$;

iv) $^{94}Pu_{241}$

v) $^{95}Am_{241,243}$; $^{96}Cm_{242,243,244,245}$

(Previous evaluations of minor actinides concerned more isotopes of Pu, Cm for the purposes of an IAEA CRP on Actinide Data Evaluation).

D **Present or planned activities.**

According to the **terms** of the **international cooperation,** as mentioned above, the activities regard **thermal** and **resonance** region **data** for:

i) **Structural materials**, such as natural isotopes of **Mg, Y, Ce, W, Nb;**

ii) Selected Fission Product nuclides, in particular **I-129;**

iii) **Burnable Poisons**, namely main natural isotopes of **Er** and **Hf** (mainly Er-166, -167 and Hf- 174, - 176, -177, -178, -179).

iv) **Minor Actinides** of relevance such as **Np-237, Am-241** and **-243.**

E. Specific data comparison.

i) Structural Materials

NUCLIDE	σ_c (b)		RI_c (b)		%
	JEF	MU84	JEF	MU84	Abn.
24-Cr-50	15.96	15.9±.2	7.43	7.8±.4	4.35
24-Cr-52	.76	.76±.06	0.47	0.40(*)	83.79
24-Cr-53	18.22	18.2±1.5	8.63	8.9(*)	9.50
24-Cr-54	.37	.36±.04	.18	.18±.04	2.36
40-Zr-90	.011	.011±.005	.16	0.14(*)	51.45
40-Zr-91	1.16	1.24±.25	4.90	5.2±.7	11.32
40-Zr-92	.26	.22±.06	.777	.63(*)	17.19
40-Zr-94	.0494	.0499±.002	.368	.23±.01	17.28
40-Zr-96	.0230	.0229±.001	5.77	5.3±.3	2.76
42-Mo-95	14.0	14.0±.5	109.6	109±5	15.92
42-Mo-97	2.14	2.1±.5	17.29	14.±3.	9.55
42-Mo-98	.13	.13±.006	7.08	6.9±.3	24.13
42-Mo-100	.198	.199±.003	3.96	3.75±.15	9.63

26-Fe natural isotopes: Capture thermal cross sections and resonance integrals adopted from MU84.

(*) Computed value.

MU84 = S.F. Mughabghab - "Neutron Cross Sections" Vol. 1 (1984).

ii) Fission Products.

NUCLIDE	σ_c (b) JEF	σ_c (b) MU84	RI_c (b) JEF	RI_c (b) MU84	% Abn.
37-Rb-85	.488	.48±.01	6.36	5.4±.5	72.17
39-Y-91	1.4	1.4±.3	1.67	------	
40-Zr-93	1.78	1.3-4	32.96	------	
40-Zr-95	.22	-----	6.12	------	
41-Nb-95	1.75	< 7	68.8	------	
43-TC-99	19.12	20±1	304.35	340±20	
44-Ru-100	5.80	5.±.6	8.16	11.2±1.1	12.6
44-Ru-101	3.41	3.4±.9	111.14	100±20	17.0
44-Ru-102	1.30	1.21±.07	3.21	4.2±.1	31.6
44-Ru-104	.30	.32±.02	5.80	4.3±.1	18.7
44-Ru-106	.146	.146±.045	2.08	2.0±.6	
44-Rh-103	146.2	145±2	1033	1100±50	100
44-Pd-105	21.83	20.0±3.0	93.77	62.2(*)	22.33
44-Pd-107	1.80	1.8±.2(*)	105.7	86.6(*)	
44-Pd-108	7.35	8.3±.5	171.9	244±4	26.46
47-Ag-109	90.7	91±1	146.8	1400±48(*)	48.17
48-Cd-111	23.71	24±3	48.35	50(*)	12.81
49-In-115	202	202±2	3215	3300±100	95.7
53-I-129	33.9	27±2	30.59	36±4	
55-Cs-133	29.09	29±1.5	438	437±26	100
55-Cs-135	9	8.7±1.5	59.9	62±2	
56-Ba-138	.35	.36±.036	.18	.32±.04	71.70
56-Ba-140	1.57	1.6±.3	13.7	13.6±1.4	
57-La-139	8.93	8.93±.04	11.9	11.8±.8	99.91
58-Ce-141	32.7	29±3	165	-----	
58-Ce-142	.90	.95±.05	1.01	1.15±.05	11.08
58-Ce-144	1.13	1.0±.1	2.72	2.6±.3	
59-Pr-141	11.48	11.5±.3	17.92	17.4±2.0	100
60-Nd-143	317	325±10	125	128±30	12.18
60-Nd-144	3.58	3.6±.3	4.16	3.9±.5(*)	23.80
60-Nd-145	41.8	42±2	231.6	240±35	8.30

60-Nd-147	440	440±150	604.8	405(*)	
60-Nd-148	2.50	2.5±.2	19.9	14±1	5.76
61-Pm-147	180.6	168.4±3.5	2130	2064±100(*)	
62-Sm-147	57.2	57±3	794	-----	15.1
62-Sm-149	40068	40140±600	3481	3390(*)	13.9
62-Sm-150	103.3	104±4	338.5	358±50	7.4
62-Sm-151	15213	15200±300	3458	3520(*)	
62-Sm-152	206	206±6	2991	2970±100	26.6
63-Eu153(°)	299.9	312±7	1448	1420±100	52.14
63-Eu-155	3627	3950±125	2180	23200±300(*)	
65-Tb-159	23.2	23.4±.4	406	418±20	100

ii) Nuclides related to burnable poisons.

63-Gd-156	1.35	1.5±1.2	100	104±15	20.6
64-Gd-157	254500	254000±815	763	700±20(*)	15.7

(°)Eu isotopes are possible candidates as burnable poisons too.

iii) Minor actinides.

NUCLIDE	σ_c (b)		σ_f (b)		RIc (b)		RIf (b)	
	JEF	MU84	JEF	MU84	JEF	MU84	JEF	MU84
94-Cm-242	16,5	16±5	5,8	< 5	117.	110±20	11.6	----
94-Cm-243	131	130±10	599	617±20	301	215±20	1855	1570±100
94-Cm-245	345	369±17	2143	2145±58	114	101±8	779	840±40

4. General Remarks

Page

4.1

Central Research Institute

of Management, Economy and Information
(Atominform)
of the Ministry of the Russian Federation for
Atomic Energy

Head Scientific Center of Branch Services on
Standard and reference Data

The V.G. Khlopin Radium Institute

To the Problem of International Nuclide Chart Development

Golashvili T.V., Lbov A.A., Chechev V.P.

Abstract

The issues resulting in the International Nuclide Chart development necessity are discussed along with the problem of different institution's participation in the task implementation.

Moscow 1994

Taking into consideration the increasing role of nuclear physics and its various applications in different branches of science, technique and technology it is highly efficient to develop the International Nuclide Chart issue involving all their basic characteristics. This chart will be based on the recent and the most reliable data established.

Due to what this standard chart issue intended for all round the world users is necessitated. At present there are several nuclide charts issued by various countries in different periods of time : for instance, the table issued in Germany ([1] -1981), in the USA ([3] -1988), in Japan ([2] -1988); moreover in France and in Great Britain such tables are at the stage of implementation. The similar proton-neutron nuclide chart has been issued in the Soviet Union - Russia as well (the recent issues are dated to 1982 -[4] and 1991 -[5]).

The chart and nuclide systems comparison reveals, that they are different in nuclide positioning, that defines their relative convenience for users. Sets of isotope's properties and characteristics themselves are not equivalent in the charts of different countries. As an example we present the comparison of half-life periods for the most practically important isotopes (see tables 1 and 2). As we may see from these table the most appreciable variations are obsreved for Ti 44, Fe 59, Co 56. Ge 68, Nb 93m, Eu 154, Au 195, Dy 165, Rb 86, Lu 177, Rn 222, and other elements half-life periods.

The establishment of the above International Nuclide Chart has been approved at International Conferences (Yulich, Germany, 1991; Wiesbaden, Germany 1992; ICSU-CODATA, Beijing, Chinese People's Republic, 1992). The task importance was also confirmed by the Task Groups held in Karlsruhe (Germany) in 1991, 1992, 1993 in Yulich (Germany) in 1991, in Gutlinburg (the USA) in 1994, in Veinna (Austria) in 1993.

The objective of the work is to establish the nuclide chart with the use of recommended and standard reference data as the

most reliable ones including the up-to-date and complete experimental data not used earlier as well as their comparison with original tables and earlier issues.

All these will enable to have the most reliable data on decay types and properties, energetic nuclide characteristics and other properties of particles the most widely used in national economy, technique, technology and medicine.

The economical effect from the nuclide chart development is conditioned by the data high reliability and completeness and specialist's saving of time for information search.

The chart is to contain the following characteristisc:

I. For stable nuclei:

1. Element symbol (isotope, nucleus)
2. Number of nucleons in a nucleus (A)
3. Z of a nucleus
4. Isotope spreading (atomic percentage)
5. Cross sections (n, γ) of isotope formation A+1 in the ground and isomeric states (barns)
6. Nuclide mass through the C 12 scale
7. Ground nucleus state spin
8. Magnetic and quadrupole moments of a nucleus

II. For radioactive nuclei:

1. Element symbol (isotope, nucleus)
2. Number of nucleons in a nucleus (A)
3. Z of a nucleus
4. Decay kind (ε, β+, β-, IT, sf, p, C12)
5. Decay kind prevalence (ratio of decay branches, percentage)
6. Half-life periods
7. β - energies (Mev), boundary and medium
8. β + energies (MeV), boundary and medium
9. α energies (MeV) of the most intensive lines (n <=3)

10. γ energies (keV) of the most intensive lines (n <=4)
11. Energies of isomeric transitions I_{γ}^{IT} (keV)
12. Isomer half-life periods
13. Medium phonon emission energy (keV)

III. For nuclei with metastable states (which coinside with corresponding place of stable and radioactive nuclei)

1. Half-life periods
2. Energies of isomeric transitions I_{γ}^{IT} (keV)

Special Task Groups may be established in IAEA dealing with the above parameters and characteristics as well as with the forms of the data representation. We think that a horizontal isotope positioning is rather preferable within the corresponding element, just as it has been done in the Chart issued in Karlsruhe, Germany [1].

Appendix I involves the Memorandum and the List of institutions and experts of different countries, which approve the necessity of the International Nuclide Chart development.

Appendix II presents the radionuclide region, which may be primarily inspected by the Russian Working Group.

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Table 1

Comparison results on half-life periods of some the most practically important isotopes according to the data of different charts

Isotope	German Chart (Karlsruhe) 1981	Japanese Chart 1988	American Cart 1988	Proton-neutron Nuclide System Russia 1982	Russia 1991
	[1]	[2]	[3]	[4]	[5]
Na 22	2.602years	2.6024year	2.605years	2.603years	2.602years
P 32	14.3days	14.26days	14.28days	14.31days	14.28days
Ti 44	47.3years	47.3 years	52 years	47 years	67 years
Fe 59	45.1 days	45.1 days	44.51days	44.6 days	44.50days
Co 56	78.76days	77.1days	77.3days	78.8days	77.4days
Co 57	271.3days	271.77days	271.8days	272 days	271.8days
Co 58	70.78days	70.8days	70.88days	70.8days	70.9 days
Ge 68	288 days	270.6days	270.8days	286 days	270 days
Ge 71	11.2days	11.8days	11.4days	11.2days	11.2days
Sr 90	28.5years	26.6years	29.1years	28.5years	26.6years
Nb 93m	13.6years	13.6years	16.1years	13.6years	13.6years
Ru 103	39.35days	39.35days	39.27days	39.4 days	39.26days
Cd 109	453 days	452.6days	462.0days	462 days	462.3days
Sb 125	2.77years	2.77years	2.758years	2.7years	2.76years
I 125	60.14days	60.14days	60.1days	60.0 days	59.39days
I 131	8.02 days	8.04days	8.040days	8.054days	8.04days
Xe 131m	11.9 days	11.77days	11.9 days	11.77days	11.9 days
Cs 134	2.06years	2.0658year	2.065years	2.062years	2.065years
Cs 137	30.17year	30.14year	30.17year	30.17year	30.21year
Eu 152	13.33years	13.5 years	13.46years	13.6years	13.33years
Eu 154	8.6years	8.8 years	8.59years	8.5 years	8.8years
Au 195	183 days	183 days	186.12day	183 days	186.1days
Hg 203	46.59days	46.582day	46.61day	46.7days	46.58days
Bi 207	33.4years	33.4years	32.2years	33.4years	32.2years
Am 241	458.6year	458.1year	458.7year	458.1year	458.8year
Am 243	7370years	7380years	7370years	7370years	7380years

Table 2

Comparison results on half-life periods of some isotopes important for biological investigations and human being activity from the ecological point of view

Isotopes	Periodic Table of the Elements (Germany) 1993 [6]	Proton-neutron Nuclide System (Russia) 1991 [5]	Table of Germany (Karlsruhe) 1981 [1]
H 3	12.3 years	12.33 years	12.328 years
He 6	808 ms	807 ms	808.1 ms
Li 8	842 ms	838 ms	842 ms
Be 7	53 days	53.3 days	53.29 days
B 12	20 ms	20.2 ms	20.20 ms
C 14	5730 years	5730 years	5730 years
N 13	10 min	9.965 min	9.96 min
O 15	2 min	2.037 min	2.03 min
F 18	110 min	109.7 min	109.7 min
Ne 23	37 s	37.2 s	37.2 s
Na 22	2.6 years	2.602 years	2.602 years
Mg 28	21 hours	20.9 hours	20.9 hours
Al 26	720000 years	720000 years	716000 years
Si 31	3 hours	2.622 hours	2.62 hours
P 32	14 days	14.28 days	14.3 days
S 35	88 days	87.5 days	87.5 days
Cl 36	300000 years	301000 years	300000 years
Ar 41	2 hours	1.83 hours	1.83 hours
K 42	12 hours	12.36 hours	12.36 hours
Ca 45	163 days	164 days	163 days
Sc 46	84 days	83.8 days	83.82 days
Ti 44	47.3 years	67 years	47.3 years
[illegible] 49	330 days	327 days	330 days
Cr 51	28 days	27.70 days	27.70 days

Mn 54	312 days	312.14 days	312.2 days
Fe 59	45 days	44.50 days	45.1 days
Co 60	5.3 years	5.271 years	5.272 years
Ni 63	100 years	100 years	100 years
Cu 64	13 hours	12.7 hours	12.7 hours
Zn 65	244 days	244.1 days	244 days
Ga 67	78 hours	78.336 hours	78.3 hours
Ge 77	11 hours	11.3 hours	11.3 hours
As73	80 days	80.3 days	80.3 days
Se 75	120 days	119.7 days	120 days
Br 82	35 hours	35.304 hours	35.34 hours
Kr 85	10.8 years	10.73 years	10.76 years
Rb 86	19 days	18.6 days	18.7 days
Sr 90	28.5 years	28.6 years	28.5 years
Y 88	107 days	106.63 days	106.6 days
Zr 95	64 days	64.02 days	64.0 days
Nb 94	20000 years	20500 years	20000 years
Mo 99	66 hours	66.0 hours	66.0 hours
Tc 99	210000years	213000 years	210000 years
Ru 103	39 days	39.26 days	39.35 days
Rh 105	36 hours	35.36 hours	35.5 hours
Pd 103	17 days	16.991 days	16.96 days
Ag 110m	250 days	249.74 days	249.9 days
Cd 109	453 days	462.3 days	453 days
In 114m	50 days	49.51 days	49.5 days
Sn 113	115 days	115.09 days	115.1 days
Sb 125	2.8 years	2.76 years	2.77 years
Te 127m	109 days	109 days	109 days
I 129	16000000 years	16000000 years	15700000years
Xe 133	5 days	5.245 days	5.25 days
Cs 137	30.2 years	30.21 years	30.17 years
Ba 133	10.5 years	10.56 years	10.5 years
La 140	40 hours	40.272hours	40.272 hours
Ce 141	33 days	32.501 days	32.5 days
Pr 143	14 days	13.58 days	13.57 days
Nd 147	11 days	10.98 days	10.98 days
Pm 147	2.6 years	2.6234 years	2.62 years

Sm 153	47 hours	47.6 hours	46.75 hours
Eu 152	13.3 years	13.33 years	13.33 years
Gd 153	242 days	241.6 days	241.6 days
Tb 160	72 days	72.3 days	72.1 days
Dy 165	2 hours	2.334 hours	2.35 hours
Ho 166m	1200 years	1200 years	1200 years
Er 169	9 days	9.40 days	9.40 days
Tu 170	129 days	128.6 days	128.6 days
Yb 169	32 days	32.022 days	32.0 days
Lu 177	7 days	6.71 days	6.71 days
Hf 181	42 days	42.39 days	42.4 days
Ta 182	114 days	114,5 days	114.43 days
W 185	75 days	75.1 days	75.1 days
Re 186	91 hours	90.64 hours	90.64 hours
Os 185	94 days	93.6 days	94 days
Ir 192	74 days	73.831 days	74.0 days
Pt 197	18 hours	18.3 hours	18.3 hours
Au 195	183 days	186.1 days	183 days
Hg 203	47 days	46.58 days	46.59 days
Tl 204	3.8 years	3.8 years	3.78 years
Pb 210	22.3 years	22.3 years	22.3 years
Bi 207	33.4 years	32.2 years	33.4 years
Po 209	102 years	102 years	102 years
At 210	8 hours	8.1 hours	8.3 hours
Rn 222	4 days	3.8235 days	3.825 days
Fr 223	22 min	21.8 min	21.8 min
Ra 226	1600 years	1600 years	1600 years
Ac 227	21.8 years	21.773 years	21.77 years
Th 232	14000000000 years	14050000000 years	14050000000 years
Pa 231	33000 years	32760 years	32760 years
U 238	4500000000 years	4468000000 years	4468000000 years
Np 237	2100000 years	2140000 years	2140000 years
Pu 244	83000000 years	82000000 years	82500000years
Am 243	7370 years	7380 years	7370 years

Cm 247	16000000years	15600000 years	15600000years
Bk 247	1380 years	1380 years	1380 years
Cf 251	898 years	898 years	898 years
Es 252	472 days	471.7 days	471.7 days
Fm 257	101 days	100.5 days	100.5 days
Md 258	56 days	55 days	56 days
No 259	58 min	60 min	58 min
Lr 260	3 min	3 min	3 min
104 261	65 s	65 s	65 s
105 262	34 s	34 s	35 s
106 263	0.8 s	0.9 s	0.9 s
107 262	100 ms	102 ms	4.7 ms
108 265	2 ms	1.8 ms	-
109 266	4 ms	3.5 ms	-

Chinese Nuclear Data Center
China Institute of Atomic Energy
P.O. Box 275(41), Beijing 102413
People's Republic of China
Telephone: 9357830. Telex: 222373 IAE CN. Telefax: 861-9357008
E-Mail: CIAEDNP@VXIHEP.IHEP.CERN.CH

4.2

Dr. H. Lemmel
Nuclear Data Section
International Atomic Energy Agency
P. O. Box 100
A-1400 Vienna
Austria

September 22, 1994

Dear Dr. Lemmel,

Thank you very much for your informing me IAEA Specialists' Meeting on the Development of an International Nuclear Half-Life and Cross-section Database, Vienna, 24-28 October 1994.

I am very sorry that I am unable to attend the meeting. But I would like to make my contribution to the meeting and submit some information about our NSDD evaluation activities:

1, As you know, NSDD evaluation and update for A=51-56 and 195-198 mass chains have been done in China. In future, they will continue to be done according to coordination of the NSDD internatinal network. Besides, the decay data for over 300 radionuclides have been updated on the basis of recently measured data and evaluated data. But they have not been published.

2, We will make our contribution to the envisaged International Nuclear Half-Livies and Thermal-Neutron Cross Sections Database (International Chart of the Nuclides) for nuclides relating to A=51-56 and 195-198 mass number range, which have been assigned to China by NSDD International Network.

3, We agree the data scope and priorities:

a), decay data: half-livies of ground states and isomers, emission probabilities, internal conversion coefficients.

b), cross section: thermal-neutron cross-sections, resonance integrals.

c), priorities: to start with ~ 250 radionuclides which are listed by the meeting of Decay Data Subgroup of NSDD Network.

4, We will agree with what the meeting decides.

Congratulation on the successful meeting.

With best regards from all of us at CNDC, Beijing.

Sincerely Yours,

Zhou Chunmei

Zhou Chunmei

On the activities of the International Committee for Radionuclide Metrology (ICRM)

G. Winkler
Presently acting president of the ICRM,
Institut für Radiumforschung und Kernphysik, University of Vienna,
Boltzmanngasse 3, A-1090 Wien, Austria

The International Committee for Radionuclide Metrology (ICRM) is an association of radionuclide metrology laboratories whose membership is composed of delegates of these laboratories together with other scientists (associate members) actively engaged in the study and applications of radioactivity. It explicitly aims at being an international forum for the dissemination of information on techniques, applications and data in the field of radionuclide metrology. The ICRM has no membership fee and no paid secretariat or other staff. The overall direction of the ICRM is determined by the delegates in General Meetings, which convene usually every two years, where organizational guidelines and directions for the working programs are agreed upon. The following appointments of officers of ICRM serving on the Executive Board were confirmed at the General Meeting on 11 June 1993:

President	G. Winkler [1]
Vice-Presidents	B. R. S. Simpson [2] (succeeded by T. Genka[3] on 3 June 1994)
	F. Amoudry [4]
	J. M. R. Hutchinson [5]
Past-President	P. Christmas [6]
Secretary	H. Schrader [7]

The activities of ICRM are largely the responsibility of its working groups. Each group is guided by a coordinator who acts as a center for ideas and communications and may organize conferences and workshops. At present there are six working groups with the respective objectives and assigned coordinators as follows:

(1) Alpha-Particle Spectrometry	E. García-Toraño [8]
(2) Gamma- and Beta-Ray Spectrometry	J. M. Los Arcos [8]
(3) Life Sciences	D. F. G. Reher [9]
(4) Low-Level Measurement Techniques	E. Holm [10]
(5) Non-Neutron Nuclear Data	A. L. Nichols [11]
(6) Radionuclide Metrology Techniques	T. Radoszewski [12]

The main areas of interest presently pursued by these working groups are:

(1) Alpha-Particle Spectrometry: Improvement of peak-fitting programs combined with a discussion of the possibilities and limits, use of these programs in isotopic analysis (e.g., for Pu isotopes), fitting of low-statistics spectra, performing an intercomparison of computer codes that analyze reference alpha-particle spectra, investigation of problems encountered in measurements of P_α data, computer simulation of the physical processes within the detector and the source that determine the recorded pulse-height distribution. development of new measurement systems and of new measurement techniques such as time-of-flight spectrometry and bolometer methods, Rutherford-backscattering spectrometry as a tool to characterize alpha sources.

(2) Gamma- and Beta-Ray Spectrometry: Methods of calculating the efficiency of Ge detectors (including geometries other than for a point-source) which will lead to the standardization of the size of commercial detectors. Low-energy calibration of detectors, coincidence-summing corrections, in particular for volume sources, evaluation of peak-fitting software with test spectra, and the determination of decision and detection limits in spectrometry.

(3) Life Sciences: Accent is on radionuclide metrology applications in medicine such as calibration of ionization chambers for brachytherapy sources (e.g., ^{192}Ir wires), developing the metrology for new candidate radionuclides for brachytherapy sources (e.g., ^{169}Yb), and quality assurance in the use of radionuclide calibrators in hospitals; the working-group program should also cover problems encountered in the accurate calibration of surface contamination monitors and in radioactivity surveillance of food and fodder samples.

(4) Low-Level Measurement Techniques: Low-level measurements of pure beta-particle emitters (e.g., ^{63}Ni, ^{99}Tc, ^{241}Pu) and radionuclides decaying by electron capture (e.g., ^{59}Ni, ^{55}Fe), improving methods for measuring ^{90}Sr, Radon and some Actinides; analytical quality control and natural-matrix standards; mass-spectrometric techniques including radiochemistry for long-lived radionuclides, which are intended to be also covered at the next planned meeting of this working group to be held in Seville, Spain, October 2-6, 1995, with the Department of Physics of the University of Seville hosting it.

(5) Non-Neutron Nuclear Data: Identifying and communicating difficulties and anomalies primarily in decay data, taking actions to assist in the resolution of decay-data problems (e.g., with ^{41}Ca, ^{37}S, ^{94m}Nb, ^{116m}In, ^{139}Ba, ^{187}W, ^{199}Au, ^{233}Pa), to consider discrepancies and define the uncertainties, recommending data fitting and data evaluation (averaging) procedures; assessment of the available tabulations of internal conversion coefficients (ICC) with the goal of recommending specific ICC data and tabulations and providing estimates of their uncertainties.

(6) Radionuclide Metrology Techniques: Accent on liquid-scintillation counting and gas counting, continuation of collaboration with the International Bureau of Weights and Measures (BIPM) for the purpose of extending the International Reference System (SIR) to pure beta-particle and low-energy photon emitters (as already pursued in an intercomparison for ^{14}C and ^{99}Tc utilizing liquid-scintillation counting employing efficiency tracing with ^{3}H or the triple-to-double coincidence ratio method for efficiency determination), intercomparison of tritiated water by internal gas counting with the goal of creating a standard solution, intercomparison of ^{63}Ni and ^{55}Fe measurements using liquid-scintillation counting.

The ICRM held its most recent biennial series of meetings from 7 to 11 June 1993 at the National Physical Laboratory (NPL), Teddington, UK, under the title ICRM'93. These meetings started with a 2½-day Symposium on Radionuclide Metrology and its Applications, organized by NPL jointly with all working-group coordinators and the ICRM Executive Board. The symposium was attended by some 130 participants from 22 countries; almost eighty papers were presented. There were contributions on counting techniques with increased interest in liquid-scintillation counting, on advances in radiation detection and measurement, on nuclear data, and on standards – in particular ^{75}Se and ^{192}Ir – and on applications of radionuclides. The symposium proceedings were published in Nuclear Instruments and Methods in Physics Research, Section A, Volume **339**, Nos.1,2, pages 1-414 (1994). This symposium was followed by business meetings of all six working groups, a meeting of the Executive Board, and by the General Meeting of the ICRM members which discussed insights into the present status of radionuclide metrology

as gained from the symposium. Officers were elected as given above. There are around 40 institutions now represented in the ICRM.

The next biennial ICRM meetings (ICRM'95) will be held from 15 to 19 May 1995 at the Ministère de l'Enseignement Supèrieur et de la Recherche in Paris, France, at the invitation of the Département des Applications et de la Métrologie des Rayonnements Ionisants CEA/DAMRI/LPRI/Saclay. The meetings will be open to all persons interested. They will comprise a Symposium on Radionuclide Metrology and its Applications with the following topics:
Alpha–particle spectrometry,
Gamma–ray and beta–particle spectrometry,
Life sciences,
Low–level measurements,
Radionuclide metrology techniques (including direct activity measurements),
Nuclear decay data (measurements and evaluations).
These topics may include, for example, source preparation techniques, reference materials and calibration standards, detector developments, liquid–scintillation counting, internal gas counting, surface contamination monitoring and novel methods.
The organization of ICRM'95 is mainly in the hands of Dr. F. Amoudry and Mme Dr. Nelcy Coursol, DAMRI/LPRI, BP 52, F–91193 Gif–Sur–Yvette Cedex, France.

An ICRM Newsletter informing on activities in the member laboratories is issued on an annual basis; the most recent ones were issue 8 (Jan. 1994) and issue 9 (Jan. 1995), both edited by D.F.G. Reher [9]. The ICRM Newsletter is also available to non–members upon request.

It does not seem to be much of a problem to find an agreement on a formulation of generally acceptable procedures for data evaluation and in particular for uncertainty assessment and furtheron for criteria to be fulfilled for entrees going into the foreseen data base [see, e.g., G. Winkler: "Data fitting and evaluation techniques for radioactive decay data", in Proc. Internat. Symp. on Nuclear Data Evaluation Methodology , 12 – 16 October 1992, Brookhaven National Laboratory, USA, ed. C.L. Dunford (World Scientific, Singapore, 1993) p. 257 – 266; S. Tagesen and G. Winkler: "Troubles, traps and tricks in fitting exponential decay data", ibid. p. 267 – 272]. But the formulations should not represent a strictly technical recipe in the sense of a stiff inflexible scheme for keying in primary data and let a computer program do the rest. The accurate quantitative assay of decay scheme data for a particular nuclide may become a very complex and elaborate task, comprising several classes of data (e.g. level properties, Q–values, types, energies and intensities of radiations emitted, half–lives), often requiring a step by step procedure. It often involves the knowledge or beforehand evaluation of several auxiliary data, for which experimentally determined values are often not readily available. They often have to be calculated or estimated with the help of nuclear or atomic structure theory or from systematics of the relevant properties. Although the techniques of obtaining best values have been gradually refined over the years, now taking special advantage of the capability of computers permitting more sophisticated and faster analyses than hitherto, no amount of statistical sophistication can make bad results any better. Therefore the first and primary task is to sort out which data should be included in an evaluation. In this sense any evaluation is subjective. And there may still exist unrecognized errors causing data to be biased.

The organization that keeps a data base in order – in this case the IAEA Nuclear Data Section – should collect the evaluations which must be well documented. A set of defined standards have to be fulfilled for an evaluation to be excepted. Agreement should be on this standards, but those should not be calculation procedures, i.e. "manipulations" of the existing input data only. A review must be made by experts who should recommend a specific evaluation. In this way acceptable data sets could be adopted.

The member laboratories of ICRM which are actively involved in radionuclide metrology and where staff members also work on collecting, testing, producing and improving radionuclide–decay data by measurements and evaluations, having command of the necessary instrumentation, should be well suited to contribute significantly to the planned International Nuclear Decay Data Database. Several ICRM–related individuals have indeed attended this IAEA Specialists' Meeting. The coordinator of the ICRM Non–Neutron Nuclear Data Working Group, in particular, could be one of the persons assisting in organizing or nominating a group of people being able and willing to do the review job and in distributing the work to be done. But – as often – in individual cases there will exist handicaps, such as laboratory policies and lack of man power. The forthcoming International Symposium on Radionuclide Metrology and its Applications, as mentioned above, is also supposed to produce valuable input by publications of new decay–data studies.

Addresses:

[1] Institut für Radiumforschung und Kernphysik der Universität Wien, Boltzmanngasse 3, A–1090 Wien, Austria
[2] National Accelerator Centre, Radioactivity Standards and Radiation Safety Division, Faure, 7131 South Africa
[3] Japan Atomic Energy Research Institute (JAERI), Radionuclide Metrology Division, Tokai–mura, Naka–gun, Ibaraki–ken, 319–11 JAPAN
[4] CEA/LPRI Laboratoire Primaire des Rayonnements Ionisants, F–91193 Gif–sur–Yvette Cedex, France
[5] National Institute of Standards and Technology (NIST), Radioactivity Group, Gaithersburg, Maryland, U.S.A.
[6] Division of Radiation Science and Acoustics, National Physical Laboratory, Teddington, Middlesex TW11 OLW, UK
[7] Physikalisch–Technische Bundesanstalt, Abteilung 6, Bundesallee 100, D–38116 Braunschweig, Germany
[8] Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Fisica de Radiaciones, Avenida Complutense 22, E–28040 Madrid, Spain
[9] Commision of the European Communities CEC–JRC, Institute for Reference Materials and Measurements (IRMM), Steenweg naar Retie, B–2440 Geel, Belgium
[10] Radiation Physics Department, Lund University, Lasarettet, S–221 85 Lund, Sweden
[11] Environmental and Process Engineering, AEA Technology, 404 Harwell, Didcot, Oxfordshire OX11 ORA, UK
[12] Radioisotope Centre, PL–05–400 Swierk–Otwock, Poland

4.4

IAEA Specialists' Meeting on the Development of an International Nuclear Decay Data and Cross-Section Database

Some details and input requirements for the international database

H.D. Lemmel

I plan to design the international database as a PC file which will be available to everyone who wants it, either on a PC diskette or as printed output. Specifically, publishers of wall charts and handbooks are invited to use it. On the other hand, data evaluators are invited to provide input. Preferably, the distribution would be through INTERNET FTP.

We will have to agree on recognized evaluation procedures which will be the topic of subgroups at this meeting.

To give an example: For a given nuclide only a single half-life measurement may exist, which may be old. In most cases one finds the original author's value quoted, with the author's original uncertainty. However, we feel that this is not adequate. Experts today know better what accuracy the author could have achieved, and we need a re-assessed uncertainty estimate to our present best knowledge.

The first evaluator's law by John Story:
If there is only one experiment, don't trust it.

The second evaluator's law by John Story:
If there are two experiments and both agree, then both may be wrong.

Two measurements confirm each other only if their methods are sufficiently different. Otherwise an increased uncertainty must be adopted.

These are only some examples. I hope that the subgroups will be able to formulate acceptable procedures for data evaluation and uncertainty assessment.

The international database must have the following features:

1. Input only when agreed evaluation procedures have been followed, and agreed procedures to approve new data.

2. Origin and evaluation procedures for each value must be documented. The database will have a reference for each value. Traditional wall-charts have the default that the documentation of the values included, existed usually only as a private card file. We offer our INDC report series to document evaluations, if they are not published elsewhere.

3. There will be space for additional notes. Some examples:

   a. "1979 evaluation reviewed again in 1994. No change required."
   b. Note: "New experimental data require a new evaluation."

This way I hope that adequate documentation will be provided for all data.

A system of circular letters will be required for the communication and coordination among the participants.

Attached are two examples. One example for two cases of recommended cross-sections, with entries for "Reference" and "Notes".

For nuclear half-lives a more detailed example is attached. It contains the half-life values that had been evaluated by our two coordinated research projects on

- Transactinide nuclear data, and on
- X-ray and gamma-ray standards for detector calibration,
- plus some data that I needed for IAEA internal purposes.

The data and the "Reference" sections are meant for distribution. The "Notes" sections would be distributed only within our cooperation. They are not meant for external distribution.

The PC file of half-lives as it stands now, offers some additional conveniences.

- it gives absolute uncertainties and per-cent uncertainties, while any style of input is accepted;
- it gives on push-button the half-lives in any desired unit: y, d, h, min, sec;
- in all these conversions it gives the correct number of significant digits.

It should also contain a date column so that one can retrieve all information that has been added or changed since a given date.

So far it has been programmed for half-life data only. But its extension to other data types could be done.

Sample of a cross-section entry:

38-Sr-90 (n,gamma)	0.0253 eV	0.015 ± 0.004 b
	20°C Maxw	0.015 ± 0.002 b
	Res.Int.	0.090 ± 0.010 b

Reference:
H.Harada et al., J.Nucl.Sci.Technol. 31 173 (1994), and JENDL-3.2 (1993).

Notes:
New experiment, confirming the value of 0.0140 ± 0.0024 b (Maxw) by L.A.McVey et al., J.Radio.Chem. 76 131 (1983). This supersedes the old experimental value by Zeisel (1966) on which the value of 0.9 ± 0.5 b was based that is given by Mughabhab 1981, and in ENDF/B-6, BROND-2, JEF-2, JENDL-3. The new JENDL-3.2 evaluation (1993) adopted 0.015 b and obtained 0.090 b for the resonance integral.

55-Cs-137 (n,gamma)	0.0253 eV	0.25 ± 0.02 b

Reference:
H.Harada et al., J.Nucl.Sci.Technol. 31 173 (1994).

Notes:
Supersedes the value of 0.11 ± 0.03 b of Stupegia (1960) which was given in ENDF/B-6, JENDL-3 and elsewhere.

IAEA Nuclear Data Section
Recommended Half-Life Values of Radionuclides
Date of retrieval: 1994/10/20
Note: This database is updated in irregular intervals.

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
6-C - 14	β-	5730 ± 40		years	(± 0.7%)

Reference:
Nucl. Phys. A523 (1991) p.61, F. Ajzenberg-Selove.

11-Na- 22	EC	950.8 ± 0.9		days	(± 0.09%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

11-Na- 24	β-	14.965 ± 0.004		hours	(± 0.03%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

19-K - 40	β-/EC	(1.277 ± 0.008)	E 9	years	(± 0.6%)

Reference:
Nucl. Phys. A521 (1990) p.615, P.M. Endt.

21-Sc- 46	β-	83.79 ± 0.04		days	(± 0.05%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

24-Cr- 51	EC	27.706 ± 0.007		days	(± 0.025%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

25-Mn- 54	EC	312.3 ± 0.4		days	(± 0.13%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

26-Fe- 55	EC	999. ± 8.		days	(± 0.8%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

27-Co- 56	EC	77.31 ± 0.19		days	(± 0.25%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)
Notes:
To be reviewed. Proposed new value: 77.26 ± 0.08. (Priv.com. A.L.Nichols 1994)

27-Co- 57	EC	271.79 ± 0.09		days	(± 0.03%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

27-Co- 58	EC	70.86 ± 0.07		days	(± 0.1%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

27-Co- 60	β-	5.2718 ± 0.0014		years	(± 0.026%)

Reference:
Evaluated by M.K.Woods, K.Debertin, IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)
Notes:
This supersedes the value of 5.2714 +- 0.0005 y given in Nuclear Data Sheets 48 (1986) p.284, P.Andersson et al.

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
30-Zn- 65	EC	244.26 ± 0.26		days	(± 0.11%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

34-Se- 75	EC	119.64 ± 0.24		days	(± 0.20%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

38-Sr- 85	EC	64.849 ± 0.004		days	(± 0.006%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

38-Sr- 90	β-	28.78 ± 0.04		years	(± 0.14%)

Reference:
Nuclear Data Sheets 67 p.619 (1992), L.P. Ekström et al.
Notes:
To be reviewed. Proposed new value: 28.64 ± 0.16 a. (Priv.com. A.L.Nichols 1994)

39-Y - 88	EC	106.630 ± 0.025		days	(± 0.023%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

41-Nb- 93m	it	16.13 ± 0.14		years	(± 0.8%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

41-Nb- 94	β-	(2.00 ± 0.25)	E 4	years	(± 12%)

Reference:
Evaluated by M.J.Woods, K.Debertin, IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)
Notes:
This supersedes the value of (2.03+-0.16)E4 y given in Nuclear Data Sheets 44 (1985) p.344, H.-W.Mueller.

41-Nb- 95	β-	34.975 ± 0.007		days	(± 0.020%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)
Notes:
To be reviewed. Proposed new value: 35.02 ± 0.05 d. (Priv.com. A.L.Nichols 1994)

43-Tc- 99	β-	(2.111 ± 0.012)	E 5	years	(± 0.6%)

Reference:
Nuclear Data Sheets 48 p.713 (1986), H.W. Müller et al.
Notes:
To be reviewed. Proposed new value: 2.113 ± 0.011 E5 a. (Priv.com. A.L.Nichols 1994)

44-Ru-106	β-	373.59 ± 0.15		days	(± 0.04%)

Reference:
D. de Frenne, Nuclear Data Sheets 53 p.105 (1988), and Nuclear Data Sheets 72 p.11 (1994).

47-Ag-110	β-	24.60 ± 0.20		sec	(± 0.8%)

Reference:
Nuclear Data Sheets 38 p.595 (1983), P. De Gelder et al. - The decay is 99.70% β- and 0.30% IT.
Notes:
To be reviewed. Proposed new value: 24.7 ± 0.2 sec. (Priv.com. A.L.Nichols 1994)

47-Ag-110m	β-	249.76 ± 0.04		days	(± 0.016%)

Reference:
Nuclear Data Sheets 38 p.595 (1983), P. De Gelder et al. - Note: The decay is 98.64% b- and 1.36% IT.
Notes:
To be reviewed. Proposed new value: 249.79 ± 0.18 d. (Priv.com. A.L.Nichols 1994)

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
48-Cd-109	EC	462.6 ± 0.7		days	(± 0.15%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

49-In-111	EC	67.313 ± 0.012		hours	(± 0.018%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

50-Sn-113	EC	115.09 ± 0.04		days	(± 0.03%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

51-Sb-125	β-	2.7590 ± 0.0016		years	(± 0.06%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

53-I -125	EC	59.43 ± 0.06		days	(± 0.10%)

Reference:
Evaluated by K.Debertin and M.J.Woods, IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)
Notes:
In Nuclear Data Sheets 70/2 (1993) p.268 a value of 59.408 ± 0.008 is recommended, evaluated by J.Katakura et al. based on the same experimental data as Debertin/Woods. - Note by Lemmel (1994): There is not sufficient evidence that the IAEA recommended value should be changed. Is the uncertainty of Katakura's value too optimistic?

53-I -129	β-	(1.57 ± 0.04)	E 7	years	(± 2.5%)

Reference:
Nuclear Data Sheets 39 p.603 (1983), A. Hashizume et al.

55-Cs-134	β-	754.28 ± 0.22		days	(± 0.03%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)
Notes:
New experiment: M.P. Unterweger, D.D. Hoppes, F.J. Schima, Nucl. Instrum. a. Methods Phys. Res. A312 p.349 (1992): 2.0640 ± 0.0004 y. Based on this and earlier experiments: Yu.V. Sergeenkov, Nuclear Data Sheets 71(3) p.571 (1994), 2.0648 ± 0.0010 y. (Compared to the IAEA value of 2.0652 ± 0.0006 y.)

55-Cs-137	β-	30.17 ± 0.16		years	(± 0.5%)

Reference:
Evaluated by K.Debertin, M.J.Woods, IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)
Notes:
This supersedes the value of 30.1 +- 0.2 y quoted in Nuclear Data Sheets 59 (1990) p.767.

56-Ba-133	EC	10.57 ± 0.04		years	(± 0.4%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

58-Ce-139	EC	137.640 ± 0.023		days	(± 0.017%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)
Notes:
To be reviewed. Proposed new value: 137.65 ± 0.03 d. (Priv.com. A.L.Nichols 1994)

63-Eu-152	EC/b-	13.51 ± 0.03		years	(± 0.22%)

Reference:
Evaluated by K.Debertin, M.J.Woods, IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)
Notes:
This supersedes the value of 13.542 +- 0.010 years given in Nuclear Data Sheets 58 (1989) p.153, L.K.Peker.
To be reviewed. Proposed new value: 13.52 ± 0.01 a. (Priv.com. A.L.Nichols 1994)

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
63-Eu-154	β-	8.588 ± 0.008		years	(± 0.09%)

Reference:
Evaluated by K.Debertin, M.J.Woods, IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)
Notes:
To be reviewed. Proposed new value: 8.593 ± 0.004 a. (Priv.com. A.L.Nichols 1994)
Compare the value of 8.592 +- 0.005 a given in Nuclear Data Sheets 52 (1987) p.50, R.G.Helmer.

63-Eu-155	β-	4.85 ± 0.14		years	(± 3%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)
Notes:
!!! IAEA-TECDOC value to be revised! More accurate value of 4.7611 ± 0.0013 y, M.P. Unterweger, D.D. Hoppes, F.J. Schima, Nucl. Instrum. a. Methods Phys. Res. A312 p.349 (1992); also adopted by C.W. Reich, Nuclear Data Sheets 71 p.737 (1994).

79-Au-198	β-	64.663 ± 0.019		hours	(± 0.03%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

80-Hg-203	β-	46.595 ± 0.013		days	(± 0.03%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

82-Pb-210	α	(1.17 ± 0.18)	E 9	years	(± 15%)

Reference:
IAEA Tech. Rept. 261 (1986).

82-Pb-210	β-	22.30 ± 0.20		years	(± 0.9%)

Reference:
Nuclear Data Sheets 65 p.225 (1992), E.Browne.
Notes:
Same value and error as IAEA Tech. Rept. 261 (1986).

83-Bi-207	EC	31.55 ± 0.05		years	(± 0.16%)

Reference:
Nuclear Data Sheets 70/2 (1993) p.350, M.J.Martin, based on M.P.Unterweger, D.D.Hoppes, F.J.Schima, Nucl.Instr.a.Methods Phys.Res. A312 (1992) p.349.
Notes:
This supersedes the IAEA value of 1.16 ± 0.07 E4 days = 31.8. ± 1.9 years recommended in IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.).

84-Po-210	α	138.40 ± 0.20		days	(± 0.14%)

Reference:
IAEA Tech. Rept. 261 (1986).
Notes:
In Nuclear Data Sheets 65 p.243 (1992) E. Browne gives a value of 138.376 +- 0.002 days from a calorimetric measurement by J.F.Eichelberger et al., report MLM-1209 (1964). There is no more recent measurement.
Note by Lemmel 1994: The IAEA group reduced the uncertainty to +-0.2 based on the evaluation rule that a high accuracy value must be based on more than a single experiment.

86-Rn-222	α	91.764 ± 0.007		hours	(± 0.008%)

Reference:
IAEA Tech. Rept. 261 (1986) p.155, A.Lorenz (ed.).
Notes:
Taken from Nuclear Data Sheets 27 (1979) p.701, K.S.Toth.
To be reviewed. The claimed high accuracy seems unrealistic. Proposed new value: 91.80 ± 0.02 h. (Priv.com. A.L.Nichols 1994)

88-Ra-226	α	1600. ± 7.		years	(± 0.4%)

Reference:
Nuclear Data Sheets 50 p.238 (1987), Y.A. Ellis-Akovali.

88-Ra-228	β-	5.75 ± 0.03		years	(± 0.5%)

Reference:
Nuclear Data Sheets 49 p.151 (1986), M.J.Martin

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
90-Th-228	α	698.2 ± 0.6		days	(± 0.09%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)

90-Th-229	α	7340 ± 160		years	(± 2.2%)

Reference:
IAEA Tech. Rept. 261 (1986) p.25, A. Lorenz (ed.).
Notes:
From Nuclear Data Sheets 24 (1978) p.263, K.S. Toth. - Not reviewed since then.

90-Th-230	α	(7.54 ± 0.03)	E 4	years	(± 0.4%)

Reference:
Nuclear Data Sheets 69 p.168 (1993), Y.A. Akovali.

90-Th-231	β-	25.520 ± 0.010		hours	(± 0.04%)

Reference:
IAEA Tech. Rept. 261 (1986) p.25, A. Lorenz (ed.).
Notes:
From Nuclear Data Sheets 40 (1983) p.1, M.R.Schmorak, based on M.J.Cabell (1958). - Kept unchanged in Nuclear Data Sheets 70/2 (1993) p.393

90-Th-232	α	(1.405 ± 0.006)	E 10	years	(± 0.4%)

Reference:
Nuclear Data Sheets 63 p.156 (1991), M.R.Schmorak.

91-Pa-231	α	(3.276 ± 0.011)	E 4	years	(± 0.3%)

Reference:
IAEA Tech. Rept. 261 (1986) p.29, A. Lorenz (ed.).
Notes:
From Nuclear Data Sheets 40 (1983) p.26, M.R. Schmorak, based on 3 experiments from 1969 and older. Kept unchanged in Nuclear Data Sheets 70/2 (1993) p.418.

91-Pa-231	sf	> 1.1	E 16	years	

Reference:
Nuclear Data Sheets 70/2 (1993) p.418, M.R.Schmorak.
Notes:
Based on a single experiment by Segré (1952).

91-Pa-233	β-	27.00 ± 0.10		days	(± 0.4%)

Reference:
IAEA Tech. Rept. 261 (1986) p.45, A. Lorenz (ed.).
Notes:
From Nuclear Data Sheets 24 (1978) p.289, Y.A. Ellis. - Not reviewed since then.

92-U -232	α	69.8 ± 0.5		years	(± 0.7%)

Reference:
IAEA Tech. Rept. 261 (1986) p.49, A. Lorenz (ed.).
Notes:
From the review by N.E. Holden (1984). - Not reviewed since then.

92-U -232	sf	(8 ± 6)	E 13	years	(± 80%)

Reference:
IAEA Tech. Rept. 261 (1986) p.157, A. Lorenz (ed.).
Notes:
Uncertainty to be reviewed. Proposed new value: (8 ± 3) E13 a. (Priv.com. A.L.Nichols 1994)

92-U -233	α	(1.5920 ± 0.0020)	E 5	years	(± 0.13%)

Reference:
1991 NEANDC/INDC Nuclear Standards File, Report NEANDC-311 (1992) p.88, W.Bambynek, H.D.Lemmel (ed.).
Notes:
From N.Holden (1984) and IAEA Tech.Rept. 261 (1986).
To be reviewed. Proposed new value: (1.5925 ± 0.0020) E5 a. (Priv.com. A.L.Nichols 1994)

92-U -233	sf	> 2.7	E 17	years	

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
92-U -234	α	(2.457 ± 0.003)	E 5	years	(± 0.12%)

Reference:
1991 NEANDC/INDC Nuclear Standards File, Report NEANDC-311 (1992) p.88, W.Bambynek, H.D.Lemmel (ed.).
Notes:
Evaluated by A.L.Nichols, IAEA Tech.Rept. 261 (1986).
Other values:
» The experimental determination of the U-235 fission cross-section, which is an important reference standard, depends strongly on the U-234 alfa-decay half-life. The 1991 NEANDC/INDC Nuclear Standards File (report NEANDC-311, 1992) does not mention explicitly, what U-234 half-life has been used for the evaluation of the U-235 fission cross-section. Actually, it is based on the ENDF/B-6 evaluation which in turn is based on E.J.Axton (European Applied Research Reports 5, 641, 1984) who used (2.454 ± 0.006) E5 a, which is not quite the same as the NEANDC/INDC recommended value.
» Y.A.Akovali, Nuclear Data Sheets 71 (1994) p.199 continues to use the value of (2.455 ± 0.006) E5 a evaluated by N.E.Holden, Pure Appl.Chem. 61, 1483 (1989).

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
92-U -234	sf	(1.42 ± 0.08)	E 16	years	(± 6%)

Reference:
IAEA Tech. Rept. 261 (1986) p.157, A.Lorenz (ed.).
Notes:
Taken from N.Holden in IAEA TECDOC-335 (1985) p.396.
To be reviewed. Proposed new value: (1.45 ± 0.08) E16 a. (Priv.com. A.L.Nichols 1994)

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
92-U -235	α	(7.038 ± 0.005)	E 8	years	(± 0.07%)

Reference:
Nuclear Data Sheets 69 (1993) p.383, M.R. Schmorak.
Notes:
This new evaluation supersedes the value of 7.037 +- 0.007 recommended in the 1991 NEANDC/INDC Nuclear Standards File, Report NEANDC-311 (1992) p.88, W.Bambynek, H.D.Lemmel (ed.) and taken from N.Holden (1984) and IAEA Tech.Rept. 261 (1986).

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
92-U -235	sf	(1.0 ± 0.3)	E 19	years	(± 30%)

Reference:
Nuclear Data Sheets 69 (1993) p.383, M.R. Schmorak.
Notes:
To be reviewed. Proposed new value: (3.5 ± 1.8) E18 a. (Priv.com. A.L.Nichols 1994)

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
92-U -236	α	(2.342 ± 0.003)	E 7	years	(± 0.13%)

Reference:
Nuclear Data Sheets 63 p.199 (1991), M.R.Schmorak.
Notes:
Uncertainty to be reviewed. Proposed new value: (2.342 ± 0.004) E18 a. (Priv.com. A.L.Nichols 1994)

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
92-U -237	β-	6.750 ± 0.010		years	(± 0.15%)

Reference:
IAEA Tech. Rept. 261 (1986) p.73, A. Lorenz (ed.).
Notes:
From Nuclear Data Sheets 23 (1978) p.71, Y.A. Ellis. - Not reviewed since then.

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
92-U -238	α	(4.470 ± 0.020)	E 9	years	(± 0.4%)

Reference:
1991 NEANDC/INDC Nuclear Standards File, Report NEANDC-311 (1992) p.88, W.Bambynek, H.D.Lemmel (ed.).
Notes:
To be reviewed. Proposed new value: (4.468 ± 0.005) E9 a. (Priv.com. A.L.Nichols 1994)

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
92-U -238	sf	(8.20 ± 0.10)	E 15	years	(± 1.2%)

Reference:
IAEA Tech. Rept. 261 (1986) p.157, A.Lorenz (ed.).
Notes:
Taken from N.Holden in IAEA TECDOC-335 (1985) p.396.
To be reviewed. Proposed new value: (8.27 ± 0.30) E15 a. (Priv.com. A.L.Nichols 1994)

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
92-U -239	β-	23.47 ± 0.05		min	(± 0.21%)

Reference:
Evaluated by A.L. Nichols, IAEA Tech. Rept. 261 (1986) p.77, A. Lorenz (ed.).
Notes:
Based on Hunt et al., (1969) and older experiments.

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
93-Np-237	α	(2.140 ± 0.010)	E 6	years	(± 0.5%)

Reference:
1991 NEANDC/INDC Nuclear Standards File, Report NEANDC-311 (1992) p.88, W.Bambynek, H.D.Lemmel (ed.).
Notes:
Only a single precise experiment by Brauer et al. (1960), compare IAEA Tech. Rept. 261 (1986) p.83.

93-Np-237	sf	> 1.0	E 18	years	

Reference:
1991 NEANDC/INDC Nuclear Standards File, Report NEANDC-311 (1992) p.88, W.Bambynek, H.D.Lemmel (ed.).

93-Np-239	β-	56.40 ± 0.10		hours	(± 0.17%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)
Notes:
To be reviewed. Proposed new value: 2.3565 ± 0.0004 d, Nuclear Data Sheets 66 p.865 (1992), based on Abzouzi et al., J.Radioanal.Nucl.Chem. 145, 361 (1990). Is the claimed high accuracy realistic?

94-Pu-238	α	87.74 ± 0.04		years	(± 0.05%)

Reference:
Nuclear Data Sheets 59, 947 (1990)
Notes:
Is the claimed high accuracy realistic? If yes, this would supersede the value of 87.7 +- 0.3 recommended in IAEA Tech. Rept. 261 p.93 (1986) based on N.Holden (1984).

94-Pu-238	sf	(4.70 ± 0.20)	E 10	years	(± 4%)

Reference:
IAEA Tech. Rept. 261 (1986) p.158, A. Lorenz (ed.).
Notes:
To be reviewed. Proposed new value: (4.72 ± 0.15) E10 a. (Priv.com. A.L.Nichols 1994)

94-Pu-239	α	(2.411 ± 0.003)	E 4	years	(± 0.12%)

Reference:
1991 NEANDC/INDC Nuclear Standards File, Report NEANDC-311 (1992) p.88, W.Bambynek, H.D.Lemmel (ed.).
Notes:
Evaluated by R.Vaninbroukx, report INDC(NDS)-105 (1979). Compare IAEA Tech. Rept. 261 (1986) p.99. - Also adopted in Nuclear Data Sheets 66 (1992) p.872, Y.A. Akovali.

94-Pu-239	sf	(8.0 ± 2.0)	E 15	years	(± 25%)

Reference:
1991 NEANDC/INDC Nuclear Standards File, Report NEANDC-311 (1992) p.88, W.Bambynek, H.D.Lemmel (ed.).
Notes:
» No documentation of evaluation in NEANDC-311.
» Compare (7.8+-1.6)E15 Druzhinin At.Energija 59 68 (1985), quoted in Nuclear Data Sheets 66 p.872 (1992).
» This value supersedes the earlier value of (5.5+-1.6)E15 by Segré Phys.Rev. 86 21 (1952) which was recommended in IAEA Tech. Rept. 261 (1986) p.99.

94-Pu-240	α	6563. ± 7.		years	(± 0.11%)

Reference:
1991 NEANDC/INDC Nuclear Standards File, Report NEANDC-311 (1992) p.88, W.Bambynek, H.D.Lemmel (ed.).
Notes:
Evaluated by R. Vaninbroukx and N. Coursol, see IAEA Tech. Rept. 261 (1986) p.107.
Uncertainty to be reviewed. Proposed new value: 6563 ± 5 a. (Priv.com. A.L.Nichols, 1994)

94-Pu-240	sf	(1.160 ± 0.020)	E 11	years	(± 1.7%)

Reference:
IAEA Tech. Rept. 261 (1986) p.158, A.Lorenz (ed.).
Notes:
Taken from N.Holden in IAEA TECDOC-335 (1985) p.396.
To be reviewed. Proposed new value: (1.15 ± 0.02) E11 a. (Priv.com. A.L.Nichols 1994)

94-Pu-241	α	(5.96 ± 0.04)	E 5	years	(± 0.7%)

Notes:
To be reviewed. Proposed new value: (5.88 ± ?) E5 a. (Priv.com. A.L.Nichols 1994)

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
94-Pu-241	β-	14.40 ± 0.10		years	(± 0.7%)

Reference:
1991 NEANDC/INDC Nuclear Standards File, Report NEANDC-311 (1992) p.88, W.Bambynek, H.D.Lemmel (ed.).
Notes:
14.4+-0.1 From N.Holden (1984), compare IAEA Tech. Rept. 261 (1986) p.115. Same value recommended by IUPAP 1989 [Pure a.Appl.Chem. 61 1483].

Note by Lemmel 1990: A new evaluation is needed! There are some recent experimental data, in particular one made in Los Alamos (high resolution spectrometry of the gammas accompanying the decay) with the result 14.335 +- 0.040 y.

Y.A. Akovali, Nuclear Data Sheets 72 p.195 (1994) recommends 14.35 ± 0.10 y.

94-Pu-242	α	(3.750 ± 0.020)	E 5	years	(± 0.5%)

Reference:
1991 NEANDC/INDC Nuclear Standards File, Report NEANDC-311 (1992) p.88, W.Bambynek, H.D.Lemmel (ed.).
Notes:
» No documentation of evaluation in NEANDC-311.
» This supersedes the value of (3.735 +- 0.011) E5 a recommended in IAEA Tech. Rept. 261 (1986) p.121 based on N.Holden (1984).

94-Pu-242	sf	(6.77 ± 0.07)	E 10	years	(± 1.0%)
94-Pu-244	α	(8.00 ± 0.09)	E 7	years	(± 1.1%)
94-Pu-244	sf	(6.60 ± 0.20)	E 10	years	(± 3%)
95-Am-241	α	432.2 ± 0.7		years	(± 0.15%)

Reference:
K.Debertin, M.J.Woods, IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.). - And: Y.A. Akovali, Nuclear Data Sheets 72 p.207 (1994).
Notes:
This supersedes the value of 432.7 +- 0.5 y from the earlier evaluation by R.Vaninbroukx in IAEA Tech. Rept. 261 (1986) p.127. Both evaluations were based on the same set of experimental data.

95-Am-242m	α	(3.11 ± 0.05)	E 4	years	(± 1.6%)

Reference:
Evaluated by A.L. Nichols, IAEA Tech. Rept. 261 (1986) p.135, A.Lorenz (ed.).

95-Am-242m	sf	(9 ± 3)	E 11	years	(± 40%)

Reference:
Evaluated by A.L. Nichols, IAEA Tech. Rept. 261 (1986) p.135, A.Lorenz (ed.).
Notes:
Re-evaluation of the experimental value of (9.5+-3.5)E11 y by Caldwell et al. (1967).

95-Am-242m	total	141.0 ± 2.0		years	(± 1.4%)

Reference:
Evaluated by A.L. Nichols, IAEA Tech. Rept. 261 (1986) p.135, A.Lorenz (ed.).

95-Am-243	α	7365. ± 22.		years	(± 0.3%)

Reference:
IAEA-TECDOC-619 (1991): X-ray and gamma-ray standards for detector calibration, A.Lorenz, H.D.Lemmel (ed.)
Notes:
The 1991 IAEA recommended value of 2.690+-0.008 E6 days (=7365+-22years) differs slightly from the value of 7370+-40 given by Y.A.Akovali in Nuclear Data Sheets 66 (1992) p.913; - and from the earlier IAEA value of 7370+-15 y evaluated by R.Vaninbroukx in IAEA Tech. Rept. 261 (1984) p.137.

95-Am-243	sf	(2.0 ± 0.5)	E 14	years	(± 25%)

Reference:
Nuclear Data Sheets 66 (1992) p.913, Y.A.Akovali.
Notes:
Based on Gvozdev et al., Radiokhimija 8 (1966) p.493.

96-Cm-242	α	162.94 ± 0.06		days	(± 0.04%)

Reference:
Evaluated by H.Okashita, IAEA Tech. Rept. 261 (1986) p.141, A.Lorenz (ed.).
Notes:
Same value as evaluated by Vaninbroukx (1982) Rept. INDC(NDS)-138.

Nuclide	Decay	Half-life ± Uncertainty	Exp.	Unit	% Uncertainty
96-Cm-242	sf	(7.05 ± 0.09)	E 6	years	(± 1.3%)

Reference:
Evaluated by H.Okashita, IAEA Tech. Rept. 261 (1986) p.141, A.Lorenz (ed.).

96-Cm-244	α	18.10 ± 0.05		years	(± 0.3%)

Reference:
IAEA Tech. Rept. 261 (1986) p.145, A.Lorenz (ed.).
Notes:
From the review by N.E.Holden (1984).
Uncertainty to be reviewed. Proposed new value: 18.10 ± 0.02 a. (Priv.com. A.L.Nichols 1994)

96-Cm-244	sf	(1.344 ± 0.007)	E 7	years	(± 0.5%)

Reference:
IAEA Tech. Rept. 261 (1986) p.159, A.Lorenz (ed.).

96-Cm-245	α	8500 ± 100		years	(± 1.2%)

Reference:
Nuclear Data Sheets 67 p.172 (1992), Y.A. Akovali.
Notes:
Uncertainty to be reviewed. Proposed new value: 8500 ± 200 a. (Priv.com. A.L.Nichols 1994)

98-Cf-252	α	2.730 ± 0.010		years	(± 0.4%)

Reference:
1991 NEANDC/INDC Nuclear Standards File, report NEANDC-311 (1992)

98-Cf-252	sf	85.5 ± 0.3		years	(± 0.4%)

Reference:
1991 NEANDC/INDC Nuclear Standards File, report NEANDC-311 (1992)

98-Cf-252	total	2.645 ± 0.008		years	(± 0.3%)

Reference:
1991 NEANDC/INDC Nuclear Standards File, Report NEANDC-311 (1992) p.88, W.Bambynek, H.D.Lemmel (ed.).
Notes:
Evaluated by J.R. Smith (1983), see IAEA Tech. Rept. 261 (1986) p.149 where a comment says that experimental values are discrepant between 2.638 and 2.651 a.
Other value: I.A. Kharitonov recommends a value of 2.6473 ± 0.0028 a; Yad. Konst. 1987/4.

Nuclear Data Section
International Atomic Energy Agency
P.O. Box 100
A-1400 Vienna
Austria

e-mail, INTERNET: SERVICES@IAEAND.IAEA.OR.AT
e-mail, BITNET: RNDS@IAEA1
fax: (43-1) 20607
cable: INATOM VIENNA
telex: 1-12645 atom a
telephone: (43-1) 2060-21710

online: TELNET or FTP: IAEAND.IAEA.OR.AT
username: IAEANDS for interactive Nuclear Data Information System
username: NDSOPEN for FTP file transfer