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Summary Report of

Consultants' Meeting

Beta-decay and decay heat

Prepared by
A.L. Nichols

IAEA Headquarters, Vienna, Austria
12-14 December 2005

IAEA Nuclear Data Section, Wagramer Strasse 5, A-1400 Vienna, Austria

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Abstract

Experts on decay data and decay heat calculations participated in a Technical Meeting organized at IAEA Headquarters on 12-14 December 2005. Debate focused on the validation of decay heat calculations as a function of cooling time for fuel irradiated in power reactors through comparisons with experimental benchmark data. Both the current understanding and quantification of mean beta and gamma decay energies were reviewed with respect to measurements and the Gross Theory of Beta Decay. Particular emphasis was placed on the known development of total absorption gamma-ray spectroscopy (TAGS), and detailed discussions took place to formulate the measurement requirements for mean beta and gamma data of individual radionuclides. This meeting was organized in cooperation with the OECD-NEA Working Party for Evaluation and Cooperation (WPEC). Proposals and recommendations were made to resolve particular difficulties, and an initial list of fission products was produced for TAGS studies. The discussions, conclusions and recommendations of the meeting are briefly described in this report.

January 2006

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1. INTRODUCTION

Confident quantification of the decay heat induced by nuclear fission within a power reactor is an extremely important factor in the design of nuclear facilities for electricity generation and for the post-irradiation handling of nuclear fuels (fuel discharge, storage, transport and reprocessing, and waste handling). The total decay heat (and beta and gamma components) as a function of cooling time impact significantly on the safe operation and various legislative and economic aspects of nuclear power generation. Such quantitative studies require comprehensive sets of nuclear data: neutron cross sections, fission yields and decay data (primarily for fission products and actinides – half-lives, and mean beta and gamma energies), and sound estimates of the uncertainties in these data.

During the course of the 1970s, confidence had grown sufficiently in the ability to undertake decay heat calculations with the various available databases, as demonstrated worldwide (particularly in France, Japan, UK and USA). These calculations included mean beta and gamma energies derived from the Gross Theory of Beta Decay [1, 2] for a significant number of important ill-defined fission products (e.g., in the JNDC-V2 and ENDF/B-VI databases), and achieved highly satisfactory agreement with decay heat benchmarks [3, 4].

Recent years have seen the evolution of total absorption gamma-ray spectroscopy (TAGS) at a number of experimental facilities (e.g., INEEL, ISOLDE and the University of Jyvaskyla) that have permitted comprehensive studies and quantification of some of these previously ill-defined fission products [5-8]. However, when the mean energies derived from the Gross Theory of Beta Decay were replaced with equivalent data derived from TAGS, agreement between the resulting decay heat calculations and benchmark experiments was seen to decline [9, 10]. Under these circumstances, a Consultants' Meeting on "Beta-decay and decay heat" was held on 12-14 December 2005 at IAEA Headquarters, Vienna, Austria, to discuss the beta-decay process, TAGS and consider the disagreements between calculation and experiment. Such an informed debate should also provide guidelines for a programme of TAGS experiments.

2. PRESENTATIONS

Dr. N. Ramamoorthy welcomed all participants to the Consultants' Meeting (Appendix 1) – decay heat calculations and the concomitant need to use accurate mean decay energies for the important fission products are essential to the safe operation of nuclear power plants on shut down. The discussions and recommendations from the meeting would point the way forward to resolving the current difficulties that have arisen between the observations of TAGS and the results of adopting the Gross Theory of Beta Decay. He also viewed this cooperative effort between the IAEA and OECD-NEA as a most welcome development.

Participants elected Prof. W. Gelletly as Chairman, and A.L. Nichols as Secretary for the meeting. The provisional agenda was accepted as appropriate, with minor alterations in the ordering of the various initial presentations during the first day (Appendix 2).

2.1. Beta decay and reactor decay heat (W. Gelletly, University of Surrey).

Gelletly reviewed specific features of the nuclear power industry worldwide with respect to decay heat (contributes 60% of the risk of radioactive release into the environment), and the continuing requirement for active decay heat removal systems. Furthermore, safety criteria include the need to know precisely the amount of decay heat in order to assess both the core and containment strategies during the course of an abnormal event. A lengthy listing of potential sources of decay heat was quickly reduced to the quantification of unstable fission products and actinide nuclei produced by successive neutron capture on U and Pu. There are known gaps in the available data required for decay heat calculations, but consideration also needs to be given to what can be successfully produced and studied at "manufacturing" facilities such as ISOLDE.

The β-decay process can be described in terms of the important shape of the spectrum included in the following equation:

$$N(p) \propto p^2 \ (Q - T_e)^2 \cdot F(Z', p) \cdot \left|M_{fi}\right|^2 \cdot S(p,q)$$

where $p^2(Q - T_e)^2$ term represents the statistical factor,
$F(Z', p)$ term represents the Fermi function,
$\left|M_{fi}\right|^2$ is the nuclear matrix element, and
$S(p,q)$ term is the shape factor,

and consideration was also given to our understanding of the interactions (Fermi and Gamow-Teller decay) and selection rules.

Gelletly stated that there has been a significant increase in the study of exotic nuclei and their decay properties, particularly with the development of such facilities as IGISOL (Ion-Guide Isotope Separator On-Line) and TAGS. Various isotope production techniques were described leading up to IGISOL (extension of the He jet techniques at the University of Jyvaskyla) that is chemistry-independent and provides ideal input to a mass separator for subsequent analysis. Refractory elements can also be studied by means of this technique, but the lack of Z discrimination poses analytical problems.

Measurements of β feeding have long been a problem in decay scheme studies - γ-ray emission probabilities and internal conversion coefficients can be used to derive β feeding, but the determination of direct β decay to the ground state of the daughter can pose serious problems for various reasons, including the unsuitability of Ge crystals for the detection and quantification of high-energy γ rays (very low intrinsic efficiency at high γ-ray energies (above ~ 1.5 MeV)) – this problem is sometimes called the "Pandemonium effect" (creates omissions in the derived decay scheme). TAGS can overcome this difficulty, and has been proposed for some of the fission products defined as problematic in decay heat calculations.

2.2. **Decay heat in reactor and fuel cycle applications** (B. Roque and R. Jacqmin, CEA Cadarache).

Jacqmin described the reasoning of the nuclear industry towards requesting more accurate calculations of decay heat for:

(a) short cooling times (< 1 year)
for reactor operators the demand arises from the economic desire for shorter

refueling times – target accuracy of ~ 10% (2σ) or better;
for reactor designers the aim is to avoid excessive conservatism;

(b) intermediate and long cooling times (> 1 year)
for fuel-cycle plant operators the aim is to avoid excessive conservatism in the transfer/transport of spent fuel assemblies, in fuel processing plants, and the storage of fuel and nuclear waste – again, the target accuracy is ~ 10% (2σ) or better.

The JEF-2.2 database and CEA decay heat codes have been validated at short cooling times against pulse fission experiments (Akiyama and Dickens), with estimated uncertainties for UOX and MOX fuels of ~ 15% (2σ); new experiments are planned at CEA – MERCI fuel rod irradiation in OSIRIS, followed by calorimetric measurements (2007-2010). Leading radionuclide contributors at intermediate and long cooling times have been clearly identified (specific actinides and fission products); only partial validation has been achieved through PIE studies, with estimated uncertainties for UOX and MOX fuels of ~ 12% (2σ).

A new fission yield and decay data library has been recently produced in Europe (within JEFF-3.1, and released in May 2005), while the Japanese produced an equivalent JENDL-FPDD file in 2000. CEA are preparing production libraries on the basis of JEFF-3.1 for validation. Some shortcomings have already been recognized at short cooling times, and will be addressed through Subgroup 25 of WPEC (and this IAEA Consultants' Meeting). These efforts are focused on JEFF-3.1 vs JENDL-FPDD discrepancies in mean β, γ energies and β, γ decay heat calculations, and the need to identify and quantify the roles of the responsible radionuclides. Detailed plots of fission-product contributions to decay heat at different cooling times were presented, and illustrated the complexity of the problem. An important question being posed by the nuclear industry at the present time is as follows: "is a reduction in the uncertainty in decay heat calculations to ~ 10% (2σ) or better achievable?"

Jacqmin stressed that one important aim of the meeting must be to identify those radionuclides that need better quantified mean β, γ energy data through sensitivity studies and direct substitutions. Consideration should also be given to the adoption of the average energy data of Rudstam [11]. Accurate new measurements are also required to determine β, γ data for key nuclides by means of the most appropriate technique (i.e., TAGS).

2.3. Decay heat calculations and comparisons with measurements – problems with TAGS (T. Yoshida, Musashi Institute of Technology)

Yoshida stressed that the primary objective of any decay heat calculation was to use an accurate combination of fission-product decay data with an appropriate summation methodology to produce calculated decay heat data that match benchmark measurements. For some considerable time, specialists have appreciated the problem of obtaining the correct match of β and γ decay due to the inability to identify and measure high-energy γ rays – a lack of such γ-ray data (to create the "Pandemonium effect") creates incorrect β data, and hence the observations made in the early 1970s that adopted mean β energies resulted in an overestimation of the β decay heat, and the adoption of incomplete γ-ray data for the mean γ energies resulted in an underestimation of the γ decay heat. These overestimations and underestimations match, so that the total decay heat remains in good agreement with the experimental data.

The appearance of TAGS data in the mid-1990s created a new challenge – introduction of measurements that could provide a comprehensive description of the β and γ decay of an individual radionuclide. Yoshida had inserted these new data into JENDL-FPDD (effectively replacing inaccurate/theoretical mean energies with the values derived from the TAGS measurements of Greenwood *et al.* [6] for 48/49 fission products). Unfortunately, the effect of this highly appropriate action has been a deterioration in the overall agreement between the benchmark data and the new TAGS-based decay heat calculations (compared with calculations based on JENDL-FPDD in which data from the Gross Theory of Beta Decay were adopted) for both the β and γ components. Agreement was shown to improve between the benchmark data and decay heat calculations that involved the incorporation of TAGS-based data into the JEFF-3.1 decay data files.

2.4. **Remarks on decay heat calculations** (O. Bersillon, CEA Bruyeres-le-Chatel).

Following the assembly of the JEFF-3.1 fission yields and decay data libraries, Bersillon had been analyzing the contents of individual files from the point of view of the most important contributors to decay heat. He provided a list of the origins of the JEFF-3.1 decay data library (Table 1), and stressed that a considerable fraction of the nuclides within this database possessed no discrete spectral data whatsoever (although their mean energies were derived through NUBASE).

Table 1. Origins and contents of JEFF-3.1 decay data library.

Original library	No. of nuclides	Comments
UKPADD6.4	360	all with spectral data (40%)
UKHEDD2.4	116	
LNHB	117	
ENSDF	900	
NUBASE	2359	without spectral data (60%)

Total decay heat calculations with JEFF-3.1 were shown to be in good agreement with benchmark measurements. However, major differences occurred when β and γ decay heat components were considered separately. Mean β energies of the main contributors to the β decay heat within JEFF-3.1 have also been compared with the equivalent contents of JENDL-FPDD for different cooling times. Ground and metastable $^{97}Y^{g,m,n}$ were highlighted for which there are three sets of recent decay data evaluations: in JENDL-FPDD, JEFF-3.1 and UKPADD (latter was evaluated in 2005 (but too late for inclusion in JEFF-3.1)). Possibilities of "Pandemonium" problems were also identified for ^{97}Sr, ^{96}Y, ^{99}Zr, ^{95}Rb, ^{101,102}Nb and ^{142}Cs. Some of these radionuclides were seen as important candidates for TAGS studies, and have subsequently been included in the preliminary list of recommendations for such measurements (see Section 4.2).

Bersillon also noted that the many TAGS measurements of Greenwood and co-workers [5, 6] in the mid-1990s had yet to be absorbed into ENSDF in any satisfactory form by the mass chain evaluators.

2.5. **Total absorption gamma-ray spectroscopy – TAGS** (J.L. Tain, CSIC, Univ. Valencia)

TAGS can be used to measure β-decay strength functions over the entire energy range through detection of the full γ-ray cascade. Thus, the problems associated with the "Pandemonium effect" can be totally avoided, and β-strengths can be correctly assigned to derive correct mean β energies (and mean γ energies). Tain used EUROBALL studies of ^{150}Ho (2^-) with six detector clusters in cubic geometry and seven Ge detectors per cluster to demonstrate the problem. Despite such efforts with a 4π detector system, many high-energy γ rays remained undetected, with evidence from TAGS of a significant series of high-energy nuclear levels that were ill-defined.

Tain outlined the extraction process adopted to determine the β-strengths from TAGS spectra through the formulation of the response matrix R. Although the resulting complexity of this process can be problematic, a Monte-Carlo simulation can be made of the TAGS γ-ray response (GEANT3 and GEANT4 codes). A number of possible systematic uncertainties were also noted:

(a) contamination/background γ radiation;
(b) studies involving β^-n decay, and the subsequent emission of prompt grand-daughter γ rays.

These difficulties can be overcome by subtraction after measurement with a high-resolution array of γ and neutron detectors, although neutron interactions may cause further problems. A BaF_2 scintillator has been developed for such studies by the Surrey-Valencia team.

2.6. Experiments at the University of Jyvaskyla, IGISOL (A. Algora, sabbatical at Univ. Valencia)

A study of the β decay of $^{102,\,104,\,105}$Tc by means of TAGS was launched on the IGISOL facility at the University of Jyvaskyla in late 2004. This work had been motivated by the decay heat studies of $^{235,\,238}$U and ^{239}Pu by Yoshida *et al.* [12] that demonstrated the underestimation of γ decay heat by calculation involving radionuclides with half-lives around 1000 secs. Therefore, TAGS was carried out to study the β decay of these inadequately characterized $^{102,\,104,\,105}$Tc nuclides that may suffer from the "Pandemonium effect".

The experimental facilities were described (IGISOL proposal 177) that included a differential pumping arrangement with skimmer for ion extraction, and a rapid tape delivery system to both the TAGS and a high-purity Ge detector for singles studies. Beam and measuring times were chosen on the basis of the half-life of the nuclide under study, along with consideration of possible contaminants (although there was no β^-n decay problem with the chosen nuclides). TAGS spectra for ^{104}Tc and ^{105}Tc have been obtained, and Monte-Carlo simulations have been implemented to calculate the response function prior to analysis. The TAGS data for ^{104}Tc were shown, and indicated that this particular radionuclide did not possess the additional β-strength required to produce an improvement in the overall fit of the measured decay heat data around 1000 secs. Algora also noted that isotopically-pure ^{105}Tc has proved to be more difficult to prepare than envisaged.

More work is required on the resulting data and the facility to improve the technique for the study of the $^{102,\,104}$Tc nuclides. A better tape system needs to be developed, laser ionization should be explored to assist in obtaining isotopically-clean spectra, and further measurements are planned for $^{100,\,102}$Tc.

2.7. **Problem fission products** (T. Yoshida, Musashi Institute of Technology, and A.L. Nichols, IAEA)

Yoshida provided a brief description of the Gross Theory of Beta Decay [1], including the representations of the sum rules for the strength functions, and summations for Fermi and Gamow-Teller transitions. This approach has been adopted in the 1970s-80s for the JENDL, ENDF/B-VI and JEF-2.2 decay data libraries in order to introduce theoretical mean β energies (and hence theoretical mean γ energies) that were missing, and these "modified" databases had exhibited close agreement with the available benchmark data. One problem that still remained was the lack of good agreement between calculations and the benchmarks for cooling times between 300 and 3000 secs [12].

Yoshida has introduced the TAGS-based data of Greenwood *et al.* [6] into JENDL-FPDD, and believed this approach was entirely correct despite the resulting increase in disagreement between the decay heat calculations and benchmark experiments. The introduction of TAGS data into the files demonstrated the importance of such data as a function of the time after fission burst – however, the positive impact of some TAGS radionuclides appeared to be matched by the negative impact of others in their contributions to the total decay heat of ^{239}Pu. Yoshida reminded the meeting that the FENDL-FPDD database has absorbed a significant amount of mean β and γ energy data from the Gross Theory of Beta Decay, unlike JEFF-3.1. Under these circumstances, he advocated the controlled introduction of TAGS-based data into JEFF-3.1 as a consequence of the "cleanliness" of this decay data library. This suggestion provoked considerable debate.

Nichols described the evolution in the 1990s of specific lists of important radionuclides identified with decay heat calculations. Consultations and discussions within the European community resulted in an agreed list of 27 fission products, while the need for extensive theoretical decay data was associated with another 35 neutron-rich nuclides. More recently, Mills (Nexia Solutions, UK) has begun a programme of work in which JEFF-3.1 fission yields and decay data are being used in conjunction with the FISPIN10 inventory code to determine those radionuclides that contribute the greatest uncertainty to the overall uncertainty of the calculated decay heat. These calculations have been carried out on $^{235}U_{th}$, $^{239}Pu_{th}$, $^{238}U_f$ and $^{232}Th_f$ for a wide range of cooling times. On a preliminary basis, the major uncertainties for $^{235}U_{th}$ are identified with the following:

(a) short cooling times – uncertainties in fission yields;
(b) half-lives – $^{98}Y^m$ (± 10%), ^{100}Nb (± 13%) and ^{102}Nb (± 15%);
(c) energy releases – ^{87}Br (± 17%), ^{89}Sr (± 40%), ^{97}Sr (no uncertainty), ^{101}Nb (± 15%), ^{102}Nb (no uncertainty) and ^{143}La (± 53%).

Similar analyses are underway for the β and γ components of decay heat, and the calculations for $^{239}Pu_{th}$, $^{238}U_f$ and $^{232}Th_f$. These studies were seen to be a potentially important source for the identification of radionuclides for TAGS measurements, and the initial findings were introduced into the preliminary list of recommendations for TAGS (Section 4.2).

2.8. **Needs and links to ENSDF/NuDat** (A.A. Sonzogni, BNL)

Sonzogni described the Evaluated Nuclear Structure Data File (ENSDF) that contains the evaluated and recommended nuclear structure and decay data for 2,935 nuclei. Evaluations are undertaken at regular intervals for the various mass chains by individuals (and teams of people) within a group of 40 contributors organized under the auspices of the international Network of Nuclear Structure and Decay Data Evaluators. NuDat-2.1 provides users with a rapid means of accessing and viewing the data within ENSDF in an extremely convenient and understandable manner. Apart from the fundamental nuclear structure and decay data, derived information includes decay schemes, mean energies and detailed energy balances.

Sonzogni indicated the value of using NuDat-2.1 before undertaking any TAGS experiments. The software can be used to assist in the identification of nuclides with incomplete decay schemes ("Pandemonium"), to check for other missing radiation, and to translate the data file to the ENDF format for nuclear applications.

3. DISCUSSIONS

Participants pulled together the different lists of important decay-heat radionuclides with decay data that appeared to be inadequately quantified in the various applications libraries – these lists originate from France, Japan and the UK (as noted throughout Section 2). While these individual lists have some overlap that engendered confidence in their validity, the dominant general opinion was that further detailed analyses were required before May 2006 (WPEC Subgroup meeting) by Bersillon, Yoshida and Mills to ensure the strength of impact of well-directed TAGS measurements on the decay databases and decay heat calculations.

Nichols believed that measurements would also be required to quantify the missing discrete γ-ray and β-particle data for these nuclides (as well as using TAGS for mean β and γ energies). Detailed spectroscopic data were merited, including the energies and absolute emission probabilities of all β and γ transitions. Rubio stressed the importance to the TAGS studies of quantifying with confidence the absolute γ transition probabilities that populate the ground state of the daughter nuclide directly – relative emission probabilities are not sufficient for an analysis of the TAGS data to generate the necessary full set of β^- transition probabilities for the calculation of the β^- component to the mean β energy.

Possible facilities for any proposed TAGS experiments were discussed, and Gelletly proposed approaching IPN-Orsay where the spectroscopic equipment already exists, including tape drive and mass separator for isobaric separation. Possible support from EdF, Unión Fenosa and Nexia Solutions (nuclear power plant designers/constructors and operators) from within Europe should be considered in conjunction with these studies. Furthermore, detailed assessment work is required in the next few months on the contents of the various libraries (JEFF-3.1 and JENDL-FPDD) to understand and possibly resolve some of the differences in the decay heat calculations. Bersillon also pointed out the significant differences that could be seen at longer cooling times between some of the benchmark data (e.g., ORNL and Yayoi). Participants agreed that all relevant benchmark data should be collected together, and Nichols noted that Mills (Nexia Solutions, UK) had recently undertaken such an exercise. TAGS data past and future should be accumulated in a similar manner by the NDS, if possible (including Greenwood *et al.*, known Russian experiments, and future TAGS).

4. RECOMMENDATIONS AND ACTIONS

See also Appendix 3.

4.1. Discrepancies between existing 21st century libraries (O. Bersillon, M. A. Kellett, A. L. Nichols, T. Yoshida and A. A. Sonzogni).

Some initial efforts have been made to identify the major differences in the mean energies to be found in the JENDL-FPDD-2000 and JEFF-3.1 decay data libraries as a function of cooling time. Furthermore, calculations and assessments are being undertaken to recognise those nuclides that contribute the greatest uncertainties to the decay heat as a function of cooling time.

Further assessment work is required to understand more precisely the nature of individual differences between the JENDL-FPDD-2000 and JEFF-3.1 libraries as a means of improving specific decay data libraries. Some discrepancies imply seriously inadequate decay schemes. These assessment exercises will aid in the elimination of particular inadequacies (due to an inadequate dataset). While new evaluations will also be needed under those circumstances, this exercise will identify those nuclides requiring new measurements (by TAGS) – but see Section 4.2, below, for a preliminary list.

Action (Bersillon/Yoshida/Kellett/Sonzogni): liaise closely, understand and resolve some of the discrepancies between libraries. This information would need to be fed into the current list of proposed TAGS measurements – see Section 4.2, below. Action to be completed by May 2006 (before the WPEC meeting).

Differences between decay heat benchmark experiments can be of the order of 15%. Some effort should be made to understand the cause and validity of such significant differences, e.g. 400 – 10000s in U-235 gamma decay heat component.

Action (Yoshida): determine whether there are any additional measurements of decay heat available from Japan, by the end of January 2006.

Action (Robert Mills (Nexia Solutions)): provide participants with a comprehensive list of decay heat measurements, and make a suitable comparison of equivalent datasets, by the end of January 2006.

4.2. Provisional list of nuclides to be studied using TAGS (O. Bersillon, M. A. Kellett, A. L. Nichols, T. Yoshida and A. A. Sonzogni).

Table 2 is a list of radionuclides recommended for TAGS measurements: this list needs to be refined further, and will require input from the required detailed analysis of discrepancies and decay heat uncertainties. We expect some of the listed radionuclides to drop out, and others to take their place (see Section 4.1, above). We estimate the list to be ~ 70% correct.

Table 2. Radionuclides recommended for TAGS measurements (Dec. 2005).

Radionuclide	Comments
35-Br-87	
37-Rb-92	
38-Sr-97	
39-Y-96	
41-Nb-98, -101, -102	
43-Tc-102, -104, -105	all three based on analysis of missing decay heat
52-Te-135	
55-Cs-142	
56-Ba-145	studied by Greenwood *et al.*
57-La-143, -145	both studied by Greenwood *et al.*

Action (Henriksson): following a fuller re-assessment of the above list of nuclei, Henriksson (on behalf of Yoshida) to introduce requests for the required measurements for these nuclei into the High Priority Request List (HPRL – OECD/NEA).

Mean energies are available from three different sources with recent pedigrees:

JENDL-FPDD-2000
JEFF-3.1
INL TAGS (and other experiments?)

A detailed comparison needs to be undertaken of the 48/49 radionuclides identified by Yoshida with respect to their mean energies. The differences would need to be tabulated and explained. Separate sets of decay heat calculations should also be compared.

Action (Sonzogni): contact Idaho National Laboratory (Greenwood *et al.*) by the end of January 2006 to obtain the raw TAGS data.

Action (Tain): undertake a re-analysis of these TAGS data, if available and permitted.

Action (Kellett/Yoshida): undertake the detailed comparison outlined above by the end of March 2006, if possible.

4.3. Experimental studies (A. Algora, W. Gelletly, H. Henriksson, J. L. Tain and B. Rubio).

We believe that accurate measurements of the average β and γ energies of the decay of fission fragments can be made by means of the total absorption gamma-ray spectroscopy technique (TAGS). Measurements of ground state to ground state transitions are also essential. Existing experimental facilities should be used for some particular cases. However, a dedicated facility should be setup at a particular particle accelerator where sufficient beam time can be devoted to these measurements in a systematic manner. Such a facility would consist of a suitable target/ion-source, a mass separator of sufficient resolution, a sample transport system, and a total absorption spectrometer with associated equipment. Furthermore, high resolution γ-ray and internal conversion detectors should be available for decay scheme studies. Sufficient collaborative manpower and resources would be required to exploit this facility fully and fulfill the desired tasks (an additional benefit of this systematic approach would be the production of highly skilled manpower).

Action (Gelletly/Tain/Rubio/Algora):
a) by the end of January 2006, contact laboratories where a programme of TAGS measurements might be undertaken;
b) convene a meeting of representatives from industry, laboratory managers and experimenters to resolve manpower and resource issues, by mid-2006;
c) undertake TAGS measurements of a small number of key nuclides (e.g., 43-Tc-102, 56-Ba-145, 57-La-143, -145) at existing facilities.

4.4. Library of TAGS data (A. Algora, W. Gelletly, H. Henriksson, J. L. Tain and B. Rubio).

Data derived from TAGS should be collected and recorded so that proper use can be made of the results of such measurements. Present databases are not suitable for this purpose because of their format. Hence, we recommend that a new database should be set up for this purpose that includes all previous measurements (e.g., Greenwood *et al.*). The contents of this new international database should be made widely available, and should not be restricted to decay heat applications. The format of the database needs to be flexible enough to contain information on beta intensities for discrete energy (real or pseudo) levels and averages over energy ranges.

Action (Henriksson/Sonzogni/Tain): organise the inclusion of the Greenwood *et al.* data (in the first instance) into an appropriate database.

5. CONCLUDING REMARKS

Significant effort should be expended in 2006 to assess and compare the available decay-heat data, and relevant decay data from the JEFF-3.1 and JENDL-FPDD libraries. Contacts should also be made with those responsible for the operational research programmes of facilities best suited for the planned TAGS measurements, based on the preliminary recommendations tabulated in Section 4.2. Assuming that the actions placed at the Consultants' Meeting can be performed on the timescales indicated (Appendix 3), another meeting should be held immediately before the WPEC meeting of May 2006 (3 May 2006).

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APPENDIX 1

International Atomic Energy Agency

Consultants' Meeting

Beta-decay and decay heat

IAEA Headquarters, Vienna, Austria

12-14 December 2005

Meeting Room ACV-03-250

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International Atomic Energy Agency

Consultants' Meeting on

Beta-decay and decay heat

IAEA Headquarters, Vienna, Austria

12 – 14 December 2005

Meeting Room ACV-03-250

AGENDA

Monday, 12 December

08:30 – 09:30	**Registration** (IAEA registration desk, Gate 1)
09:30 – 10:00	**Opening Session**
	Opening and introductory remarks (Dr. N. Ramamoorthy, DIR-NAPC)
	Election of Chairman and Secretary
	Discussion and adoption of the Agenda (Chairman)
10:00 – 10:45	*Coffee break and Administrative matters*
10:45 – 12:00	**Session 1: Participants' presentations**
	Beta decay: introduction – Prof. W. Gelletly
	Decay heat – reactor applications – Dr. R. Jacqmin
	Decay heat calculations and comparisons with measurements (and problems with TAGS) – Dr. T. Yoshida
12:00 – 14:00	*Lunch*
14:00 – 15:30	**Session 2: Participants' presentations**
	Remarks on decay heat calculations – Dr. O. Bersillon
	TAGS – Dr. J.L. Tain
	Experiments at the University of Jyvaskyla – Dr. A. Algora
15:30 – 16:00	*Coffee break*
16:00 – 17:30	**Session 2** (cont'd): **Participants' presentations**
	Problem FPs – Drs. T. Yoshida and A. Nichols
	Needs and links to ENSDF/NuDat – Dr. A. Sonzogni

Tuesday, 13 December

09:00 – 10:00	**Session 3: Discussions**
	Everyone
10:00 – 10:30	*Coffee break*
10:30 – 12:00	**Session 3** (cont'd): **Discussions**
	Everyone
12:00 – 14:00	*Lunch*
14:00 – 17:00	**Session 4:**
	Discussions and drafting of recommendations - everyone
19:00 onwards	*Dinner in Vienna*

Wednesday, 14 December

09:00 – 12:00	**Session 5:**
	Review of recommendations - everyone
12:00	*Lunch*

ACTIONS

Action	Responsible Member	Deadline	Status
Understand and resolve some of the discrepancies between libraries.	Bersillon/Yoshida/ Kellett/Sonzogni	May 2006	
Identify any additional decay heat measurements from Japan.	Yoshida	end-January 2006	$^{235}U_f$ and $^{237}Np_f$ on Yayoi; Y. Ohkawachi, A. Shono, *J. Nucl. Sci. Technol. Supplement 2* (2002) 483-496 – agrees with old Yayoi and Lowell measurements.
If possible, provide comprehensive list of decay measurements.	Robert Mills	end-January 2006	
Introduce requests for required TAGS measurements in NEA High Priority Request List.	Henriksson		
Contact Idaho National Laboratory to obtain raw TAGS data of Greenwood *et al*.	Sonzogni	end-January 2006	
Undertake analyses of INL TAGS data (if available).	Tain		
Undertake detailed comparisons of 48/49 INL-TAGS radionuclides (JENDL-FPDD, JEFF-3.1 and INL TAGS).	Kellett/Yoshida	end-March 2006	
Contact laboratories where a programme of TAGS measurements might be undertaken.	Gelletly/Tain/Rubio/ Algora	end-January 2006	
Convene meeting of representatives from industry, laboratory managers and experimenters to resolve manpower and resource issues.	Gelletly/Tain/Rubio/ Algora	mid-2006	
Undertake TAGS measurements of a small number of key nuclides (e.g., 43-Tc-102, 56-Ba-145, 57-La-143, -145) at existing facilities.	Gelletly/Tain/Rubio/ Algora		

ACTIONS (cont'd).

Action	Responsible Member	Deadline	Status
Organise inclusion of the Greenwood *et al.* data (in the first instance) into an appropriate database.	Henriksson/ Sonzogni/Tain		

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