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# INDC International Nuclear Data Committee

## Nuclear Data for the International Fusion Materials Irradiation Facility (IFMIF)

### Summary Report of Technical Meeting

Forschungszentrum (FZK), Karlsruhe, Germany
4-6 October 2005

Prepared by

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UK Atomic Energy Authority, Culham, UK

and

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IAEA Nuclear Data Section

October 2005

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

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## Abstract

Experts on reaction cross-section databases participated in a Technical Meeting organized at the Forschungszentrum Zentrum (FZK), Karlsruhe, Germany on 4-6 October 2005. The overall objective of the meeting was to explore the possibilities for improving the status of the nuclear database for the assessment of radiation damage to structural components of large fusion devices. The discussions and recommendations of the meeting are briefly described in this report.

October 2005

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# 1. Introduction

A high energy, high intensity neutron source is required for the generation of a materials database, definition of engineering rules, verification of the performance of the structural and functional materials, licensing and operation of future fusion power reactors. The proposed International Fusion Materials Irradiation Facility (IFMIF) is the most suitable neutron source because of its very close match to the neutron spectra in a fusion reactor. The European Union considers the IFMIF project to be an essential facility on the critical path to fusion power reactors. The European activities for IFMIF are managed by the European Fusion Development Agreement (EFDA). Up to 12 European Associations have strongly contributed to IFMIF and IFMIF is now ready to enter the next phase that is mainly focused on validation and detailed engineering design (called EVEDA).

The overall objective of the meeting was to review the status of the nuclear databases for assessment of radiation damage to structural components of IFMIF, which is in an advanced stage of planning and design. The meeting served to help researchers (both evaluators and experimentalists) focus on nuclear data of primary importance and yet poor quality.

The main part of the meeting was devoted to an overview of the main topics to be assessed, with presentations on:

- IFMIF overview;
- nuclear data evaluation and validation analyses;
- experimental facilities and measurements: status, potentials and perspectives;
- preparing for the future.

The presentations session has been followed by a discussion session in which the conclusions and recommendations have been produced.

The meeting started with welcoming addresses from A. Mengoni (IAEA) and U. Fischer (FZK), and then proceeded with the election of the Chairman (D. Smith) and Rapporteur (R.A. Forrest).

The provisional Agenda was accepted as appropriate, and adopted with minor corrections (Appendix 1).

# 2. Presentations

Brief outlines of each presentation are reported below, including the discussions that followed the talks in some cases. All the electronic versions of the presentations are available on the IAEA NDS website created for the purpose of disseminating all relevant documentation from the meeting. The address of the website is:

http://www-nds.iaea.org/tm-fzk/

## IFMIF Overview

***Status and perspectives of the IFMIF project (R. Lässer, EFDA)***

After a number of IEA workshops (1989-1994) it was decided that only an accelerator based d-Li neutron source is appropriate for qualification of materials for fusion power plants. The present transition phase is expected to be followed by the initiation of design activities (EVEDA) next year. Within the EFDA programme, ‘Tritium Breeding and Materials’ (long–term technology) contains the IFMIF and nuclear data areas. Until the start of EVEDA, the important EFDA priorities are to reduce technical risk and carry out an independent technical assessment. The most important conclusion is the need to pursue a fast-track approach to shortening construction from 15 to 10 years. The various European activities were described along with the budgets and scenarios.

*Discussion*: Möslang, asked about budget for nuclear data: there may be some reduction from (0.9 M€) in 2006. Note that several new associations are participating. Fischer noted that TTMN is the area for nuclear data for both ITER and IFMIF. Baba asked about the meaning of "optimization": main objective is to reduce risks.

***IFMIF: Objectives and facilities (A. Möslang, FZK)***

Technical details of the design were presented. Möslang also stressed that for many areas nuclear data for neutronics and activation analysis are vital for safety analysis, licensing and optimization of the design to reduce cost and risk.

*Discussion*: Forrest asked about the calculation of doses in the accelerator structure to determine whether remote handling is required: it was agreed that this is the most important remaining uncertainty. Lässer asked how the user community will acquire the information about the gamma and neutron distributions in the test rigs: sensors are planned to give this information. Cheng asked about the dpa and He production in the various designs, and noted that the dpa values are calculated while the He can be measured. There is some large uncertainty in the ADS values shown in the presentation: much of the He in ADS is produced from the primary H beam. The very high values shown are for the window. Baba asked if the neutron spectrum is very different with one or two accelerator beams: this is the case because of the varying angles the d beams interact with the Li target. There is a need to have a database of neutron spectra in various regions and under different conditions under the custodianship and maintenance of IFMIF. Möslang stated that the design is nearing finalization, so this will be possible. Fischer noted and others agreed that while the high flux region design is complete, there are still many options in the medium and low flux regions. Cheng asked whether the materials for the structure of the rigs had been decided. There is some doubt that a common steel such as SS316 could be used in the high flux region because of temperature changes: Eurofer cannot be used for the rigs as this material is not yet qualified for the safety case! Fischer noted that the gamma flux in the test regions is reasonably well known. In summary, the plan is for the rigs to be used for about one year, and the safety case can be made using fission reactor data.

***Status of neutronics and nuclear data for IFMIF (U. Fischer, FZK)***

The key role of neutronics has been re-assessed, including the most import issues that concern the simulation of the d-Li source term and the general purpose and activation data above 20 MeV. There has been very significant recent progress on the source term. Data above 20 MeV are also becoming more available, but there is an urgent need for validation. There was discussion about the calculations of elemental transmutation following IFMIF irradiation. It was noted that minor elements such as Ti could be increased by 30% per full power year due to transmutation of the major elements; this effect may have significant materials implications, and could be especially important for ODS steels. There was further discussion about He production data.

***Li target and high flux, test module activation (S. P. Simakov, FZK)***

A detailed 3-D Monte Carlo model of the IFMIT test cells has been prepared and the nuclear responses calculated. The production of $^{3}H$ and $^{7}Be$ radioactive inventories has been calculated for the whole Li-loop. The importance of gamma rays in the heating were noted and compared with that due to neutrons.

*Discussion*: Haight asked about magnetic properties and whether these are changed by irradiation. Lässer stated that this effect will not be investigated in IFMIF.

***Medium flux test module (P. Vladimirov, FZK)***

Neutronics study of the Medium Flux Test Module shows that the neutron spectrum can be adjusted to simulate the neutron response of fusion irradiation by using tungsten plates and carbon coating. The carbon coating acts as a suitable neutron moderator/reflector adjusting the low energy tail of the IFMIF spectrum to be closer to that of a typical DEMO reactor blanket.

The Creep-Fatigue Test Module and Tritium Release Module were studied and it was concluded that more fusion relevant values of He and T production could be obtained if the positions of these were interchanged.

*Discussion*: Fischer asked what Be data were used for the calculations - this would be checked later.

***JAERI nuclear analyses for IFMIF (T. Nishitani, JAERI)***

Neutronics study of the options for the concrete shielding for IFMIF have been undertaken. It may be possible to replace part of the concrete by either steel or water-cooled steel. Work has been carried out on the corrosion of activated materials into the lithium loop. This has implications for the design of traps to reduce the plating out of these corrosion products.

*Discussion*: Fischer asked if MCNPX was used: yes, and a standard neutron source was used. Rullhusen asked about the IFMIF shielding: present design is for 4 m of concrete. Smith asked about the engineering of the cold trap - can 90% efficiency be achieved? Haight noted that corrosion products will not be uniformly laid down, and there will be hot spots at the corners of pipes.

## Nuclear Data Evaluations and Validation Analyses

***JENDL High Energy File 2004 and benchmark testing (T. Fukahori, JAERI)***

Reported on progress with the production of the JENDL high-energy file (for both n and p, up to an energy of 3 GeV) - release of this file in 2004 covered 66 nuclides, and a total of 132 nuclides are planned for the next version. Examples of the agreement of data with experiment, especially for incident protons, were shown. The benchmarking of the library has started using data on iron and concrete slabs and neutrons generated by 43 and 68 MeV protons on lithium. JENDL and other high energy evaluations were compared.

*Discussion*: Blokin asked how the data files were processed: a JAERI-patched version of NJOY was used. Pereslavtsev asked about processing using the various formats in the HE file. Fischer asked if the high energy file can be processed with standard NJOY: this is not possible. Patches have been sent to Los Alamos to be included in a future version of NJOY. Pereslavtsev asked about the C-12(n,2n) data which showed a second peak at about 700 MeV: Fukahori believes this to be a real physical effect. There are some discontinuities at 250 MeV for the proton data, where the computer codes change: this was acknowledged and will be corrected where there are experimental data. Pereslavtsev asked if recoil information is present in the high energy file: not yet. Smith asked if the TIERA benchmark data have been used to calculate doses rather than neutron fluxes as these may be more sensitive: it is believed that these data are probably in the original papers.

***IEAF-2001 activation data file (U. Fischer, FZK)***

The IEAF-2001 activation library was described. This library uses a format with all the cross sections lumped together, and then the amounts of product nuclides are described in the same way as fission yields. This format can be used by the ALARA code, but in order to use in conjunction with FISPACT changes were made to the code by FZK. Comparison with the standard FISPACT results below 20 MeV confirms this approach, while validation using integral data is under way. Note that there is an intention to extend the energy to about 1 GeV, which would make it more useful for non-fusion applications and complementary to EAF-2005.

*Discussion*: Kopecky asked what was included in the MF=2 part of the file: just a skeleton (contains the scattering radius), so that the file can be processed. Haight asked about the validation of activation libraries, could activation foils be used in IFMIF to help this in such studies? This possibility is under discussion. Plompen asked if there are covariance data in the file: no. It was noted that it would be useful to compare IEAF-2001 with relevant parts of the JENDL HE file.

***EAF-2005 activation library and future plans (R. A. Forrest, UKAEA)***

The EAF-2005 activation file covers the energy range up to 60 MeV, and is designed specifically for IFMIF. It uses the same format as earlier EAF libraries, necessitating the use of non-standard MT numbers to describe the reactions. The data above 20 MeV is largely based on TALYS model code calculations. The importance of experimental data, both differential and integral, was stressed. The latter are used for validation. EAF is part of EASY, and the other parts of the software such as SAFEPAQ-II and FISPACT were described. A preliminary d-induced library has been constructed (also based on TALYS) which can be used with FISPACT for deuteron activation calculations.

*Discussion*: Smith asked if the new tools in SAFEPAQ-II that give distributions of, say, maximum cross sections are used to estimate uncertainties - new work of Koning was noted to produce a theoretical calculation of uncertainties and covariances. Forrest stated that the distribution of systematics had been used in the past to estimate uncertainties, and that the new theoretical approaches would be considered for future EAF libraries. Mengoni asked if TALYS uses systematics when doing global parameter calculations: Forrest believed that they were not used. Plompen asked about importance diagrams: these give a pictorial indication of the important nuclides for, say, activity at various neutron energies and decay times.

***Evaluated d+$^{6,7}$Li cross-section data (P. Pereslavtsev, FZK)***

The data for the reaction of deuterons with lithium are fundamental in determining the neutron field produced by IFMIF. New evaluation work has been carried out, and the new experimental data are crucial in improving the emitted neutron spectra. Detailed studies of the various nuclear levels and the optical potentials have enabled a complete evaluation up to 50 MeV to be completed. These new files have been processed by NJOY and used for preliminary benchmark calculations. They appear to be adequate for IFMIF needs.

*Discussion*: Haight asked if there needs to be a further measurement programme to help improve the lithium evaluations before starting IFMIF construction, or are the data sufficient? Pereslavtsev noted that while additional measurements would be useful, the current evaluations appear to be adequate. Baba asked about the high energy peak in the emitted neutron spectra: this is due to direct reactions. Smith asked if there are any uncertainty data in the file as these will be needed: their absence was acknowledged, but there are no plans to generate these data.

***RF efforts on nuclear data evaluations for IFMIF (A. Blokhin, IPPE)***

A new data library (ACDAM) has been produced. In addition to activation cross sections and decay data, ACDAM includes damage cross sections (processed from general purpose libraries). At present this extends to 20 MeV, although work is in hand to extend this energy to 50 MeV. The data have been used to model the irradiation of materials in fast reactor spectra, as support to future irradiations in IFMIF. In addition, some calculations on the activation of the backplate in the IFMIF target have been carried out.

*Discussion*: Time constraints postponed any discussions.

***Validation of EAF-2005 (new tools for EAF-2007) (J. Kopecky, Juko Research)***

The strategy of validation of the EAF-2005 library was outlined. Only about 1,650 reactions out of a total of 62,637 have experimental data. Comparison is made against both differential and integral data. Problems occur with reactions such at (n,t) in which the threshold is close to the measured data. To help validate the majority of reactions with no data, some new tools have been developed to look at the distribution of maximum cross sections and widths. Examples of obvious errors in the library were given. Such testing will lead to the release of a maintenance version EAF-2005.1.

***Validation analyses of IEAF-2001 data (S. P. Simakov, FZK)***

Validation of activation libraries with data above 20 MeV is very important. Both the IEAF-2001 and EAF-2005 libraries can be tested using new integral data from the Řež cyclotron. A detailed discussion of the determination of the neutron spectrum was given. It was noted that the dosimetry data above 20 MeV required for unfolding have large uncertainties and need improvement. Examples of the comparison of both libraries with the integral data were presented, and it was stressed that additional integral data are needed.

***Verification of important cross-section data (E. Cheng, TSI Research)***

Examples of reactions that are important for fusion technology were discussed for which standard activation measurements are impossible. Considered $^{28}Si(n,n'p)^{27}Al$, $^{51}V(n,n'p)^{50}Ti$ and Helium Production Data. A possible approach for the first reaction is to use hyper-pure silicon and try to detect $^{24}Na$ activity due to a second step reaction on the $^{27}Al$. For vanadium, it may be possible to measure the proton production and then subtract the $^{51}V(n,p)^{51}Ti$ values.

## Experimental Facilities and Measurements: Status, Potentials, Perspectives

***Measurement of neutron emission spectrum and activation in Li, Be, C, Al, Fe, Ta (d,n) reactions in the 20-40 MeV region (M. Baba, Univ. Tohoku)***

A large number of measurements have been made at the CYRIC facility at Tohoku University. Measured neutron spectra were shown for materials at 25 and 40 MeV deuteron energy for which there are virtually no other data. Comparisons for lithium were made with recent calculations using the FZK codes. A considerable number of activation measurements (such as $^{27}Al(d,x)^{24}Na$) were reported. Future work will extend the reactions to neutron-induced reactions.

*Discussion*: Fischer asked for further details on the 25 MeV data. Forrest asked about the neutron-induced measurements: there are results already for N and O. Mengoni asked for more details about which break up reactions make contributions at various energies in the spectrum.

***JAERI facilities for IFMIF nuclear data (T. Nishitani, JAERI)***

The two main facilities are the FNS neutron facility at Tokai (14 MeV) and the TIARA AVF cyclotron at Takasaki (both n and charged particles). Examples of measurements were given, including d-induced reactions.

*Discussion*: Simakov asked whether the $^{7}Li$ mono-energetic source will be used for activation measurements: probably not because there are no bending magnets. Haight asked if the previous micro-calorimetry measurements at FNS will be continued: no such experiments are planned.

***LANSCE nuclear data measurement capabilities (R. Haight, LANL)***

A review of the facilities was given; neutrons spanning 16 orders of magnitude in energy can be produced. Most measurements use the time-of-flight technique. Examples of measurements were given, and future upgrade plans (more intense beam) were discussed.

***Materials Test Station(MTS): review of capabilities (R. Haight, LANL)***

This proposal is a possible extension of the LANSCE facility to give a fast-spectrum irradiation capability. It would use a spallation target and would provide neutron fields that could complement IFMIF for materials testing. The capabilities depend on what type of upgrades are implemented at LANSCE.

*Discussion*: Fischer asked about the status of the MTS: advanced planning phase. Simakov asked for more details on the cooling of the tungsten target: water or heavy water cooling channels are proposed. Mengoni asked if the proposed upgrades of LANSCE will have a benefit for the other measuring stations: yes, for current, but no for energy increase.

***European facilities for nuclear data measurements (P. Rullhusen, IRMM)***

The nuclear data needs for IFMIF can be significantly met by the existing facilities and programmes. The facilities at Louvain-la-Neuve (ERONS) and IRMM Geel (NUDAME) were highlighted, and the EFNUDAT initiative links together all remaining European facilities. The main problem is the lack of manpower due to retirements that must be tackled by more involvement from the IFMIF user community, otherwise there will be an irreversible loss of capabilities for measurements.

*Discussion*: Fischer - what is really needed if measurements are to be made at Louvain? Experienced people, and not just money. Haight asked about the possibility of external groups using the facilities: only applies to European groups (proposals must have a European coordinator, but could include American co-workers). Smith reminded the meeting that often there is a real problem with obtaining suitable samples for measurements.

***NPI cyclotron-based fast neutron facility (P. Bem, NPI Rez)***

Measurements of the d+Li neutron yield were described. A neutron transport benchmark on iron is important, as the energies are above 20 MeV and thus relevant for IFMIF. Further discussion ensued on the determination of the spectrum in d+$D_2O$ source - this is very important for integral measurements to validate the activation libraries. The importance of high energy dosimetry data for unfolding was also stressed.

***ELBE neutron source (K. Seidel, TUD)***

The ELBE photo-neutron source is under construction at FZ Rossendorf to produce $7.1 \times 10^{13}$ n $s^{-1}$ at energies up to 30 MeV. The set of reactions that can be measured on tantalum were considered and reactions such as (n,3n), (n,4n) and (n,2nα) that can not be measured at the present facility will be accessible and contribute greatly to the validation of the activation libraries.

*Discussion*: Plompen asked about the measurement of the spectrum from the photonuclear source: will be undertaken in the first year before the activation measurements. The need for high energy dosimetry foils was again highlighted.

***Nuclear data activities at PTB (R. Nolte, PTB)***

Both mono-energetic and white neutron sources are available. The main areas of work have been measurements of scattering cross sections and activation cross sections (latter area of work will probably be stopped due to retirement of senior staff). Steps will have to be taken quickly to ensure knowledge transfer. Some measurements at intermediate energy are being made using the facilities at Louvain-la-Neuve (33-60 MeV) and Cape Town (60-200 MeV).

*Discussion*: Fischer noted the problems with making new measurements. Cheng said that double-differential cross sections have been requested in the past, and that PTB have provided much of the data. Cheng asked for more details on the N and O sources: O source used a water target. Smith and Baba asked why ENDF/B-V data were still used for standards: because they appear to be good enough (accuracy is about 5%). Mengoni asked why there are very different uncertainties for U and Bi fission: they are actually similar.

### *The n_TOF facility at CERN (A. Mengoni, IAEA-NDS)*

This facility has enabled very high precision measurements of cross sections relevant for astrophysics, nuclear transmutation and fundamental physics. A new experimental area is planned that will enable the neutron flux to be increased by a factor of 20 to 100.

*Discussion*: Forrest asked about the progress of analysis: much has been completed; data analyses for the actinides are taking the longest. The production of EXFOR files is ongoing. All Sm data are already complied in this format and the remainder will be available soon. Blokhin asked who is doing the analysis and does this include evaluations: no evaluations are planned, and the work is being done by many different groups.

## Preparing for the Future

### *NEA Nuclear Data Request List, HPRL (A. Plompen, IRMM)*

HPRL is web-based, and has been completely revised to enable a justified list of real needs to be maintained that will be kept up to date. This list would be a good vehicle by which to communicate the data needs of IFMIF.

*Discussion*: Cheng asked how often the list will be reviewed: probably every month at the beginning. Note that there is an annual meeting of WPEC Subgroup C to ensure that the list remains timely. Nolte asked how justifications for requests will be stored: there is provision for the justification in the form of a paper that can be downloaded. Fischer asked if the web site would be open to everyone: yes, but it will be reviewed to ensure no hoax data are added. Running a programme as part of the justification could be problematic: however, participants felt that this process would be essential if requests are realistic. Forrest asked if the HPRL is restricted to cross sections: no, any nuclear data can be included. Cheng asked about fulfilled requests: these will transferred to a separate section, but the data will not be available on the site. The list could be used to monitor and report progress on fulfilling requests.

### *Neutron reaction data for IFMIF: pointing the way forward (D. Smith, ANL)*

This presentation summarized the problems and solutions that the meeting had been considering. The main points are:

- the existing database of evaluated neutron cross sections is unlikely to be fully adequate for IFMIF;
- IFMIF project needs to define and justify the nuclear data needs carefully in order to guide the work of data providers;
- the data provider community needs to survey the current status of evaluated data for IFMIF applications;
- a combination of measurements and nuclear modeling will be required to satisfy IFMIF data needs adequately;
- contributions from many individuals and laboratories will be necessary to complete this job;

- targeted financial support will be required to insure that specific data development work for IFMIF is completed;
- a committee should be formed under the auspices of an international organization to oversee data development activities for IFMIF.

*Discussion*: Fischer asked how this ambitious programme should proceed: start now! Ibarra noted that this discussion concentrates on neutron data, but there is also a need for deuteron data. Fischer turned this argument around and noted that sometimes the IFMIF team gives the impression that only deuteron data are needed, but there are still many neutron data needs as well. Ibarra agreed. Forrest noted that one of the first priorities is leadership: can IAEA be involved in providing such support? Mengoni believed that such a proposal would need to be discussed beyond the meeting. Fischer noted that it is likely that IFMIF will soon fall under the coordination of IAEA rather than IEA, so it is ideal that the nuclear data is also coordinated by IAEA. Kopecky asked why the IFMIF team need to be convinced that there are nuclear data requirements; surely, they already appreciate this need? The example of the FENDL project for ITER was raised, while this was very valuable, such an approach did not provide extra resources for the nuclear data community. Rullhusen noted the importance of trained manpower if data are to be measured. Mengoni feels that if the IFMIF team is convinced that there is a need, for example, for deuteron activation then resources will be found. Smith noted that one easy thing to do is to have a collection of characterised neutron spectra for IFMIF, and (if possible) this database should include some estimate of uncertainties. Fischer noted that estimation of uncertainties and covariances for the spectra are major problems. Kopecky suggested that a CRP on deuteron activation cross sections would be a good way to make some progress. However, Forrest noted that an IAEA CRP takes typically about two years to set up. Mengoni agreed, but felt that this process could be speeded up if the need was judged to be really important. Smith agreed that this suggestion on deuteron activation should be given high priority.

## 3. Discussions and recommendations

General discussions focused on the way forward, leading to a set of recommendations to be forwarded to the IAEA. The deuteron activation need was felt to be suitable for the establishment of an IAEA Coordinated Research Project (CRP). Ibarra summarized the most important needs: data so that activation calculations can be made both in the accelerator and in the lithium target. The priority materials should be Li, corrosion products, Al, Cu and Nb. Data are needed at 40 MeV for the target, but lower energies are also required for the accelerator. There are already EXFOR data for some materials. Complete files are required that can then be used to calculate thick target yields. Measurements may be needed for some materials to back up the calculations. So it will be necessary to undertake the following:

- establish list of relevant materials;
- perform model calculations of d-induced activation using existing ENDF files;
- establish the required accuracy;
- compare calculations with experiments;
- make additional measurements;
- produce files to use in design codes.

The existing IFMIF documentation should be checked to determine the current estimates of deuteron activation and what need there is for additional nuclear data. Simakov noted that FZK are already involved in such calculations - they have found a lack of data for some channels, but some relevant data can be obtained from appropriate medical databases. Smith gave a summary of how CRPs are set up and function. Cheng gave as an example the CRP on Long-lived activation. A well-defined deliverable is essential that can be readily used by IFMIF designers. A proposal for a CRP will be prepared by Mengoni, with input from Ibarra and others. An action was placed on Simakov to define the status of the missing data.

*Recommendation from this committee: deuteron activation is important and would be a good topic for an IAEA CRP.*
*ACTION: Mengoni, Smith and Forrest will draft a document, and other participants at the meeting will provide comments on this draft.*

The need for high energy dosimetry data has been noted during several of the presentations. Extending the IRDF file to include those suitable for high energies would be a good solution. Blokhin discussed some possible reactions from his experience. These include (n,p), (n,α), (n,He prod) on Fe-54, Fe-56, Ni-58, Ni-60, Co-59 and Au-197. Mono-isotopic materials would be preferable to nickel, and He-prod is not very easy to measure.

*Recommendation from this committee: there is a need to extend the energy of dosimetry files and that the IRDF-2002 file should be extended, possibly using well-defined reactions on mono-isotopic materials. Also the half-lives may need to be long if the foil is to be irradiated in IFMIF. He-production may be useful in determining the integrated flux. A more modest IAEA Decay Data Project may be a suitable way to achieve this aim.*

The existing NEA HPRL would be a good way of keeping track of the data needs for IFMIF. Plompen welcomed this proposal, but noted that a good justification document is required. Deuteron activation data would be a good request with which to start. Plompen also noted that referees from the committee would be useful to assess entries into the HPRL.

*The committee noted that the new NEA HPRL was presented at the meeting and that this would be a good method of cataloging the data needs of the IFMIF project. Initial possibilities for inclusion: d-activation data and the W-182(n,nα)Hf-178n reaction.*

*Recommendation from this committee: a database of characterized neutron spectra that would be generally available would be very valuable, and should include some statement on the uncertainty of the spectra; this database could be held on the FZK web site.*

Given the importance of the FENDL library to the ITER project, a sensible proposal would be to consider if this library could be extended to become more relevant to IFMIF. Cheng noted that at the last FENDL meeting, some debate had occurred as to whether FENDL-3 should only be considered for formulation after the new regional libraries become available. An IFMIF data library might not be part of FENDL, since the existing rather formal nature of FENDL may not be flexible enough for IFMIF. Kopecky noted that a disadvantage of FENDL is that the original library was essentially frozen for about 10 years. A new library for IFMIF would need to be updated more frequently. There are three options: start with a calculated library, start with an existing high-energy library, or extend FENDL-2.1.

*Recommendation from this committee: IAEA hold a meeting to consider options for producing a new general purpose neutron-induced library suitable for the IFMIF project.*

Baba noted that dpa and He production are very important materials properties, and that the values in IFMIF must be relevant to fusion power plants. Also, the accuracy of these ratios needs to be investigated. Simakov agreed, but noted that calculations are very dependent on the libraries used - existing libraries suggest uncertainties of about 10%.

Simakov noted that there is a need for gamma-ray yield data from the d-Li target region (gamma rays contribute about 10% to the total heat). At present all the data are calculated, and there is a need for measurements to validate the predictions.

An action was put on all participants to produce a short summary of each presentation, and to also provide a list of reactions with missing data.

The Committee members thanked FZK and IAEA for organizing and hosting the meeting, and the chairman closed the meeting.

**APPENDIX 1**

**IAEA Technical Meeting on**
**Nuclear Data for the International Fusion Materials Facility (IFMIF)**
**Forschungszentrum, Karlsruhe (FZK), Germany**
**4-6 October 2005**

## AGENDA

**4th October**

| | | |
|---|---|---|
| 9.00 | ***Opening session*** | |
| | Welcome by IAEA | A. Mengoni, IAEA/NDS |
| | Welcome by FZK | U. Fischer, FZK |
| | Election of chairman and rapporteur | |
| | Adoption of agenda | |
| 9.30 | ***IFMIF overview*** | |
| | Status and perspectives of the IFMIF project | R. Lässer/A. Ibarra, EFDA |
| | IFMIF: Objectives and Facilities | A. Möslang, FZK |
| | Status of neutronics and nuclear data for IFMIF | U. Fischer, FZK |
| 12.30 | Lunch | |
| 14.00 | ***IFMIF neutronics analyses*** | |
| | Li target and high flux test module, activation | S. P. Simakov, FZK |
| | Medium flux test module | P. Vladimirov, FZK |
| | JAERI nuclear analyses for IFMIF | T. Nishitani, JAERI |
| 16.00 | ***Nuclear data evaluations & validation analyses*** | |
| | The JENDL high energy data file and its benchmark tests | T. Fukahori, JAERI |
| | IEAF-2001 activation data file | U. Fischer, FZK |
| | EAF-2005 activation library and future plans | R. Forrest, UKAEA |
| | Evaluated d+6,7Li cross-section data | P. Pereslavtsev, FZK |
| 18.00 | Adjourn | |

**5th October**

| | | |
|---|---|---|
| 9.00 | RF efforts on nuclear data evaluations for IFMIF | A. Blokhin, IPPE |
| | Validation of EAF-2005 data | J. Kopecky, Juko Research |
| | Validation analyses of IEAF-2001 data | S. P. Simakov, FZK |
| | Verification of important cross-section data | E. Cheng, TSI Research |
| 11.00 | ***Experimental facilities & measurements: status, potentials, perspectives*** | |
| | Measurement of neutron emission spectra and activation in Li,C,Al,Fe,Ta(d,n) reactions in the 20-40 MeV region | M. Baba, Univ. Tohoku |
| | JAERI facilities | T. Nishitani, JAERI |
| | LANSCE | R. Haight, LANL |
| 12.30 | Lunch | |
| 14.00 | IRMM Geel & European facilities | P. Rullhusen, IRMM |
| | NPI Rez cyclotron | P. Bem, NPI Rez |
| | ELBE neutron source | K. Seidel, TUD |
| | Hannover University | R. Michel, Univ. Hannover |
| | PTB and related facilities | R. Nolte, PTB |

| | | |
|---|---|---|
| 16.30 | Preparing the Future | |
| | NEA Nuclear Data Request List | A. Plompen, IRMM |
| | Nuclear Reaction Data for IFMIF: Pointing the Way Forward | D. Smith, ANL |
| | Discussion | All |

18.00 Adjourn
19.30 Dinner

**6th October**

9.00 Elaboration of priority list for IFMIF relevant cross-section measurements
11.00 Preparation of summary report
12.30 Lunch

14.00 Preparation of summary report (cont'd)
16.00 Adjourn

**APPENDIX 2**

**IAEA Technical Meeting on**
**Nuclear Data for the International Fusion Materials Facility (IFMIF)**
**Forschungszentrum, Karlsruhe (FZK), Germany**
**4-6 October 2005**

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**APPENDIX 3**

## SUMMARY OF SOME PRESENTATIONS

1. Status and Perspectives of the IFMIF Project,
   R. Lässer and A. Ibarra, EFDA – CSU Garching.

2. JAERI Nuclear Analyses for IFMIF, JAERI Facilities,
   T. Nishitani, Japan Atomic Energy Agency.

3. JENDL High Energy File 2004 and its Benchmark Tests,
   T. Fukahori, Japan Atomic Energy Agency.

4 EASY-2005 Activation Library and Future Plans,
   R.A. Forrest, UK Atomic Energy Authority.

5. Validation of EAF-2005 Data,
   J. Kopecky, JUKO Research.

6. Verification of Important Cross Section Data,
   E.T. Cheng, TSI Research Inc.

7. NPI Cyclotron-based Fast Neutron Facility,
   P. Bėm, V. Burjan, M. Götz, M. Honusek, V. Kroha, J. Novák and E. Šimečková.

8. ELBE Neutron Source,
   K. Seidel, Technische Universität Dresden.

9. Nuclear Data Activities at PTB,
   R. Nolte, Physikalisch-Technische Bundesanstalt, Braunschweig.

10. Neutron Reaction Data for IFMIF: Pointing the Way Forward,
    D.L. Smith, Nuclear Engineering Division, Argonne National Laboratory

## Status and Perspectives of the IFMIF Project

*R. Lässe and A. Ibarra*
EFDA - CSU Garching

A high energy, high intensity neutron source is required for the generation of a materials database, definition of engineering rules, verification of the performance of the structural and functional materials, licensing and operation of future fusion power reactors. The proposed International Fusion Materials Irradiation Facility (IFMIF) is the most suitable neutron source because of its very close match to the neutron spectra in a fusion reactor. The European Union considers the IFMIF project as an essential facility on the critical path to fusion power reactors.

During the last few years a sound design has been developed for the different IFMIF Facilities under the framework of an IAEA Implementing Agreement. The European activities for IFMIF are managed by the European Fusion Development Agreement. Up to 12 European Associations have strongly contributed to IFMIF. IFMIF is now ready to enter the next phase, mainly focused on engineering validation and detailed engineering design (called EVEDA).

Recently IFMIF (EVEDA and/or facility) has been included in the so-called Broader Approach and various scenarios of EVEDA phases were discussed between JA and EU.

The presentation gives a short historical back view of the IFMIF project, discusses the present and future organisational scenarios, e.g. the “Optimized EVEDA” phase, and gives details of activities to be performed now and in the near future.

## JAERI Nuclear Analyses for IFMIF

*T. Nishitani*
Japan Atomic Energy Agency

In JAEA, which is a new name of JAERI, a shielding analysis of the IFMIF target room concrete wall and an analysis of radioactive erosion and corrosion products in the IFMIF lithium loop have been accried out for IFMIF.

When replacing heavy concrete at the front wall to normal concrete, neutron doses become ~ 10 (at 2m depth) to 100 (4m depth) times higher. In this case, introduction of the steel layer at the surface of the wall can compensate the degradation. On the other hand, introduction of the water channels in the surface of the wall is not effective to enhance the shielding performance.

An analysis of radioactive erosion and corrosion products was conducted to estimate the radioactive corrosion products with a design code ACT-4 developed in JAERI, the activation cross sections based on the FENDL library and the IEAF-2001 library. The result says the concentration of the corrosion in lithium is not very large compared with that of $^{7}$Be. However, the behavior of the nuclides such as accumulation and detachment on material has not been clarified yet. When the dose rate around the lithium loop was estimated under the condition of 100% plate-out, the value was beyond the acceptable level for the hands-on maintenance near the loop soon after the operation stop. It means that a very efficient cold trap is required so that the 90% activity in the lithium loop is removed

## JAERI Facilities

*T. Nishitani*
Japan Atomic Energy Agency

In JAEA, a 14 MeV neutron generator FNS and a TIARA AVF cyclotron are used for the IFMIF related nuclear data measurements.

Double-differential charged-particle emission cross section (DDXc) for several light elements have been measured by using a pencil-beam DT neutron source of FNS, where a newly developed a counter-telescope system with very thin silicon surface barrier detectors of appropriate thicknesses has been emplyed. The detailed DDXc data in a wide emission energy range were obtained for $^{27}$Al, $^{9}$Be, $^{nat}$C and $^{19}$F. For $^{27}$Al(n,xα) reactions, the measured total cross section agreed well with the evaluated data. For $^{9}$Be(n,xα) reactions, there were differences in the α-particle emission DDX between measurement and the evaluated data in the detail of energy structure. For $^{19}$F(n, charged particle) reactions, some peaks corresponding to excited states of the residual nuclei were observed in the energy spectrum of emitted proton, deuteron, and triton particles.

Activation cross sections for deuteron-induced reactions in aluminum, iron, copper, tantalum and tungsten were measured by using the stacked-foil method. The stacked-foils were irradiated with a deuteron beam at the TIARA AVF cyclotron. We obtained the activation cross sections for $^{27}$Al(d,x)$^{22,24}$Na, $^{nat}$Fe(d,x)$^{55,56}$Co, $^{nat}$Cu(d,x)$^{61}$Cu, $^{nat}$Cu(d,x)$^{62}$Zn, $^{nat}$Ta(d,x)$^{178,180}$Ta and $^{nat}$W(d,x)$^{181,183}$Re in 20-40MeV region. These cross sections were compared with other experimental ones and the data in the ACSELAM library calculated by the ALICE-F code. Also Li(p,n) quasi-monochromatic neutron source is available for the IFMIF neutron cross section measurements.

## JENDL High Energy File 2004 and its Benchmark Tests

*T. Fukahori*
Japan Atomic Energy Agency

JENDL High Energy File (JENDL/HE) stores nuclear data for neutron and proton induced reactions up to 3 GeV. The 2004 version of JENDL/HE (JENDL/HE-2004) has been released in March, 2004. The JENDL/HE-2004 has data for total, elastic and isotope production cross sections, and double-differential cross section for secondary emitted neutron, proton, deuteron, triton, He-3 and alpha particles and pion for 66 nuclides. The data can be downloaded from the URL of http://wwwndc.tokai-sc.jaea.go.jp/. In the presentation, reported are the status of JENDL/HE, methods and tools for evaluation, samples of evaluated results and benchmark calculations as well as comparison with experimental data and those using LA150 and NRG2003 libraries. We have still discrepant evaluated data between the libraries to be solved. MCNPX calculations for TIARA integral experiment of iron and concrete using library processed from JENDL/HE-2004 can reproduce the experimental data reasonably. The MCNP library (ACE format) processed from JENDL/HE-2004 by using Japanese version of NJOY based on NJOY 99.97 is available upon the request. The update and addition of nuclides (planned full number of nuclides stored in JENDL/HE is 132) will be continuously done.

## EASY-2005 Activation Library and Future Plans

*R.A. Forrest*
UK Atomic Energy Authority

Understanding and predicting the effect of neutrons on materials is fundamental to fusion technology. The European Activation System (EASY) is the European tool; previous versions such as EASY-2003 have an energy range < 20 MeV. There is a need for a materials test facility such as IFMIF which will use accelerated deuteron beams, giving a high energy tail (up to 55 MeV) in the neutron spectrum. To do activation calculations on IFMIF there was a need to extend EASY and this has been carried out over two years leading to EASY-2005. IFMIF will use deuterons and so there is also a need for a library of deuteron-induced cross sections that can be used as part of EASY.

The SAFEPAQ-II application in EASY is used to produce the EAF libraries. Many new features have been added for EAF-2005. The new cross section library includes 62,637 reactions (12,617 in EAF-2003), with 86 reaction types. The decay data library is also enlarged and covers 2,192 nuclides (278 new). New non-standard MT numbers have been used to define the new reaction types. Most of the data above 20 MeV have been generated by the TALYS model code. Examples of the new data and improvements over earlier EAF libraries are presented. Validation using experimental integral data is discussed by Kopecky elsewhere, but only a small number of reactions have any type of experimental data and so new tools have been developed in SAFEPAQ-II to check the bulk of the reactions. These tools plot quantities such as maximum cross section and half-width as functions of A, Z or s; there are distinct trends in the distributions and outliers can be investigated further. These studies have shown that a significant number of data in EAF-2005 need to be improved and a maintenance release (EAF-2005.1) is planned for early 2006. The deuteron-induced library (data for 60,688 reactions calculated using TALYS) will also be released in the maintenance release. Future deuteron libraries will be improved by the use of experimental data available in EXFOR. The EASY-2007 release will incorporate feedback from the validation and new physics results for both neutron and deuteron libraries.

# Validation of EAF-2005 Data

*J. Kopecky*
JUKO Research, the Netherlands

Validation procedures applied on EAF-2003 starter file, which lead to the production of EAF-2005 library, are described. The results in terms of reactions with assigned quality scores in EAF-20005 are given. Further the extensive validation against the recent integral data is discussed together with the status of the final report “Validation of EASY-2005 using integral measurements”. Finally, the novel “cross section trend analysis” is presented with some examples of its use. This action will lead to the release of improved library EAF-2005.1 at the end of 2005, which shall be used as the starter file for EAF-2007.

# Verification of Important Cross Section Data

*E.T. Cheng*
TSI Research Inc

Continuing efforts in nuclear data development have made the design of a fusion power system less uncertain. The fusion evaluated nuclear data library (FENDL) development effort since 1987 under the leadership of the IAEA Nuclear Data Section has provided a credible international library for the investigation and design of the International Thermonuclear Engineering Reactor (ITER). Integral neutronics experiments are being carried out for ITER and fusion power plant blanket and shield assemblies to validate the available nuclear database and to identify deficiencies for further improvement.

Important cross section data need experimental verifications if these data are evaluated based on physics model calculations and there are no measured data points available. A particular reaction cross section is Si28(n,x)Al27, which is the important cross section to determine whether the low activation SiC composite structure can be qualified as low level nuclear waste after life time exposure in the first wall neutron environment in a fusion power plant. Measurements of helium production data for candidate fusion materials are also needed, particularly at energies above 14 MeV for the assessment of materials damage in the IFMIF neutron spectrum. To a less extent, it appears that V51(n,x)Ti50 reaction cross section also needs to be measured to further confirm a recent new evaluation of vanadium for ENDF/B-VII.

# NPI Cyclotron-based Fast Neutron Facility

*P. Bém,V.Burjan, M.Götz, M.Honusek, V.Kroha, J.Novák and E.Šimečková*
Nuclear Physics Institute

The calculation of neutron flux, the spectrum and the neutronic responses in the IFMIF Test Cell requires checking and validating the cross section database of the Li(d,xn) source reaction. An important role in the development of IFMIF has the benchmarking of neutron transport- and activation cross-section data-base against experiments performed on IFMIF related materials with a neutron beam having a realistic energy distribution (IFMIF-like). All these measurements are under way employing the Cyclotron-based Fast Neutron Facility of the Nuclear Physics Institute Řež.

The thick-target yield data of d+Li - and double-differential cross-section of the $^{7}$Li(d,xn) reactions were measured for incident deuteron energy of 17.1 MeV and for neutron energies down to 1 MeV. Present data being added to higher-energy data obtained at JAERI will complete the database of the M$^{C}$DeLicious model developed for the IFMIF De-Li source term at FZ Karlsruhe.

To validate the neutron transport calculations based on the iron cross-section data evaluations from the FZK/INPE and the LANL, the integral benchmark experiments were conducted on iron employing the $D_2O(^3He,xn)$ reaction with 40 MeV helium ions to produce an IFMIF-like white neutron source spectrum extending up to 35 MeV neutron energy. The computational analysis of these experiments is continuing at FZ Karlsruhe.

For validating activation cross-section data in the energy range relevant to IFMIF a white neutron field with flux density up to $10^{11}$ n/cm$^2$/s and energy spectrum extending to 32 MeV (mean energy of 14 MeV) was developed employing a flowing heavy water target irradiated by 37 MeV proton beam. The neutron spectrum at sample position is determined utilizing both the dosimetry-foil and proton-recoil-telescope method. The wide range of activation experiments on the low activation steel Eurofer-97 and its constituents is curried out in this field. Resulting experimental data are analysed at FZ Karlsruhe in terms of the ALARA inventory code using the activations cross-sections from the Intermediate Energy Activation File IEAF-2001.

# ELBE Neutron Source

*Klaus Seidel*
Technische Universität Dresden

The superconducting 'Electron Linac for beams with high Brilliance and low Emittance' (ELBE), which is in operation at Forschungszentrum Rossendorf, shall be used by TU Dresden for the production of photoneutrons. With an electron energy of 40 MeV and a current of 1 mA, a neutron source strength of about $7 \cdot 10^{13}$ $s^{-1}$ is expected. The spectral distribution of the neutrons, calculated for the source assembly with the Monte Carlo code MCNPX, has a high-energy tail ranging up to 30 MeV. The fluence of the neutrons with energy between 15 and 30 MeV, which is of particular interest for the IFMIF project, will amount up to ~$10^{12}$ $cm^{-2}$ after 10 hours of irradiation at sample positions close to the source.

Tantalum was used, as an example with typical neutron reaction performance of a heavy nucleus, to investigate by calculations with the European Activation System (EASY-2005) the activities which are produced by such an irradiation. It was found that 11 nuclides are produced with γ-activities sufficiently high to be measured with a HPGe-spectrometer. These activities can be used for integral testing of the $^{181}$Ta cross section data for the reactions (n,γ), (n,2n), (n,4n), (n,p), (n,d), (n,n′p), (n,α), (n,n′α) and (n,2nα). Most of these reactions have effective thresholds at E > 15 MeV. For medium-mass nuclei the Coulomb wall for p- and α-emission is lower than in the case of heavy nuclei, and more gas production reactions may be expected.

It was concluded that the facility could be used for integral validation experiments of IFMIF relevant EASY data as at present carried out with fusion peak neutrons.

# Nuclear Data Activities at PTB

*Ralf Nolte*
Physikalisch-Technische Bundesanstalt, Braunschweig

The nuclear data work at PTB concentrates on the measurement of differential elastic and inelastic neutron scattering cross section, double differential neutron emission spectra and activation cross section for nuclides of relevance in fusion technology. For these investigations, a multi-detector time-of-flight spectrometer is installed at the PTB CV28 isochronous cyclotron. The D(d,n) reaction is employed for neutron production using a $D_2$ gas target. The measurements are carried out in the energy range between 6 MeV and 15 MeV where no monoenergetic neutron sources are available. So far, cross sections for the following materials were measured with high precision:

- elastic and inelastic scattering section (DX): $^{14}$N, $^{16}$O, $^{nat}$Si, $^{nat}$Ti, $^{41}$V, $^{nat}$Cr, $^{nat}$Fe, $^{nat}$Cu, $^{nat}$Pb
- neutron emission cross sections (DDX): $^{nat}$Ti, $^{41}$V, $^{nat}$Cr, $^{nat}$Cu, $^{nat}$Pb
- activation cross sections: $^{19}$F, $^{24}$Mg, $^{27}$Al, $^{28}$Si, $^{29}$Si, $^{30}$Si, $^{46}$Ti, $^{48}$Ti, $^{51}$V, $^{52}$Cr, $^{54}$Fe, $^{56}$Fe, $^{59}$Co, $^{58}$Ni, $^{63}$Cu, $^{65}$Cu, $^{64}$Zn, $^{93}$Nb, $^{103}$Rh

All finally analyzed cross section data were submitted to the NEA data bank with full documentation of uncertainties for inclusion in the EXFOR data bank.

In addition to the work carried out at the PTB accelerator facility, experience in neutron metrology and nuclear data measurements at neutron energies above 20 MeV were acquired in experiments at the neutron beam facilities in Louvain-la-Neuve ands Cape Town where cross sections for the production of residual nuclei, fission cross sections and $(n, x n \gamma)$ cross sections were measured in collaboration with other groups.

This expertise can also be used for work related to the special nuclear data needs of the IFMIF project, e.g. Li+d neutron and photon emission cross sections at lower deuteron energies, scattering and activation cross sections for structural materials as well as dosimetry cross sections at energies below and above 20 MeV.

## Neutron Reaction Data for IFMIF: Pointing the Way Forward

*Donald L. Smith*
Nuclear Engineering Division, Argonne National Laboratory

There is an international consensus on the need to construct a facility to test materials for neutron radiation damage under high dose conditions resembling those to be found in fusion reactors. This challenges the nuclear data community to provide an adequate database of evaluated nuclear data that will support the development of such a facility (to be called IFMIF). The availability of fast computers and sophisticated system modeling tools suggests that mathematical modeling will play a greater role in the development of IFMIF than it has for past facility development projects. The data needs for cross sections and radioactivity data for this enterprise will be extensive. Furthermore, it is evident that the current status of available information is inadequate to satisfy these needs. Since the time frame for meeting this challenge is short (5 – 10 years), the process of developing the needed data cannot be left to chance. A well organized international program involving nuclear modeling, measurements, and data evaluation activities is necessary. A suggested approach to achieving the goal is outlined in the following table:

| *A strategic approach to developing neutron reaction data for IFMIF* |
|---|
| • Characterize the relevant neutron spectra<br>• Decide on the relative importance of various candidate materials<br>• Identify the key elements and isotopes<br>• Determine the open neutron reaction channels versus incident energy<br>• Perform global nuclear model calculations for all reaction channels<br>• Perform system sensitivity studies to estimate the required data accuracies<br>• Survey the status of existing experimental data and evaluations<br>• Identify the neutron data deficiencies<br>• Develop a detailed plan for improving the neutron data<br>• Prioritize the work to be done<br>• Identify the laboratories and individuals who could carry out the work<br>• Establish a coordination and support framework for the various activities<br>• Determine deliverables, schedules and milestones for the work |

This paper discusses the points mentioned in this table in some detail and it also reviews some of the physics principles that need to be considered in pursuing the various data development tasks. Some shortcomings of approaches taken in previous data development programs are mentioned with the hope that lessons from the past can be learned and pitfalls can be avoided for the IFMIF project. Close cooperation between data producers and data users will be needed to insure that the high priority nuclear data needs are identified and realistic accuracy requirements are clearly established. Effort should be focused in accordance with the perceived importance of the various data needs for IFMIF. Furthermore, the flow of information from producer to user should be made as smooth as possible in order to insure optimal efficiency of this activity.

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