IEC-226

WPEC Subgroup Proposal

Title:

Neutron Activation Cross Section Measurements from Threshold to 20 MeV for the Validation of Nuclear Models and their Parameters

Justification for Subgroup:

Reliable nuclear models and their associated parameters are needed for computation of physical quantities that cannot be easily measured. Examples of these are reaction processes on radioactive targets, production of long-lived activation products and comprehensive particle-emission cross sections, angular distributions, and energy spectra associated with incident neutrons in the range of several MeV to several tens of MeV. In accordance with the NEA High-Priority Request List (HPRL), such data are essential for the design of advanced nuclear energy production systems such as fusion reactors and ADS as well as for analysis of the performance of ATW systems intended to reduce the inventory of long-lived radioisotopes in nuclear waste.
The necessity of improved model calculations became apparent from recent measurements of a large number of reaction cross sections using the activation technique at IRMM and FZ Jülich. Often evaluated data from JEFF, ENDF and JENDL were discrepant with each other and with the measured data, especially when measured data are scarce or previously non-existent. On the other hand it was shown that statistical model calculations (including pre-equilibrium emission) with carefully determined model parameters lead to much better results. This latter approach should be undertaken in a systematic fashion addressing all reaction channels and the available experimental data with an internally consistent model description. Additional experimental data are required to further benchmark these nuclear models and to pin down model parameters.

Objective of this subgroup:

The unifying objectives of this subgroup are the validation of nuclear modeling by benchmarking model calculations to new and recent measurements and the development of a means to define data needs for nuclear energy applications in a more systematic fashion than was done in the past. The following subdivision is made:

i) to generate a large collection of pertinent experimental nuclear data that can be used for validation of these nuclear models;
ii) to determine those nuclear model parameters that yield the best agreement with these data and compare them to the RIPL parameter set from the IAEA, and certain recent proposals for level density, optical model, pre-equilibrium and complex particle emission descriptions.
iii) to provide reliable evaluations for a large number of neutron activation reactions and the competing channels of interest for the above-mentioned applications;
iv) to perform nuclear-model sensitivity studies for specific reactions selected from the HPRL in order to identify those important future experiments that should be performed. These will contribute to the documentation of data requirements for the above-mentioned nuclear energy technologies by providing important additional motivation.

Subgroup Monitor(s):

Mark Chadwick (LANL)	ENDF
Arjan Koning (NRG-Petten)	JEFF

Subgroup Chairman:

Arjan Plompen (IRMM)	JEFF

List of Subgroup Participants:

Arjan Plompen (IRMM) and Peter Reimer (IRMM, FZ-Jülich)	JEFF
S.M. Qaim (FZ-Jülich, U. of Cologne)	JEFF
Donald L. Smith and Andreas Fessler (ANL, IRMM)	ENDF
V. Avrigeanu (NIPNE, Bucharest, Romania)	FENDL
S. Sudár (Institute of Physics University of Debrecen, Hungary)	FENDL

Definition of the Project:

Neutron activation cross sections will be measured for a large number of threshold neutron-induced activation reactions in the energy range below 20 MeV. Measurements at the IRMM Van de Graaff accelerator facility will concentrate on the 16-20 MeV range, whereas for certain reactions complementary measurements will be performed at FZ Jülich below 12 MeV. These measurements will be carried out using existing experimental apparatus and techniques and on available elemental samples as well as isotopically enriched samples obtained on loan from JAERI. The work will also benefit by access to chemical separation technologies practiced at FZ-Jülich. The data produced by this project, along with complementary results compiled from the literature, will be used to validate statistical, pre-compound nuclear model calculations performed with contemporary codes (e.g., STAPRE-H and/or GNASH). These calculated results will, in turn, be used to generate reliable evaluations for the studied reactions and competing reaction channels from threshold to 20 MeV. A comparison will then be made between the model parameters that lead to the best agreement with experimental data and the existing RIPL parameter set compiled by the IAEA. The details of this investigation will be thoroughly documented. Furthermore, calculations will be performed with these model codes to ascertain the sensitivity of the derived physical quantities, such as cross sections at different neutron energies, to the nuclear model parameters. This information will serve to guide future measurement programs. It will also help to clarify the prospects for satisfying developing nuclear data needs for fusion, ADS, and ATW neutronic systems when one has to rely on nuclear model calculations validated by comparisons to available microscopic experimental data.

Relevance to Evaluated Data Files:

This project will generate a large number of evaluated excitation functions for the specific reactions studied. Evaluations will be obtained as consistent model descriptions of all reaction channels using all available cross section, level, level density and, where necessary, scattering information. Consistency will justify the use of these evaluations in libraries intended for all neutron physics applications (neutron transport, neutron damage, gas-production, decay-heat,...). At the same time they will be of use to dedicated activation files. These results will be provided in the ENDF format so that they can be employed in such libraries as ENDF, JEFF, JENDL, FENDL, EAF, etc.

Deliverables:

- A new set of measured activation cross sections for incident neutrons below 20 MeV. The emphasis is on the mass regions of Si to Zn (structural materials), from Sr to Mo (structural materials/fission products) and on Pb (moderator/coolant/shielding material).
- Evaluated cross sections for a large number of activation cross sections. Consistent description of all reaction channels taking into account all pertinent experimental data. A complete picture for each target nucleus should emerge in agreement with the needs for files like JEFF, ENDF, FENDL, and JENDL. Evaluated data will also be offered to the compilers of dedicated activation libraries such as EAF and IRDF.
- Results from a detailed comparison of best-fit nuclear model parameters with the RIPL set. Certain recent proposals of level density, optical model, pre-equilibrium, and complex particle emission approaches will be tested.
- A collection of sensitivity parameters that relate the physical quantities studied by this subgroup to the most significant nuclear model parameters.
- Recommendations for high-priority new measurements. Estimates of the uncertainties, which could be expected in calculating unmeasurable physical quantities by means of nuclear models validated with experimental data. The latter are of interest when such unmeasurable quantities are needed for contemporary applications.

Time Schedule and Milestones:

1999-2000

ANL/IRMM: A. Fessler

- Insure that experimental data already generated from an ANL/IRMM/FZ-Jülich collaboration are compiled in the EXFOR system.
- Assemble these data, as well as complementary information from the literature for structural materials such as Ti, V, Cr, Mn, Fe, in preparation for a nuclear model validation study.
- Generate best-fit, nuclear-model-calculated excitation functions for this collected database and produce evaluated files in ENDF format for the studied reactions.
- Compare determined best-fit parameters with those from the RIPL library (IAEA). Compare to recent proposals of optimized parameter systematics.

ANL: D.L. Smith

- Data analysis of measurement campaign started in November 1998 (See table 1, for reactions under study). Determination of summing-coincidence corrections.
- Compile experimental data from the literature for use in guidance of the nuclear modeling analysis.
- Prepare a journal publication on the model parameter sensitivity analysis method used in this project.

IRMM and FZ-Jülich: P. Reimer, A. Plompen, R. Puglisi, C. Chaves, J. Gonzales, and S.M. Qaim

- Completion of irradiations and activity determinations of reactions listed in table 1. Start with data-analysis. Compilation of existing measurements and evaluations for comparison.
- Preparation of an automated repetitive pneumatic sample transport system for short-lived activity measurements (1-20 s).

NIPNE: V. Avrigeanu

- Cross sections for the fast-neutron induced reactions on the stable Cr isotopes, previously analyzed within IRMM (1998), ^{51}V, and the stable Ti isotopes will be calculated by using the modified STAPRE-H code. A start will be made with calculations for the chain of Mo isotopes. In order to establish model parameters, in addition to the NLD analysis, the following methods will be used:
    - the SPRT method in order to validate the neutron optical model parameters (OMP), by using the corresponding experimental data compiled in RIPL;
    - analysis of the proton and alpha-particle induced reactions on the corresponding residual nuclei, in order to validate the charged-particle OMP parameter sets;
    - analysis of the charged-particle emission spectra in the neutron-induced reactions, in order to check the eventual different charged-particle transmission coefficients in the incident/emergent reaction channels (well-known at higher energies but found also in the case of low-energy alpha-particle emission).
- The BSFG level density parameters obtained through the above-mentioned method will be compared with the RIPL values.
- Evaluated data files within the ENDF-B6 format will be prepared on the basis of the calculated reaction cross sections.

University of Debrecen: S. Sudár

- Start of calculations for $^{99}Tc(n,p)^{99}Mo$ and $^{99}Tc(n,\alpha)^{96}Nb$. Investigation of parameter sensitivity and comparison with the RIPL parameter set.

FZ-Jülich and University of Debrecen: S.M. Qaim and S. Sudár

- Measurements of cross sections for (n,p) and (n,α) reactions on isotopes of Zn and Zr from 8-12 MeV.

<u>2001</u>

IRMM, ANL and FZ-Jülich: P. Reimer, A. Plompen, D.L. Smith, R. Puglisi, C. Chaves

- Complete a new round of experimental measurements and finalize the data analysis for the obtained raw data. These experimental results should reflect a recently developed capability of this project to generate data at the IRMM Van de Graaff facility for relatively short-lived radioactive species (i.e., those involving half lives as low as 3-5 sec). It will also involve extension to higher sample mass numbers than were considered in the first round of measurements (e.g., heavy fission products, Bi, Pb, etc.). Specific measurements to be undertaken during this period will be guided by the HPRL, the available sample materials, and the allocated accelerator time at IRMM.
- Publish the experimental results and make them available to the EXFOR system.

NIPNE: V. Avrigeanu

- Cross sections for the fast-neutron induced reactions on the stable Mo isotopes and the stable Zr isotopes will be calculated by using the modified STAPRE-H code, and the above-mentioned methods.
- The BSFG level density parameters obtained through the above-mentioned method will be compared with the RIPL values.
- Evaluated data files within the ENDF-B6 format will be prepared on the basis of the calculated reaction cross sections.

University of Debrecen: S. Sudár

- Modification of Stapre for calculation of triton and ^{3}He emission. Completion of the calculations of ^{99}Tc and method comparison with V. Avrigeanu for selected cases of Mo and Zr. Stapre calculations for isotopes of Fe-Zn.

<u>2002</u>:

IRMM and ANL: A. Plompen, D.L. Smith

- Perform nuclear model analyses, model parameter comparisons, and model-parameter sensitivity studies related to the newly acquired data and complementary results from the literature, in the same manner as described above for the earlier assembled data sets. Focus on nuclei not addressed earlier in the project.
- Publish the results of this analytical study.
- Prepare a final formal report of the subgroup activities during the period 1999-2002.

NIPNE: V. Avrigeanu

- Cross sections for the fast-neutron induced reactions on ^{89}Y and the stable Sr isotopes will be calculated by using the modified STAPRE-H code, and the same above-mentioned methods.

- The BSFG level density parameters obtained through the above-mentioned method will be compared with the RIPL values.
- Evaluated data files within the ENDF-B6 format will be prepared on the basis of the calculated reaction cross sections.

University of Debrecen and FZ-Jülich: S. Sudár and S.M. Qaim

- Calculation of excitation functions for triton, deuteron and ^{3}He emission. Parameter sensitivity investigation. Comparison to RIPL parameters. Target nuclides will be chosen in the mass region of Ti-Zn and Sr-Mo depending on the available experimental information.

Table 1 Neutron-induced reactions currently under study by the IRMM-ANL-FZ Jülich collaboration using the activation technique. Enriched samples are on loan from JAERI.

Reaction	Sample	Reaction	Sample
V-51(n,n'a)Sc-47	nat	Zr-90(n,pn)Y-89m	enr
Cr-50(n,2n)Cr-49	enr	Zr-91(n,an)Sr-87	enr
Cu-65(n,a)Co-62g+m	nat	Zr-91(n,np)Y-90m	enr
Zn-64(n,2n)Zn-63	nat	Zr-91(n,p)Y-91m	enr+nat
Zn-66(n,2n)Zn-65	enr+nat	Zr-92(n,p)Y-92	enr+nat
Zn-66(n,p)Cu-66	enr+nat	Zr-92(n,pn)Y-91m	enr
Zn-67(n,np)Cu-66	enr+nat	Zr-94(n,p)Y-94	nat
Zn-67(n,p)Cu-67	enr+nat	Zr-96(n,2n)Zr-95	enr
Zn-68(n,a)Ni-65	nat	Zr-96(n,a)Sr-93	enr
Zn-68(n,p)Cu-68g+m	nat	Mo-92(n,2n)Mo-91m	enr+nat
Zn-70(n,2n)Zn-69	nat	Mo-92(n,a)Zr-89g+m	enr+nat
Se-74(n,np)As-73	nat	Mo-92(n,p)Nb-92m	enr+nat
Se-74(n,p)As-74	nat	Mo-92(n,p2n)Nb-90g	enr
Se-76(n,2n)Se-75	nat	Mo-94(n,2n)Mo-93m	nat
Se-76(n,p)As-76	nat	Mo-95(n,p)Nb-95g+m	nat
Se-77(n,p)As-75	nat	Mo-96(n,np)Nb-95g+m	enr+nat
Se-78(n,a)Ge-75	nat	Mo-96(n,p)Nb-96	enr+nat
Sr-84(n,2n)Sr-83	enr	Mo-97(n,np)Nb-96	enr+nat
Sr-84(n,p)Rb-84m	enr	Mo-97(n,p)Nb-97g+m	enr+nat
Sr-86(n,2n)Sr-85m	enr+nat	Mo-98(n,p)Nb-98	enr+nat
Sr-86(n,p)Rb-86m	enr+nat	Mo-98(n,pn)Nb-97g+m	enr+nat
Sr-88(n,2n)Sr-87	nat	Mo-100(n,np)Nb-99	enr
Sr-88(n,p)Rb-88	nat	Tc-99(n,n')Tc-99m	
Zr-90 (n,a)Sr-87	enr+nat	Tc-99(n,p)Mo-99	
Zr-90(n,2n)Zr-89g+m	enr+nat	Tc-99(n,a)Nb-96	
Zr-90(n,p)Y-90m	enr+nat		