Report

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UK Nuclear Science Forum

Progress Report: Data Studies During 1997

A report produced for IMC

Milestone M5 of Contract BL/G/59057/N
NSF Support RPS/GNSR/5002

Edited by A L Nichols

The running of the UK Nuclear Science Forum is financed by the Industry Management Committee (IMC) comprising Nuclear Electric Limited, Scottish Nuclear Limited and British Nuclear Fuels Limited and their successor companies.

May 1998

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Executive Summary

Nuclear data studies for commercial applications in the UK are formulated, monitored and reviewed by the UK Nuclear Science Forum (UKNSF). This work includes the measurement and evaluation of decay data (eg half-lives and gamma-ray emission probabilities) and fission yields; all known UK studies in 1997 are summarised in this document. Applications developments and international links of relevance in the field of nuclear data are also described.

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Tables

1. INTRODUCTION

The UK Nuclear Science Forum (UKNSF) is the principal body within the UK for technical discussions on the measurement and evaluation of nuclear data (e.g., neutron cross sections, decay data and fission yields). Membership covers approximately 20 different organisations, including nuclear plant operators, vendors, regulators, non-energy applications, academia, and various data measurers and evaluators. The Forum also has the support of the UK Department of Trade and Industry and the nuclear-based Industry Management Committee (IMC) to act as the communications network for all matters relating to the NEA Data Bank/Nuclear Science Committee and the IAEA-Nuclear Data Section.

Two meetings of the UKNSF were held in 1997 on 15 May and 5 December (Chairman, A L Nichols (AEA Technology, Harwell) and Secretary, R W Mills (BNFL plc)). Significant efforts have been made to resolve funding and membership issues relating to the NEA Data Bank. These discussions will continue into 1998. UKNSF members have also assisted the NEA - Nuclear Science Committee and the IAEA Nuclear Data Section during the year to formulate new programmes and define data-based priorities.

2. MEASUREMENTS

2.1 Decay Scheme Data (S I Kafala, T D MacMahon and K Usman (Centre for Analytical Research in the Environment, Imperial College at Silwood Park, Ascot))

The half-life of ^{233}Pa has been determined by gamma-ray spectrometry. Gamma-ray spectra of ^{233}Pa sources produced in the Imperial College reactor were measured for several half-lives, yielding a value of 27.02(3) days (1).

2.2 Radionuclide Standardisation and Measurement of Nuclear Data (contact: S A Woods (Radioactivity Measurement Group, Centre for Ionising Radiation Metrology, National Physical Laboratory, Teddington))

Work has continued on the standardisation of radionuclides identified as being of importance to the UK measurement community, in parallel with studies of selected decay scheme parameters. NPL provides recommended radionuclide decay data upon demand, and has provided standard gamma-ray spectra for the testing of software analysis programs.

(a) Standardisation of ^{90}Sr, ^{204}Tl, ^{153}Sm (2), ^{169}Yb and ^{65}Zn have been completed.

(b) Emission probabilities have been determined for selected gamma-ray transitions following the decay of ^{153}Sm and ^{169}Yb.

(c) Measurements to facilitate the standardisation of ^{237}Np/^{233}Pa, ^{210}Pb and ^{192}Ir have been progressed.

(d) As part of the standardisation of ^{210}Pb, a measurement of the half-life of ^{210}Bi is on-going using a re-entrant, unsealed air-filled ionisation chamber.

(e) The method of Digital Coincidence Counting (DCC) has been validated with measurements of ^{60}Co. Good agreement was obtained between the DCC and conventional counting methods (3).

(f) Standard gamma-ray spectra have been provided for the comparison of spectral analysis software (4). Six test spectra of varying complexity, derived from the measurement of previously standardised radionuclides traceable to national standards, were produced together with calibration and background spectra for the more complex test spectra.

(g) An international intercomparison of measurements of tritiated water by absolute and non-absolute techniques has been completed (5). A number of discrepancies were identified that required further investigation.

(h) An international intercomparison of radon-in-water standards has been completed, and a UK standard established (6).

Financial support of the National Measurement System Policy Unit of the UK Department of Trade and Industry is acknowledged.

2.3 An Epithermal Neutron Beam for Use in Boron Cancer Therapy

(A Brown, D Tattam and D R Weaver (University of Birmingham))

Work is underway to produce a well-characterised epithermal neutron beam for use with Boron Cancer Therapy (BCT). The neutrons are produced by bombarding a thick lithium-metal target with protons. The resulting neutrons are partially moderated to epithermal energies in heavy water, and their transport through the moderator is calculated using the Monte Carlo code MCNP, which calls upon ENDF/B-V data for neutron cross sections. Current work is concentrated on the production of a suitable target for high-power proton beams. Other projects on dosimetry, radiobiology and the preparation of a patient treatment facility are in hand.

A PhD thesis on the comparison between experimental measurements in a water head-phantom and associated MCNP modelling has been completed (D Tattam).

2.4 Fast Fission of ^{238}U (M A Kellett and D R Weaver (University of Birmingham))

The experimental phase of the project has now been completed on the 3 MV Dynamitron facility at the University of Birmingham, and work continues on the analysis of these results. A series of measurements were performed using three different samples (9.6, 24 and 48g) of depleted uranium with a ^{238}U content of 99.7%. The same studies were also carried out for a sample of highly-enriched ^{235}U (99.3% and 40g). Various mono-energetic neutron beams ranging from 1.4 to 2.0 MeV and 4.2 to 5.7 MeV were used, along with timing cycles involving 20 and 40 second irradiation and count periods.

A PhD thesis will be submitted in early 1998.

2.5 Large-Area Surveying of Land Contaminated with Radioactivity (A R Meehan and D R Weaver (University of Birmingham), and M E Phillips (BNFL plc, Berkeley Centre))

Progress has been made in gaining experience of the use of high-resolution gamma-ray spectrometry equipment, combined with GPS and laser-ranging navigational techniques, to carry out contamination surveys on nuclear licensed sites. Investigations have been made of the feasibility of using the scattered components of the radiation to determine the depth distribution of the contamination.

3. DATA LIBRARIES: EVALUATIONS

3.1 Data Library Developments

The status of the UK Decay Data and Fission Yield Libraries is summarised in Table 1. Progress has been maintained in the evaluation of specific decay data (primarily activation and fission products). These studies have been undertaken to assist in the development of the Joint Evaluated Fission and Fusion Files (JEFF).

(a) Activation and Fission Product Decay Data (A L Nichols (AEA Technology, Harwell))

Discussions were initiated in mid-1995 to focus the limited amount of UK evaluation effort on improving the quality of the decay data for a specific number of radionuclides of particular interest to the nuclear industry. Lists of problematic nuclides were assembled that were initially based on discussions involving the JEF Working Group on Fission Yields and Radioactive Decay Data. Communications were also initiated with staff at CEN Cadarache and BNF plc Sellafield, and a series of agreed tabulations were assembled.

A list of radionuclides in priority order was formulated for which the decay-data files were assessed in order to judge whether a detailed re-evaluation was required. Decay data for a further 35 radionuclides were defined as being important in decay heat and inventory calculations, although their measured data are known to be extremely sparse. Detailed assessments were made of the decay data to be found in JEF-2.2 (and ENDF/B-VI data library) for all of these fission-product radionuclides. As a consequence, a series of detailed decay-data evaluations have been undertaken in 1996 and 1997 (Table 2).

The decay data files of approximately 50 radionuclides within EAF (European Activation File) have also been identified as problematic or incomplete when used for fusion-reactor applications. Approximately 20 other radionuclides have been added to this list for completeness, as shown in Table 3. Some of the data files exhibit inconsistencies between the mean gamma energies and component radiations as listed in the files (gamma rays, x-rays, annihilation radiation and internal bremsstrahlung), while others lack consistent gamma-ray transitions or do not exist in JEF-2.2. One aim is to generate the recommended decay data files in ENDF-B6 format for use in JEFF-3.

Table 1: UKNSF Decay Data and Fission Yield Libraries - Status Table, December 1997.

Data	Present status	File development
Fission product decay data	UKFPDD-2 evaluations (ENDF/B-V format) were submitted for JEF-1.1 and partially included. Some of these evaluations have been carried through to JEF-2.2.	None, but see UKPADD-5.
Activation product decay data	UKPADD-5 library (ENDF/B-VI format) has been completed: comprehensive decay-scheme data for 380 activation products and specific fission products have now been evaluated for this library.	Decay data for further sets of radionuclides (mainly activation products) are being evaluated, as agreed through the NEA Data Bank (see Section 3.1(a)).
Heavy element and actinide decay data	UKHEDD-2 evaluations (ENDF/B-VI format) have been submitted and absorbed into JEF-2.2.	UKHEDD-2.2 includes newly recommended decay data for Pa-234g, Pa-234m and Th-234.
Fission yields	UKFY-2 was submitted and accepted for JEF in 1990. After minor modifications (to achieve consistency with JEF-2.2 decay data and to allow for missing decay data), a final version of UKFY-2 was incorporated into JEF-2.2. A new draft evaluation was produced in 1994 (UKFY-3), maintaining consistency and continuing to allow for missing decay data.	An update is envisaged when JEFF-3 decay data become available (ensuring consistency with JEFF-3 decay data, and including fewer approximations for missing decay data); this updated file will be submitted for inclusion in JEFF-3.

As outlined above, the decay data for a number of fission- and fusion-based radionuclides have been evaluated during 1997:

^{58}Mn, ^{58m}Mn, ^{85}As, ^{88}Br, ^{89}Br, ^{90}Br, ^{91}Br, ^{98}Y, ^{98m}Y, ^{99}Y, ^{112}Pd, ^{112}In, ^{112m}In, ^{135}Sb, ^{152}Pm, ^{152m}Pm, ^{152n}Pm, ^{137}I, ^{138}I and ^{139}I.

Many of these radionuclides have extremely complex decay schemes, and their evaluations have proved to be very labour intensive. Their data will be incorporated in UKPADD as highly consistent data files (7). Evaluations will hopefully continue in 1998, 1999 and 2000 to complete these fission- and fusion-based programmes of work.

Studies funded by British Nuclear Fuels plc and UK Atomic Energy Authority (Fusion Division).

Table 2: Decay-Data Evaluations - Fission Products
Evaluations include related metastable states and daughter radionuclides when deemed appropriate (although not listed below).

Nuclide	Importance	Priority
45-Rh-106	Instrumentation for recycling	high
57-La-140	Fission product standard	high
62-Sm-147	Instrumentation for recycling	high
34-Se-79	Radiotoxicity	high
40-Zr-93	Radiotoxicity	high
50-Sn-126	Radiotoxicity	high
51-Sb-127	Reprocessing	medium
53-I-132	Reprocessing	medium
52-Te-132	Reprocessing	medium
53-I-138	Reprocessing/Delayed neutron emission	medium
59-Pr-143	Reprocessing	medium
59-Pr-144	Reprocessing	medium
65-Tb-161	Reprocessing	medium
35-Br-88	Delayed neutron emission	medium
35-Br-89	Delayed neutron emission	medium
35-Br-90	Delayed neutron emission	medium
37-Rb-94*	Delayed neutron emission	medium
39-Y-98m	Delayed neutron emission	medium
53-I-137	Delayed neutron emission	medium
39-Y-99	Delayed neutron emission	low
51-Sb-135	Delayed neutron emission	low
53-I-139	Delayed neutron emission	low
35-Br-87*	Delayed neutron emission	low
35-Br-91	Delayed neutron emission	low
37-Rb-95*	Delayed neutron emission	low
37-Rb-93*	Delayed neutron emission	low
33-As-85	Delayed neutron emission	low

*Still to be evaluated

(b) Heavy Element and Actinide Decay Data (A L Nichols (AEA Technology, Harwell))

An evaluation of the decay data for ^{234}Th, ^{234m}Pa and ^{234g}Pa has been reported (8), along with experimental studies to assess the consistency and correctness of the recommended data; agreement with the measurements of various well-defined samples of silt from Ribble Estuary ranged from good to excellent.

Table 3: Decay-Data Evaluations - Fusion Activation Products

Nuclide	Nuclide	Nuclide
7-N-17	49-In-112	75-Re-191*
(25-Mn-58)	(49-In-112m)	75-Re-192*
25-Mn-58m*	56-Ba-129	76-Os-185
31-Ga-77	56-Ba-129m*	(76-Os-191m)
33-As-82	58-Ce-147	76-Os-195*
(33-As-82m)	59-Pr-143	77-Ir-187
34-Se-79*	59-Pr-144	(77-Ir-190)
34-Se-79m	(59-Pr-144m)	(77-Ir-190m)
38-Sr-87m	59-Pr-150	77-Ir-190n
39-Y-96*	(61-Pm-152)	(77-Ir-191m)
(39-Y-96m)	(61-Pm-152m)	77-Ir-191n**
(39-Y-96n)(?)	61-Pm-152n*	(77-Ir-192)
41-Nb-100	(65-Tb-156)	77-Ir-192m
(41-Nb-100m)	65-Tb-156m*	(77-Ir-192n)
43-Tc-97*	65-Tb-156n*	77-Ir-197
43-Tc-97m	67-Ho-160**	77-Ir-197m**
46-Pd-109	67-Ho-160m	78-Pt-193*
(46-Pd-109m)	67-Ho-160n**	(78-Pt-193m)
46-Pd-112	67-Ho-161	(79-Au-192)
(47-Ag-107m)	(67-Ho-161m)	79-Au-192m
(47-Ag-114)	(67-Ho-170)	80-Hg-199m
47-Ag-114m*	67-Ho-170m	(82-Pb-201)
(47-Ag-115)	72-Hf-178m	82-Pb-201m*
47-Ag-115m*	72-Hf-178n	83-Bi-208*
48-Cd-107	72-Hf-180m	84-Po-208*

* No gamma lines in EAF/JEF library.
** No EAF/JEF data file.
Nuclides in parenthesis have not been requested, but are included for completeness.

3.2 Decay Data and Neutron Cross-Section Evaluations (S I Kafala, T D MacMahon and K Usman (Centre for Analytical Research in the Environment, Imperial College at Silwood Park, Ascot))

(a) International Decay Data Evaluation Project:

Imperial College is participating with collaborators at AEA Technology (UK), Idaho Falls, Brookhaven National Laboratory and Lawrence Berkeley Laboratory (USA), LPRI (France), PTB (Germany), CIEMAT (Spain) and Khlopin Radium Institute (Russia), to provide evaluated decay scheme data for the following:

(i) ENSDF,
(ii) new Table of Radionuclides by LPRI/PTB,
(iii) IAEA decay database.

(b) Neutron Cross-Section Evaluations:

Experimental cross-section data for the following reactions have been evaluated (9): ^{231}Pa(n,γ), ^{147,149}Sm(n, total), (n,γ) and (n,α), and ^{241,243}Am fission and capture in the neutron energy range 10^{-5} eV to 20 MeV.

3.3 Database of $^{240}Pu_{effective}$ and $^{235}U_{effective}$ Coefficients (P M J Chard and S Croft (AEA Technology, Harwell))

Passive neutron coincidence counting (PNCC) is used in safeguards for the assay of special nuclear material, and plutonium contaminated material (PCM). All spontaneously fissionable (fertile) radionuclides contribute to the assay result, which is often expressed in terms of ^{240}Pu effective mass. Similarly, the results of active neutron assays of fissile mass are often expressed as ^{235}U effective mass.

The mass of each radionuclide is multiplied by a characteristic coefficient to determine the corresponding contribution to the ^{240}Pu effective or ^{235}U effective mass. These coefficients depend on the spontaneous fission and induced fission parameters respectively.

A database of effective ^{240}Pu and effective ^{235}U coefficients has been compiled for a wide range of nuclides, of interest in passive Totals and Reals assay modes, active Cf-shuffler, Differential Die-Away and Active Well Coincidence Counting modes respectively (10). The results will enable the expected $^{240}Pu_{effective}$ and $^{235}U_{effective}$ responses to be determined for trace elements in nuclear material samples and in PCM waste. Other applications include calculating the ^{240}Pu effective masses for different radionuclidic compositions and correcting for burn-up variations.

3.4 Resonance Neutron Cross-Section Evaluation (C J Dean (AEA Technology, Winfrith))

Further international evaluation activity on ^{235}U cross-section data has resulted in the adoption of the Leal, Derrien and Larson evaluation for JEFF-3, subject to the resolution of some

inconsistencies. Benchmark results show significant improvements over JEF-2.2, particularly for the prediction of ^{236}U arisings in MOX fuel. The alternative ^{235}U file produced by Moxon (JEF/DOC-702) is also available for evaluation purposes. The international working group is still active as further improvements are being sought.

3.5 Evaluation of Gd(n,γ) Cross Sections (S P Fox and D L Watson (University of York))

Experimental data on the (n,γ) cross section of the naturally-occurring radionuclides of gadolinium have been compiled from standard sources and evaluated. The results were presented at 5th International Conference on Nuclear Data, Trieste, Italy, May 1997.

3.6 Evaluation of Techniques and Data Used in Non-Destructive Assay (S P Fox and D L Watson (University of York))

The techniques of non-destructive assay (NDA) are heavily dependent on the accuracy of the primary data used to calculate the quantities of radionuclides present from the detected radiative emissions. NDA allows the identification of radioactive sources within sealed sources whilst reducing the radiation exposure to personnel.

In order to provide an evaluation of the techniques and data required for the accurate application of the NDS procedure, evaluations of the following data have been undertaken:

(a) Thick target neutron yields from (α,n) reaction on the light nuclei, eg carbon. oxygen (oxides) and fluorine; yields can either be measured directly or calculated using (α,n) cross sections and tabulated stopping powers.

(b) (α,n) cross sections of carbon, oxygen and fluorine.

(c) Stopping powers of the relevant elements for incident alpha particles.

(d) Calculation of thick-target neutron yields from cross sections.

(e) Neutron multiplicities of the spontaneous fission of Pu radionuclides.

A report is being prepared for submission to the NII by the end of May 1998.

3.7 JEF-PC: A PC-computer Based Program to Display Data from the JEF-2.2 Library (D R Weaver (University of Birmingham) and M Konieczny (NEA Data Bank))

Version 2 of JEF-PC was completed and forwarded for publication at the end of 1997. Work has been concentrated on making the program run with all the new Version 2 features, while at the same time not exceeding the memory requirements on the PC. This aim was achieved by separating (a) the cross section related parts of the code from (b) those parts associated with the decay data and fission yields. In practice (a) and (b) are now handled by two separate codes, but there is automatic transfer between the versions when the user switches between

cross sections and other parts of the code. Beta testing was carried out and a number of bugs removed.

Features new to Version 2 are:

(a) over 26,000 sets of experimental cross-section data, taken from the EXFOR data base;
(b) pointwise cross-section data for four additional libraries - BROND-2.2, CENDL-2.1, EAF-97, and EFF-2.4;
(c) integral data, including thermal, Maxwellian spectrum-averaged, fission spectrum-averaged, and 14 MeV cross sections, and resonance integrals for all reactions in the JEF-2.2 library;
(d) flux weighting of cross-section data for a range of reactor types, fuel enrichments and burn-up;
(e) plots of radioactive decay chains;
(f) electron emission data.

3.8 Nuclear Fission Yield Evaluation (D J Hale and D R Weaver (University of Birmingham), and R W Mills (BNFL plc, Sellafield))

The aim of this project is to investigate the evaluation of nuclear fission data using current and new theories of nuclear fission. It is hoped that by applying more recent models to the available experimental fission chain yields, values for the modelled yields can be improved in future evaluations (beyond JEFF-3). The Brosa and Mebel models have been applied to many fissioning systems using the experimental data evaluated in the preparation of UKFY-3. Analysis is being performed on the output parameters to determine equations that can describe the variation of the parameters with fissioning system mass and inducing neutron energy. Fission theory will be carefully examined to pursue the question of the variation of fission yields with neutron energy to determine the effects on parameters such as yield of burn-up monitors and yield of nuclides significant to decay heat and disposal for example. The Wahl Ap' model is being applied to the isobaric yield data within the UKFY3 file in order to see if this model is an improvement over the Zp model; results indicate that this may not be the case. This Ap' model will be applied to as many fissioning systems as is practically possible in an attempt to extrapolate the model parameters to other fissioning systems and inducing neutron energies. However, due to the large number of parameters that this model uses, the number of fissioning systems that can be examined may be few.

The UK group has continued international collaboration with colleagues in the USA, China, France, Germany, Japan, Netherlands, Russia and Sweden, within the forum of the IAEA CRP on Fission Product Yield Data Required for Transmutation of Minor Actined Nuclear Waste. This work is being carried out with financial support from British Nuclear Fuels Ltd. at Sellafield.

3.9 JEF-X (R F Evans (BNFL plc, Sellafield))

JEF-X is a graphical interface to the JEF-2.2 evaluated file for use on X-Windows-based workstations, emulating the functionality of JEF-PC. The code has been adapted to include all

of the pointwise cross-section libraries available with JEF-PC. Experimental data from EXFOR can be plotted as graphs, and decay chains of nuclides within the JEF-2.2 decay-data library can be tabulated and plotted.

4. APPLICATIONS DEVELOPMENT

4.1 Reactor Physics, Shielding and Criticality Applications (N R Smith (AEA Technology, Winfrith))

JEF-2.2 nuclear data libraries for the codes WIMS (reactor physics), MCBEND (shielding) and MONK (criticality) have been provided to the UK nuclear industry for evaluation in field trials. Some further benchmarking activity has also occurred, supported by the IMC. One outstanding issue that has been resolved is the confirmation of the good agreement of the MONK JEF-2.2 library for low-enriched damp powder experiments - previous inconclusive experimental comparisons can now be attributed to errors and uncertainties in one of the experiments. The JEF-2.2 library performs well for criticality studies, and a recently published summary document recommends adoption by UK industry.

Improvements in shielding benchmarks have resulted from a review of the effect of utilising a new file which takes account of recent iron data measurements made at Geel. However, this file has not yet been finalised (for JEFF-3) and hence the MCBEND library remains dependent on JEF-2.2 data.

Further reactor physics calculations have been performed for graphite systems (BICEP and Dungeness experiments); the results support the adoption of the JEF-2.2 graphite file for UK reactor calculations.

4.2 Inventory Applications Libraries (E B Webster (AEA Technology, Winfrith))

The TRAIL program is used in conjunction with the WIMS7 reactor physics program, from which multi-group spectra and cross sections for the resonance self-shieldable actinides are taken and used to generate burnup-dependent cross-section libraries for the nuclide inventory code FISPIN. Both the 69 and 172 energy group cross-section databases for the TRAIL program have been updated, exploiting data from the European Activation File (EAF-97) for those nuclides not available in the JEF-2.2, ENDF/B-VI and JENDL-3.2 files.

4.3 Reactivity Worth of Fission Products (N T Gulliford (AEA Technology, Winfrith))

A scoping study has been performed to generate lumped fission product worths from JEF-2.2 and JENDL-3.2 for thermal reactors (JEF/DOC-730). Compositions generated from a WIMS burnup calculation (to 27.35 GWD/te) were used to model a 3.1% enriched PWR pincell from phase IB of the NEA Burnup Credit Benchmark. A 14x14 clean fuelled cluster model of the Calvert Cliffs reactor provided fluxes and adjoints in the 172 group XMAS scheme. This approach was adopted to model 82 fission products, following studies that indicated that they generated 99% of absorption at all burn-ups for PWRs and AGRs with UO_2 and MOX fuel. JEF-PCv2 provided capture cross sections from JEF-2.2 and JENDL-3.2. EXCEL spreadsheets were used to generate worths of each fission product based on JEF-2.2 and

JENDL-3.2 data. These data were compared and ordered by contribution, before summing to form lumped fission product worths. The difference in overall worth between JEF-2.2 and JENDL-3.2 was less than 1%.

A study had shown the effect of using JENDL-3.2 instead of JEF-2.2 data for the leading CERES fission products (JEF/DOC-732). This comparison indicated little difference for ^{153}Eu, whereas the scoping study showed 4.38% differences. Hence the study was restricted to three nuclides with differences greater than 5%. JEF-PCv2 was used to generate graphs of the capture cross sections of ^{133}Cs, ^{152}Sm and ^{95}Mo: differences were seen in the lowest energy resonances of each nuclide which accounted for the main swing between JEF-2.2 and JENDL-3.2. Thus, it was recommended that the ^{152}Sm and ^{95}Mo evaluations be taken from JEF-2.2, and ^{133}Cs from JENDL-3.2. However, an earlier proposal had been to adopt the EFF evaluations for the natural isotopes of Mo, but these include the JENDL-3.2 evaluations in the thermal and resonance region; this recommendation is now being reconsidered, together with the requirement for a further study of ^{153}Eu data.

4.4 Extensions to Product Data Libraries (C J Dean (AEA Technology, Winfrith))

The resonance self shielding in the WIMS lattice code has been improved by tabulating the ^{238}U and ^{232}Th resonance integrals at 30 background cross sections (isotopic dilutions) instead of 10. An enhanced interpolation procedure has also been coded (AEA Technology Report AEAT-2235 - available through IMC).

Damage response functions for graphite and Fe, together with ^{58}Ni(n,p) fast activation detector data have been added to the WIMS7/JEF-2.2 library (AEA Technology Report AEAT-2512 - available through IMC).

Covariance data have been generated for the Monte-Carlo shielding code MCBEND (AEA Technology Reports AEAT-3075 and 3079 - available through IMC)

4.5 ^{237}Np(n,2n)/[^{237}Np(γ,n) + ^{237}Np(n,2n)] Reaction Rate Ratio in Mixed n-γ Fields Associated with the Thermal Neutron Induced Fission of ^{235}U and the Spontaneous Fission of ^{252}Cf (S Croft (AEA Technology, Harwell))

^{237}Np(γ,n) cross-section has been folded with the fission-gamma-spectra from the ^{235}U(n_{th},f) and ^{252}Cf systems in order to estimate the ^{237}Np(n,2n)/[^{237}Np(γn) + ^{237}Np(n,2n)] reaction rate ratio expected in integral cross-section determinations (11). The (γ,n) contribution was shown to be about 1%.

4.6 Thick Target (α,n) Yield of Fluorine Compounds for a Broad Range of Actinides (S Croft (AEA Technology, Harwell))

Alpha-particle emitting nuclear materials and actinides are commonly encountered in the nuclear fuel cycle in combination with fluorine, giving rise to neutrons from the F(α,n) reaction. These reactions are important for a number of reasons including the contribution they make to personnel dose uptake and the influence they exert on the choice and

performance of radiometric instrumentation used for process control, criticality, accountancy and SNM safeguard purposes.

Thick target (α,n) yields from fluorine-bearing compounds have been estimated in order to determine a recommended excitation curve. This curve has then been used to calculate (α,n) yields in UF_6, UO_2F_2 and PuF_4 for the different U and Pu radionuclides and a range of other actinides (12).

5. INTERNATIONAL COOPERATION

5.1 JEFF Programme (C J Dean and A L Nichols (AEA Technology), D J Edens (Magnox Electric) and R W Mills (BNFL plc, Sellafield))

UK specialists have continued to contribute to a number of OECD/NEA and IAEA programmes involving nuclear data development, particularly those undertaken as part of the JEFF Project. The main aim is to assemble the starter file for JEFF-3, following the near-completion of a report by Rowlands specifying data sources. A number of issues remain to be resolved, and the NEA are injecting additional effort to try to address these problems.

Validation of JEFF-3 is scheduled to commence in June 1998, and be undertaken by CEA staff. Studies had already been performed on the proposed ^{235}U evaluation, and plans are being made to assess the effect of the Geel inelastic cross-section measurements for iron on reactor-shield analyses. The French nuclear industry is committed to the validation of JEFF-3. Speaking on behalf of the UK, Edens has noted that the nuclear industry will be considering the impact of the new ^{235}U and Fe files, but until such time that JEF-2.2 is fully adopted, additional validation requirements could not be defined. However, the UK will assess the deficiencies in JEF-2.2, and will support work on JEFF-3 aimed at addressing those inadequacies of greatest significance.

5.2 European Activation File Development (R A Forrest and J-Ch Sublet (UKAEA, Culham))

Staff at UKAEA Fusion have continued the development of the European Activation File (EAF) under the Nuclear Data Programme of the Euratom Fusion Technology Programme. EAF covers the neutron-induced cross sections and decay data libraries that are required as input to the inventory code FISPACT.

The documentation for the EAF library and the FISPACT inventory code was completed in 1997. A start has been made distributing the complete package to users. A summary of recent work was made at the 1997 Symposium on Fusion Engineering (13). Continued testing of the cross section library has revealed a subtle error in some of the evaluated files concerning the choice of interpolation laws. Under certain conditions some (mostly non-threshold) reactions have group cross sections that do not agree with the pointwise files. This problem is being corrected, and a revision of EAF-97 will be distributed early in 1998.

A major area of work concerns validation and improvement of the EAF libraries. A set of experimental measurements made at the FNS facility at JAERI contains data on the after-heat

of 32 materials following neutron irradiation. Calculations using FISPACT and EAF allow comparison, and there is excellent agreement for some materials, while others show large discrepancies (14). Analysis allows identification of the cross sections and decay data that could be incorrect, and will allow improvements to be incorporated in the next EAF version. This experiment is especially valuable in checking the half-lives and gamma-ray energies as well as the cross sections.

Validation of EAF will continue in 1998 using activation measurements from several European laboratories, and feedback will be incorporated into the next version. Another area that will be substantially improved is the file of uncertainty estimates for the cross sections for all 12,469 reactions. Improvements in the processing tools SAFEPAQ and SYMPAL are also underway or planned.

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