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Summary Report of

Third Research Coordination Meeting on

Minor Actinide Nuclear Reaction Data (MANREAD)

International Atomic Energy Agency (IAEA)
Vienna, Austria

19 – 22 October 2010

Prepared by

Frank Gunsing
Commissariat à l'énergie atomique (CEA), France

and

Naohiko Otsuka
IAEA Nuclear Data Section, Vienna, Austria

December 2010

IAEA Nuclear Data Section, Vienna International Centre, A-1400 Vienna, Austria

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Abstract

The Third Research Co-ordination Meeting of the MANREAD (Minor Actinides Neutron Reaction Data) Coordinated Research Project (CRP) was held at IAEA Headquarters in Vienna from 19 to 22 October 2010. A summary of the presentation, and the discussions which took place during the meeting, are reported here. In addition, a task assignment list of the experimental data assessment activities was agreed, and is provided together with the plan for future CRP activities.

December 2010

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1. INTRODUCTION

The participants of the Third Research Coordination Meeting (RCM) on Minor Actinide Nuclear Reaction Data (MANREAD) were welcomed at the IAEA by S. Simakov. On behalf of the Nuclear Data Section (NDS) he emphasised the importance of this CRP and its results for the evaluation of new reactor systems, partitioning of radioactive nuclides, closed fuel cycles, waste transmutation and safe disposal. It was also highlighted that the outcomes of this CRP closely interact with other programmes guided by NDS, such as nuclear standards, prompt fission neutron spectra, inelastic scattering on fissile nuclei and nuclear data modelling.

N. Otsuka acted as the new Project Officer of the CRP MANREAD. He prepared several working documents for the meeting and stressed that there is still much to do before the end of the CRP in December 2011. A. Plompen chaired the meeting and F. Gunsing was selected as Rapporteur. The agenda was discussed and adopted.

2. PRESENTATIONS

V. Pronyaev - *IPPE, Obninsk, Russian Federation*
Evaluation of Fission and Capture Cross Sections for ^{237}Np, ^{241}Am and ^{243}Am

Pronyaev presented the approach and the results of evaluation of fission and capture cross sections for ^{237}Np, ^{241}Am and ^{243}Am in the combined fit with the standards data. The experimental data for fission and capture cross sections were analysed and reduced, where it was needed to their primarily measured quantities if they were not the results of absolute measurements (shape data, absolute ratios, shape of the ratios) and in the case of ^{237}Np data were added to the standards database following a least-squares fit with the GMA code. In cases of poor chi-square the outlaying data were identified and an additional component of the uncertainties was added for the energy ranges where data were discrepant. It was found that the influence of the ^{237}Np data on the standards cross sections were negligible, because of the large number (about 430) of data sets that were selected for the evaluation of the standard cross sections. Due to this, a simplified approach was used for ^{241}Am and ^{243}Am: only these standard cross sections and their covariance matrices were used in the combined fit, which were coupled with the evaluated americium reaction cross sections through absolute ratio or shape of the ratio measurements. The results of the evaluations cover the energy ranges where experimental data are given, ranging from 0.1 keV to 200 MeV in the case of ^{237}Np(n,f) to narrow energy ranges for capture cross section evaluations. The results (central values) are generally consistent with results of the JENDL-4 evaluation done using a least squares fit based on a different approach. The covariance matrices of the evaluated data include cross-reaction blocks. Per-cent uncertainties of the evaluated reactions are close to the uncertainty of the evaluated standard cross sections, if a few tens of consistent experimental data sets are included in the fit, as in the case of fission cross sections.

Y. Han - *China Nuclear Data Center, China Institute of Atomic Energy, Beijing, China*
The Theoretical Calculation of Minor Actinide Nuclear Reaction Data

A set of new global phenomenological optical model potential parameters for the actinide region ($220 \leq A \leq 260$) with incident nucleon energies from 1 keV up to 300

MeV were obtained by using the experimental data for neutron total, nonelastic cross sections, elastic cross sections and angular distributions, proton total reaction cross sections and elastic scattering angular distributions.

All cross sections of neutron-induced reactions, angular distributions, double differential cross sections, angle-integrated spectra, prompt fission neutron spectra, γ-ray production cross sections and energy spectra were calculated using theoretical model codes UNF [1] and MEND [2] for n+^{234,236,238}U, ^{237}Np, ^{238,240,241,242}Pu, ^{241,242,242m,243}Am at incident neutron energies from 0.01 to 200 MeV. The reaction channels including (n,γ), (n,n′), (n,p), (n,α), (n,d), (n,t), (n,2n), (n,3n), (n,f), (n,nf) and (n,2nf) were studied. The present consistent theoretical calculated results are in good agreement with recent experimental data at an incident neutron energy of 200 MeV. The evaluated data of neutron-induced nuclear reaction from ENDF/B-VII.0, JENDL-3.3 were compared with the present calculated results and existing experimental data. The calculated results are given in ENDF/B format.

[1]. Jingshang Zhang, Nucl. Sci. Eng., **142** (2002) 207.
[2]. Chonghai Cai, Nucl. Sci. Eng., **153** (2006) 93.

V. Maslov - *Joint Institute for Energy and Nuclear Research, Minsk, Belarus*

Advanced Evaluation of ^{237}Np, ^{241}Am, ^{243}Am Neutron Data

The evaluation methodology, tuned in the case of n+^{237}Np, is applied to the n+^{241}Am and n+^{243}Am data evaluation. It is based on a statistical model description of the GMA-code generated generalized least squares fits of capture and fission cross sections. Evaluated neutron data files are available from the IAEA NDS web-site at http://www-nds.iaea.org/minskactinides. Consistent descriptions of the total, fission and partial inelastic scattering data of n+^{237}Np in the 1-3 MeV energy range provides an important constraint for the neutron absorption cross section. These make possible a robust estimate of the capture cross section in the 0.5~500 keV energy range. Important constraints for the measured capture cross section come also from the average radiation S_0 and S_1 strength functions. The evaluated inelastic cross sections of major data libraries are in severe disagreement with measured data for the inelastic scattering of neutrons with excitation of specific groups of levels. An abrupt change of the inelastic data shape at E_n ~1.5 MeV is explained by the sharp increase of the level density of the residual odd-even nuclide ^{237}Np due to the onset of three-quasi-particle excitations. The influence of exclusive (n,xnf) pre-fission neutrons on the prompt fission neutron spectra and (n,xn) reactions spectra is modelled. Contributions of emissive/non-emissive fission and exclusive spectra of (n,xnf) reactions are defined by a consistent description of the ^{237}Np(n,f), ^{237}Np(n,2n)^{236s}Np reactions and the ratio of the yields of the short-lived isomer (1^-) and the long-lived ground (6^-) ^{236}Np states measured at ~14 MeV. Excited levels of ^{236}Np are modelled using predicted Gallher-Moshkowski doublets. The reaction chain ^{237}Np(n,2n)^{236s}Np(β^-)^{236}Pu(α)^{232}U is one of the major sources of the accumulation of ^{232}U in irradiated reactor fuel. The long-lived state, emerging from the reaction ^{237}Np(n,2n)^{236l}Np has a large thermal fission cross section, which may strongly influence the core neutronics.

The theoretical methods, demonstrated in the case of n+^{237}Np, are used for ^{241}Am and ^{243}Am. One of the examples is the analysis of (n,2n) cross sections. For ^{241}Am(n,2n) the best fit of recent data measured at IRMM is obtained, provided a rather low contribution of the ^{241}Am(n,2nf) channel to the total ^{241}Am(n,f) reaction is used. The isomer ratio of the yields of the short-lived ground (1^-) ^{242g}Am and long-lived isomer (5^-) ^{242m}Am states in the ^{243}Am(n,2n) reaction is calculated, modelling the gamma-decay of the possible Gallaher-Moshkowski doublet states of ^{242}Am, the only difference from the ^{236}Np case is the reversed order of short- and long-lived states. Yields of the ^{242g}Am and ^{242m}Am states in ^{243}Am(n,2n) reaction are shown to be compatible with measured data by Gancarz (1982) of the yield of ^{242g}Am. Estimates of $^{243(g+m)}$Am(n,2n), ^{243g}Am(n,2n), ^{243}Am(n,f) and calculated isomeric ratio are consistent with each other.

The phenomenological approach, used previously for prompt fission neutron spectra of ^{235}U(n,f) and ^{238}U(n,f), correlates the influence of the exclusive (n,xnf) pre-fission neutrons with the observed PFNS Combined the effects of fission chances and exclusive pre-fission neutron spectra leads to the lowering of the average energy of the PFNS in the vicinity of the (n,xnf) reaction thresholds (see Fig. 2), which is compatible with the measured PFNS average energy of ^{237}Np(n,f). At 8 and 14.7 MeV the PFNS shapes of ^{237}Np(n,f) are reproduced, revealing explicitly the pre-fission neutrons influence on the observed PFNS.

T. Belgya - *Institute of Isotopes Hungarian Academy of Sciences, Budapest, Hungary*

Measurement of ^{241}Am Ground State Radiative Neutron Capture Cross Section with Cold Neutron Beam

The radiative neutron capture cross section of ^{241}Am leading to the ground state of ^{242}Am has been measured with a beam of cold neutrons at the Budapest Research Reactor using the X-ray emission of the ^{242}Pu decay product which accumulates in the ^{241}Am containing sample. This methodology avoids the uncertainty caused by resonance neutrons in the pile activations and provides a spectrum average value. The target was originally produced by Amersham for the purpose of being an alpha source. The ^{241}Am was sintered onto one side of a silver backing-strip and covered with a thin layer of gold. The target layer thicknesses were characterized with gamma- and X-ray spectrometry. The homogeneity of the Am layer was determined from auto- and Röntgen-radiography. During the stack activation which included a standard 25 mm gold monitor on the neutron exit side of the target, sizable neutron absorption of the silver backing was recognized and calculated with the MCNP5 Monte Carlo program using a measured, realistic neutron energy distribution. This lowered our value reported at the ND2010 conference by a factor of about 0.79. If the ^{241}Am cross section is supposed to be of 1/v type in the sub-thermal energy region then our preliminary cross section is calculated to be 540±44 b at 2200 m/s neutron velocity. This value is in the lower range of the most recent literature values, but agrees with them within their uncertainties. Some minor corrections are still to be taken in to the account due to our new radiography results. The uncertainty calculations took into account all of the statistical and systematic errors. The total uncertainty is dominated by the emission probability uncertainties of the X-rays emitted by the ^{242}Pu, which can only be lowered if they are measured with higher accuracy.

F. Käppeler – *KIT, Karlsruhe, Germany*

Neutron Capture Measurements on ^{141}Am in the keV Region

Recent measurements of the neutron capture cross section on ^{241}Am have been performed at LANL [1], IRMM [2], and by the n_TOF collaboration [3]. In addition there is a current attempt to measure the isomeric ratio in the keV region [4]. This presentation dealt with the experiments related to [3,4], whereas the information concerning [1,2] was provided in the presentations of R. Reifarth and F. Gunsing, respectively.

The n_TOF collaboration has performed two independent measurements [3] by means of a pair of C_6D_6 liquid scintillators as well as with a total absorption calorimeter consisting of a 4π array of BaF_2 detectors. The sample used in both experiments contained 32 mg of ^{241}Am in a 305 mg Al_2O_3 matrix encapsulated in an 0.5 mm thick Al canning. The measurements, which covered the energy range from 1 eV to 1 MeV, have been completed and the excellent quality of the data promises that accurate high-resolution cross section can be provided.

The isomeric ratio measurement consists of neutron irradiations at 25 and 500 keV, which were carried out at the Karlsruhe Van de Graaff, and subsequent radiochemical analysis at Los Alamos. The decay of ^{242}Am will be studied by sequential radiochemical separations by isolating the ^{242}Cm fractions from the decay of the short-lived ground state and the 141 yr isomer in ^{242}Am. Presently, work at LANL for demonstrating the required separation efficiency is nearing completion.

[1] M. Jandel et al., Phys. Rev. C **78** (2008) 034609.
[2] F. Gunsing, contribution to this CRP Meeting.
[3] C. Guerrero et al., n_TOF internal note (October 2010).
[4] D. Vieira et al., private communication (October 2010).

R. Vlastou - *National Technical University of Athens (NTUA), Athens, Greece*

Attempted ^{237}Np(n,2n) Cross Section Measurements at the Athens Tandem Accelerator NCSR Demokritos

An attempt to measure the (n,2n), (n,p) and (n,α) cross sections on ^{237}Np, implementing the activation technique at the Athens Tandem 5MV Accelerator at NCSR "Demokritos"**,** was reported. A Np sample of 155MBq activity was provided by IRMM in 2009. It was prepared in 1994 from 99.99% pure NpO_2, of 6.892g mixed with 40.152g S and canned in 0.5mm Al. Now the sample is contaminated by the daughter nucleus ^{233}Pa, which is in secular equilibrium with ^{237}Np, resulting in double the initial activity. The sample was irradiated by 9.5 MeV neutrons for 44 hours and the induced activity was measured with a HPGe detector of 80% efficiency. The most prominent γ-rays, 642, 208 and 946keV respectively, coming from the three reactions, were found in the spectrum to be contaminated by neighbouring transitions from the reaction products of the ^{233}Pa content in the target. Thus, no conclusive results could be extracted from the spectra, confirming that chemical separation of Pa from Np before the irradiation is essential in order to measure these cross sections by means of γ-spectroscopy.

In addition, the preliminary results from the analysis of n_TOF data on the ^{237}Np(n,f) reaction were presented. The measurements were performed in the n_TOF facility at CERN with the FIC ionization chamber, relative to the ^{235}U and ^{238}U fission cross sections. The targets were thin layers of 100% enriched isotopes deposited on 100μm thick Al backing using the painting technique. The total masses were 12.82±0.08 mg for ^{237}Np, 35.6±0.2 mg for ^{235}U and 51.7±0.2 mg for ^{238}U. The Flash Analog to Digital Converter (FADC) data were analyzed using pulse shape analysis techniques, implemented with the MINUIT code, to discriminate fission events from background signals. The rippling and undershooting effect, caused by the γ-flash, was corrected by subtracting an "average" FADC output for each detector channel. At some points however, the signal recognition becomes impossible, due to the strong fluctuations in the time evolution of the signal amplitude induced by the γ-flash. Thus, for the neutron energy range 10-100 MeV, it was not possible to extract reliable cross section values and the results in this preliminary analysis process were limited to the region 0.02-9 MeV. The deduced cross sections are in good agreement with ENDF and JENDL evaluations as well as with the n_TOF data measured with PPACs, up to 1MeV. Above 1 MeV, both FIC and PPAC results are higher by ~6% compared to the evaluations. Final results are expected to be available in a few months.

A. Wallner - *VERA, University of Vienna, Vienna, Austria*
Neutron Capture Studies of ^{235}U and ^{238}U via AMS

In this talk a method was introduced which combines neutron activation with subsequent accelerator mass spectrometry (AMS) measurement. Such an approach represents an independent technique, where interference from fission is completely excluded.

As a prime example neutron capture on the main U isotopes was studied within the European EFNUDAT project, neutron activations were performed with the goal to determine the capture cross section of ^{235}U via irradiations with thermal (cold) and keV-neutrons. The use of natural uranium samples, allowed Wallner to measure simultaneously the ^{238}U(n,γ) capture from the same samples. Activations were performed with cold neutrons (Budapest Research Reactor), thermal (Atominstitut, Vienna) and with neutrons of 25 and 500 keV (Karlsruhe Institute of Technology), the latter with an energy spread of 20 and 50 keV FWHM, respectively. The produced long-lived ^{236}U and the decay product of ^{239}U, ^{239}Pu, were subsequently counted by AMS at the Vienna Environmental Research Accelerator (VERA). AMS represents a technique with excellent sensitivity for the detection of long-lived radionuclides through ultra-low isotope ratio measurements without any molecular isobaric interference. The accuracy of AMS measurements of actinides is of the order of a few %. Existing data and evaluations show discrepancies in the keV energy range. First preliminary results show a good agreement with some of the evaluations.

This technique can also be extended to other isotopes in this mass range. Limitations of this approach for minor actinides are mainly due to depositing tens of µg to mg of material in the ion source, which will contaminate the source area with the bulk material; therefore for such applications a dedicated source would be needed. For the production of shorter-lived reaction products; the chemical separation of them from the bulk material would avoid such limitations (see e.g. ^{239}Pu in case of ^{238}U(n,γ)).

F. Gunsing - *CEA Saclay, Irfu, France*
Nuclear Data Activities of CEA Saclay - Irfu-SPhN relevant to MANREAD

F. Gunsing described the involvement of CEA Saclay, Irfu-SPhN in nuclear data activities relevant to MANREAD. They concern participation to experimental activities at several facilities, all in collaboration with other institutes, some also participation in the MANREAD project. References of published work are given and will be taken into account for the final assessment. Activities were reported concerning neutron time-of-flight measurements at the neutron time-of-flight facilities n_TOF at CERN and at GELINA of the JRC-IRMM in Geel, activation measurements at the research reactor ILL in Grenoble, and at the Van de Graaff of IRMM, as well as surrogate measurements at the Tandem accelerator at Orsay and more recently at the Oslo cyclotron.

The measurements of ^{241}Am capture and transmission experiments with a 324 mg sample in a Y_2O_3 matrix at IRMM are mentioned. Data have been taken and are currently under analysis. Smaller samples of about 32 mg in an Al_2O_3 matrix have been used for the (n,2n) measurements. A measurement of ^{236}U(n,γ) at GELINA has to be completed with a normalization measurement. At the n_TOF facility a ^{241}Am sample, used at IRMM for (n,2n) measurements [1], has been measured. Data taking for neutron capture with both a C_6D_6 total energy setup and with a 4π BaF_2 total absorption calorimeter setup has just finished. The collaboration on this topic with several other participants in the meeting was mentioned [2].

The measurement programme at ILL on capture and fission cross sections with thermal neutrons for a range of actinides was highlighted. The programme has been terminated, an overview of preliminary results has been reported [3] and final publications are coming out. Of particular interest for the MANREAD project is the final publication of ^{237}Np(n,γ) [4], and final data for ^{234}U(n,γ) [5], while data for ^{237}Np(n,γ), ^{238}Pu(n,γ), ^{241}Am(n,γ), ^{242m}Am(n,γ), ^{242g}Am(n,f), ^{242}Cm(n,γ), ^{244}Cm(n,γ) and ^{245}Cm(n,f) are underway.

Surrogate reactions are an important tool to study neutron-induced reactions when the target isotope is difficult to produce or to handle. From the work initiated at Orsay with measurements of ^{233}Pa(n,f) and (n,γ), the recent results on ^{241}Am(n,f), ^{242}Cm(n,f), ^{243}Cm(n,f) [6] by ^{3}He-induced reactions on ^{243}Am are highlighted. Mention was made of follow-up experiments at the Oslo cyclotron.

[1] C. Sage et al., Phys. Rev. C **81** (2010) 064604.

[2] See presentations, F. Käppeler, A. Plompen, N. Colonna in this meeting.

[3] O. Bringer et al., Proc. ND2007 (2008) 619.

[4] A. Letourneau et al., Appl. Rad. Is. **68** (2010) 432.

[5] O. Bringer et al., Nucl. Instr. Meth. A**591** (2008) 510.

[6] G. Kessedjian et al., Phys. Lett. **B692** (2010) 297.

H. Harada - *JAEA, Tokai-mura, Japan*

Np, Am and Cm Capture Measurements at J-PARC, KURRI and YAYOI

Recent activities on capture cross section measurements for Np, Am and Cm at J-PARC, KURRI and YAYOI have been reviewed.

The capture measurements for highly radioactive MA, such as, ^{244}Cm (18 years) and ^{241}Am have been started at J-PARC/MLF (Materials and Life Science Experimental Facility)/ANNRI (Accurate Neutron-Nucleus Reaction measurement Instrument). It was shown, based on the recent measurements, that not only high statistics, but also high S/N ratio and high resolution data are obtainable by using the ANNRI facility.

The thermal neutron capture cross section measurements by activation methods performed at KURRI (Kyoto University Research Reactor Institute) have been reviewed. Based on the experience of ^{237}Np experiments, importance and needs of accurate decay data were pointed out. The large discrepancy between experimental data was reduced by taking into account the recent decay data. The importance of correct treatment of cut-off energy and Westcott convention were discussed based on the analysis of ^{241}Am capture data, in which there are strong resonance effect below 0.5 eV.

The neutron capture cross section measurements for ^{237}Np by activation methods for fast neutrons performed at YAYOI (The University of Tokyo) have been discussed. In order to extract the pointwise cross section from activation data by fast reactor neutrons, the concept of representation energy and the corresponding cross section was proposed. Even though the method is not able to deduce the energy dependence of the cross section, the measurement gives a strong constraint on the cross section.

Although the discrepancies between the existing experimental data are reduced by recent experimental efforts, there still remain apparent discrepancies exceeding experimental errors. In order to solve the problem, double-check experiments were proposed.

N. Colonna - *Istituto Nazionale Fisica Nucleare, Sezione di Bari, Italy*

^{241}Am, ^{243}Am, ^{245}Cm and ^{235,238}U Fission Measurements at n_TOF

N. Colonna presented the fission cross sections for ^{241}Am, ^{243}Am and ^{245}Cm obtained at the n_TOF facility. He noted that the characteristics of the neutron beam are particularly convenient for measurements of fission cross sections on actinides: the very high neutron flux minimizes the background due to the natural radioactivity of the sample, the wide energy range allows the measurement to be extended up to 1 GeV and, finally, the very low duty cycle essentially eliminates the background related to the wrap around of neutron bunches. It was stressed that the large energy range covered by the n_TOF neutron beam, allows a determination of the cross sections in the whole energy range simultaneously, minimizing normalization problems.

The measurements were performed with a Fast Ionization Chamber, to minimize dead-time and pile-up effects. The cross sections for the minor actinides were determined relative to ^{235}U. All measured samples had exactly the same dimensions (8 cm diameter), and were mechanically aligned to within less than 1 mm. The uniformity of the samples was typically 5-10%, which however does not pose a problem thanks to the flat spatial profile of the neutron beam intercepting the sample.

For ^{241}Am, an unknown contamination of ^{239}Pu, at the level of 0.01% was observed, by some isolated resonances. This contribution was then subtracted from the measured yield. Since the sample activity was several tens of MBq, a large pile-up of α-particles was present in the data, and had to be reduced in the data analysis by applying a high threshold on the signal amplitude, and by subtracting the residual part. This results in large uncertainties in the efficiency corrections, making it necessary to renormalize the n_TOF results to previous data or an evaluation. It was decided to normalize the n_TOF data to those of Dabbs-83, at the third resonance (1.27 eV). The results in the RRR up to 100 eV clearly show that several problems are present in the evaluations, in particular for JEFF-3.1. Above this region, the n_TOF data confirm present evaluations, all the way up to several MeV. It should be emphasized, however, that only relative shape data will be available, although with an accuracy of 5% in the whole energy region.

For ^{243}Am, the background is small, so that the absolute value of the cross section can be determined. The presence of contaminations from ^{241}Am, ^{242m}Am and ^{239}Pu prevents the determination of the cross section at low energy, except for the largest resonances. Around and above the threshold, instead, cross sections have been extracted with a 3% accuracy. The new results confirm present evaluations.

For ^{245}Cm, the contamination of 6.6% of ^{244}Cm, which has a relatively short half-life, produces a large background due to α-particle pile-up. As in the case of ^{241}Am, it was necessary to apply a high amplitude threshold, which prevents high-accuracy absolute cross sections being obtained. It was decided to normalize the n_TOF results to the most recent thermal cross sections. The accuracy in the shape of the cross sections is estimated to be 5%, in all cases. Several discrepancies with evaluated data are observed in the RRR, while at higher energy a better agreement is observed.

All presented data are being finalized and will be made available in EXFOR immediately after the relavent publication is accepted.

B. Fursov - *IPPE, Obninsk, Russian Federation*

Fission Cross Section Measurements of ^{242m}Am, ^{243}Cm, ^{244}Cm, ^{245}Cm, ^{246}Cm, ^{247}Cm, ^{248}Cm

Using a lead slowing down spectrometer LSDS-100 (INR RAS) based on the proton linac at the "Moscow Meson Factory", new data on the fission cros -sections of ^{243}Cm, ^{244}Cm, ^{246}Cm, ^{247}Cm, ^{248}Cm were obtained within the neutron energy range from 0.03 eV to 20 keV. For the first time the operating energy range of the LSDS spectrometer has been extended down to epithermal neutrons due to a LSDS mathematical model (based on a Monte-Carlo method). It is necessary to note that the LSDS-100 spectrometer has given the possibility to obtain new data on the neutron induced fission cross sections and the fission resonance integrals for ^{247}Cm and ^{248}Cm. The obtained results for the fission areas, the neutron widths and for the fission widths have essentially enhanced the information field for these parameters. The results demonstrate also the level of our knowledge of the measured fission cross sections and show the need of revision of the cross section libraries for Cm isotopes.

A. Plompen - *EC-JRC-IRMM, Geel, Belgium*

Data needs and IRMM experimental program relevant to MANREAD

At IRMM measurements were made for the ^{241}Am(n,2n)^{240}Am, ^{241}Am(n,tot), ^{241}Am(n,γ)^{242}Am, ^{234}U(n,f), ^{236}U(n,f) and ^{245}Cm(n,f) reactions. The ^{241}Am(n,2n)^{240}Am cross section was determined by the activation technique at the JRC-Geel Van de Graaff laboratory with uncertainties in the range from 4 to 9%. All aspects of the experiment were documented in detail and a full correlation matrix was presented in the final publication [1]. Measurements for the total and capture cross sections were made at the GELINA time-of-flight facility. Data analysis of this work is ongoing. The status was presented at the nuclear data conference ND2010 in Jeju, April 2010 [2]. The fission cross section measurements were made by C. Wagemans from the U. Gent in collaboration with SCK-CEN, CEA/Cadarache and IRMM. Sub-threshold fission yields for ^{234}U and ^{236}U were determined with high purity samples. A remaining ^{235}U fission contribution was carefully subtracted by measuring the ^{235}U fission yield under identical conditions. This procedure also provides for an accurate method of normalization of the ^{234,236}U and ^{245}Cm results. The experimental results for ^{234,236}U are finalized and described in full detail in refs [3,4]. For ^{245}Cm the status is given in the proceedings of the FISSION2009 conference [5]. The analysis method is described in a manner that allows extraction of correlations of uncertainties. All three fission cross section measurements have important implications for the evaluation of these reaction channels in the resonance range.

[1] C. Sage et al., Phys. Rev. C**81** (2010) 064604.

[2] C. Lampoudis et al., Proceedings of the International Conference on Nuclear Data for Science and Technology, Jeju, April 2010.

[3] J. Heyse et al., Nucl. Sci. Eng. **156** (2007) 211.

[4] C. Wagemans et al., Nucl. Sci. Eng. **160** (2008) 200.

[5] O. Serot et al., Proceedings of the 4th International Workshop on Nuclear Fission and Fission- Product Spectroscopy: Cadarache, France, May 13- 16 2009.

N. Otsuka – *International Atomic Energy Agency, Vienna, Austria*
Recent Progress in Minor Actinide Data Compilation for EXFOR

The current status of the EXFOR database was reviewed for experimental data relevant to the MANREAD CRP. Various cross sections measured during the CRP have been collected and compiled by the Nuclear Reaction Data Centres (NRDC) in timely manner. NRDC is trying to keep values not shown in the articles but useful for future evaluation (e.g., cross sections relative to standard cross sections, partial uncertainties) in addition to values shown in the source articles. It was reported that this effort is supported by the Technical Meeting on Nuclear Cross Section Covariance (27-30 Sept. 2010, Vienna). In the context of the Technical Meeting, possible sources of correlation between measurements were also discussed. In order to keep information used in the reduction of experimental data for future evaluation, an appropriate template (EXFOR Template) for numerical data submission by authors to NRDC centres was proposed.

R. Reifarth – *GSI, Darmstadt, Germany*
Research on Minor Actinides at Los Alamos

Several measurements have been performed during the time of the CRP.

Several neutron-induced fission measurements have been completed and peer-reviewed articles are available. The experiments were performed from thermal energies to several hundred MeV. The energy regime between thermal and a few hundred keV was covered at the Lujan Scattering Center and the energies above at the Weapons Neutron Research center, both located at LANSCE at the Los Alamos National Laboratory. The investigated and completed isotopes are ^{237}Np [1] and $^{239\text{-}242}$Pu [2a,b]. The leading scientist on those experiments is Fredrik Tovesson. There are plans to investigate ^{234,236}U and ^{242m,243}Am in the near future (next few years).

Neutron capture experiments have been performed on several minor actinides at the Lujan Scattering Center in the energy regime between thermal and a few hundred keV. The analysis of ^{234,236}U(n,γ) is still in progress, but data on ^{234}U(n,γ) have already been included in the recent ENDF/B-VII evaluation. ^{237}Np(n,γ) is completed and published in a peer-reviewed article [3]. The analysis of ^{241,243}Am(n,γ) is finalized. The data on ^{241}Am are published in a peer-reviewed article [4], and the data on ^{243}Am published in proceedings of the last CGS conference [5]. The analysis of ^{242m}Am(n,γ) is still in progress and the status is reported in the same proceedings. The leading scientist on the Am measurements is Marian Jandel. Capture experiments on several Pu isotopes have been performed, but none of the results has been published yet. The analysis of ^{240,242}Pu(n,γ) is almost completed, data have been taken on ^{239}Pu(n,γ) and in 10/2010 data have been taken on ^{241}Pu(n,γ).

[1] F. Tovesson et al, Phys. Rev. C, **75** (2007) 034610.
[2a] F. Tovesson et al, Phys. Rev. C **79** (2009) 014613 (240,242).
[2b] F. Tovesson et al, Nucl. Sci. Eng. **165** (2010) 224.
[3] E.I. Esch et al, Phys. Rev. C **77** (2008) 034309.
[4] M. Jandel et al Phys. Rev. C **78** (2008) 034609.
[5] M. Jandel et al AIP Conference

Y. Nagai - *JAEA, Tokai, Japan*
Assessment of Am, Cm Capture Cross Sections, and Effective Neutron Energy

The current status of the assessment of neutron capture cross section measurements on Am and Cm, and the importance of a common definition of effective neutron energy associated with an observed reaction yield were discussed.

1) A typical example of our assessment

The current status of the measurement and analysisof the ^{241}Am(n,γ)^{242}Am reaction was discussed as a typical example. A special emphasis was put on the description of the quality of documentation, and it was clearly stated that a message of "well documented" is necessary.

2) Effective neutron energy

Effective neutron energy (and its error), E_{eff}, associated with an observed reaction yield must be clearly defined to compare measured cross sections of a reaction from two groups. E_{eff} could be defined as the energy associated with an observed reaction yield in the energy range from E_1 to E_2 so that the reaction yield in the energy range from E_1 to E_{eff} would be equal to half of the yield in the energy range (E_1 to E_2). The error of E_{eff} should be also described in the paper, which certainly contributes to the error of a measured value.

3) A draft on information on neutron facilities throughout the world was presented.

4) A neutron beam line at J-PARC is ready for an experiment related to nuclear data, and it was noted that the facility is open to international users.

3. LAYOUT OF THE FINAL REPORT

The structure of the final report was discussed and the coordination for the different parts assigned. This layout covers the objectives of the CRP. The deadline of the final report to be submitted to the IAEA for final production is December 2011. The document should be ready for fine-tuning by June 2011. An introduction and conclusion, as well as the overall coordination will be done by F. Käppeler, Y. Nagai, N. Otsuka and A. Plompen. A chapter "Minor Actinide Data" will be coordinated by N. Colonna and F. Gunsing. This chapter will contain the results of the assessment of existing data as well as a reporting on recent measurements. A chapter with the working title "Outlook" will report on the experimental options for the future and achievable accuracies, and will be coordinated by H. Harada and R. Reifarth. Finally a chapter on "Progress in evaluations" will be coordinated by Y. Han, O. Iwamoto, V. Maslov and V. Pronyaev. The detailed layout of the final report is attached as an appendix.

4. ASSESSMENT

The realization of the assessment of existing data was discussed in detail. It has been decided that the wiki will continue to be used to collect the material on the assessment for the final report, allowing the participants to streamline style and degree of detail, but will not be made publicly available, and will be used only as an internally accessible working tool. Harmonization of content can then be done afterwards if necessary. Figures, in colour where possible, should be used to illustrate clear points. The degree of detail for the treatment of each isotope and reaction will depend on the amount of available data. Where possible, the adequacy of a work and its documentation for evaluation should be addressed. The reactions (n,2n) and (n,inl) will be combined into (n,xn). F. Gunsing will provide a graphical overview of the energy ranges covered by the EXFOR entries for the reactions and isotopes in MANREAD. The experimental input that assessors feel to be crucial information to be included in EXFOR entries will be collected for possible use in a recommended template for EXFOR. The participants were asked to commit their share of this part of the work in final form by December 2010.

5. LIST OF ACTIONS

Several points came up during the discussions and are summarized here as a list of actions.

- The assessment wiki will be closed for editing from outside and be transferred to a not-listed link (action IAEA).
- A file share point will be set up so participants can easily share computer documents (action IAEA).
- A template and instructions for bibliographic references will be provided for use in the final report (action IAEA).
- The possibility to extract critical fields automatically from EXFOR entries in order to smooth the assessment work will be investigated (action IAEA).
- Graphical visualizations of the EXFOR entries versus energy range for each isotope/reaction will be provided (action F. Gunsing).
- The assessment wiki will be completed by December 2010 (action all).
- A draft of the final report will be completed by June 2011 (action all).
- Since no more RCM meetings are foreseen, further actions and feedback will be organized by the participants as needed (action all).

6. CLOSING

All participants were thanked for their cooperation and contributions. The participants thank the IAEA for the hospitality and organization of the meeting. The meeting was closed.

Appendix A

Third Research Coordination Meeting on

Minor Actinide Nuclear Reaction Data
(MANREAD)

International Atomic Energy Agency (IAEA)
Vienna, Austria
19 - 22 October 2010
Meeting Room F08 17

AGENDA

Tuesday, 19 October

08:30 - 09:30 **Registration (UN Pass Office at Gate 1)**

09:30 – 10:30 **Opening Session**
- Welcome address (S. Simakov)
- Introductory Remarks (N. Otsuka)
- Election of Chairman and Rapporteur
- Discussion and adoption of the Agenda (Chairman)

10:30 – 11:30 **Administrative Matters**

11:30 – 12:15 **Evaluation (1)**
- Yinlu. Han (30+15 min)
  The theoretical calculation of minor actinide nuclear reaction data

12:15 – 14:00 **Lunch Break**

14:00 – 14:45 **Evaluation (2)**
-
- V. Maslov (30+15 min)
  Advanced evaluation of ^{237}Np, ^{241}Am, ^{243}Am neutron data

14:45 – 15:30 **Measurement (1)**
- T. Belgya (30+15 min)
  Measurement of ^{241}Am ground state radiative neutron capture cross section with cold neutron beam

15:30 – 16:00 **Coffee Break**

16:00 – 17:30 **Measurement (2)**
- F. Käppeler (30+15 min)
  Neutron capture measurements on ^{241}Am in the keV region

- R. Vlastou (30+15 min)
  Attempted ^{237}Np(n,2n) cross section measurements at the Athens Tandem Accelerator NCSR Demokritos

Wednesday, 20 October

09:30- – 11:00 **Measurement (3)**

- A. Wallner (30+15 min)
  Neutron capture studies of ^{235}U and ^{238}U via AMS

- F. Gunsing (30+15 min)
  Nuclear data activities of CEA Saclay - Irfu-SPhN relevant to MANREAD

11:00 – 11:30 **Coffee Break**

11:30 – 12:15 **Measurement (4)**

- H. Harada (30+15 min)
  Np, Am and Cm capture measurements at J-PARC, KURRI and YAYOI

12:15 – 14:00 **Lunch Break**

14:00 – 15:30 **Measurement (5)**

- N. Colonna (30+15 min)
  ^{241}Am, ^{243}Am and ^{245}Cm and ^{235,238}U fission measurements at n_TOF

- B. Fursov (30+15 min)
  Fission Cross Section Measurement of ^{242m}Am, ^{243}Cm, ^{244}Cm, ^{245}Cm, ^{246}Cm, ^{247}Cm, ^{248}Cm

15:30 – 16:00 **Coffee Break**

16:00 – 16:45 **Uncertainty and target accuracy**

- A. Plompen (30+15 min)
  Data needs and IRMM experimental program relevant to MANREAD

16:45 – 17:15 **Experimental Database**

- N. Otsuka (20+10 min)
  Recent progress in minor actinide data compilation for EXFOR

19:00 **Dinner (Melker Stiftkeller, Schottengasse 3)**

Thursday, 21 October

09:30 – 10:15 **Measurements (6)**
- R. Reifarth (GSI, 30+15 min)
  Research on Minor Actinides at Los Alamos

10:15 – 10:45 **Assessment**
- Y. Nagai (30 min)
  Assessment of Am and Cm capture cross sections

10:45 – 12:15 **Discussion (Assessment)**

12:15 – 14:00 **Lunch Break**

14:00 – 17:30 **Layout of the Final Report**
(Coffee break as appropriate)

Friday, 22 October

09:30 – 12:30 **Drafting of the 3rd RCM Summary Report**
(Coffee break as appropriate)

12:30 – 14:00 **Lunch Break**

14:00 – 15:30 **Drafting of the Final Report**

15:30 **Close of the Meeting**

Appendix B

Third Research Coordination Meeting on

Minor Actinide Nuclear Reaction Data
(MANREAD)

International Atomic Energy Agency (IAEA)
Vienna, Austria
19 - 22 October 2010
Meeting Room F08 17

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Appendix C

LAYOUT OF THE FINAL REPORT AND CORRESPONDING TIME TABLE

Final report

People with overall responsibilities: Käppeler, Nagai, Otsuka, Plompen

Preface (Mengoni)

0. Executive summary
1. Introduction (Käppeler, Nagai, Otsuka, Plompen)
2. Minor actinide data (Colonna, Gunsing)
    a. Recent measurements
    b. Summary of the assessment
3. Outlook (Harada, Reifarth)
    a. Experimental options for the future
    b. Achievable accuracies
4. Progress in evaluations (Han, Iwamoto, Maslov, Pronyaev)
5. Conclusions and recommendations (Käppeler, Nagai, Otsuka, Plompen)
6. References
7. Appendices

Assessment

- First establish template for EXFOR
    - Aspects of measurement to be documented
        - Method of measurement
        - Data analysis method
        - Sample preparation and characterization
        - Normalization
        - Backgrounds
        - Uncertainties and correlations
        - Numerical data given (or digitized from paper)
- Qualify the experiments for future evaluations
    - Adequacy of documentation (papers, reports)
    - Adequacy of EXFOR entry for evaluation
- Wiki or appendix?

Introduction (Ch.1, 4-5 pages, Käppeler, Nagai, Otsuka, Plompen)

1. Intention, motivation, objectives of MANREAD
    a. SG-26, sensitivity studies (NUDATRA/EUROTRANS, Cabellos-Sanz). Relation with PFNS-CRP, standards, Th-U CRP
    b. Relevance for evaluation
    c. Relevance for new experiments
    d. Coordinated efforts, resources, competences, facilities, staff

e. Recommendations

2. Organization and actions of MANREAD
    a. Reference to member list (appendix)
    b. Scope of the CRP (MAs and reactions considered)
    c. RCMs
    d. Wiki
    e. experimental work
        i. new work
        ii. new plans
        iii. importance for assessment
    f. evaluation
        i. new work
        ii. relation of data to existing and new evaluations
3. Outline of the report

Minor Actinide Data (Ch.2, Colonna, Gunsing)

1. Results from new measurements (follow EXFOR template information)
    a. Content per contribution
        i. Description facility
        ii. Description experimental method (incl. samples and detectors)
        iii. Results and uncertainties
        iv. Indicative 1-4 pages per contribution
        v. Few figures
    b. Contributions
        i. B. Fursov, LSDS Am and Cm (n,f) data
        ii. N. Colonna, n_TOF results for fission (^{241,243}Am, ^{245}Cm) and capture (^{237}Np, ^{240}Pu, ^{234}U)
        iii. R. Reifarth, LANSCE actinide measurements
        iv. F. Käppeler, KIT/LANSCE ^{241}Am capture at 25 keV
        v. R. Vlastou, NTUA measurements for ^{237}Np(n,2n), (n,p), (n,α) and ^{241}Am(n,2n)
        vi. H. Harada, Y. Nagai, JPARC, YAYOI and KURRI capture cross section measurements fro Np, Am and Cm
        vii. T. Belgya, ^{241}Am capture measurement at BNC
        viii. F. Gunsing, A. Plompen, ^{236}U(n,γ), ^{241}Am(n,γ), (n,tot), (n,2n), ^{234,236}U(n,f) and ^{245}Cm(n,f) measurements at GELINA and IRMM VdG
        ix. A. Wallner AMS (this chapter or chapter 4)
2. Summary of the assessment
    a. A clean high quality write-up of the (intended) content of the wiki.
    b. Focus on important conclusions for evaluators and for further experimental work
    c. Figures only to illustrate important points
    d. Organized in the following order

        i. Isotope
        ii. Reaction
        iii. Energy range
    e. Be sure to cover all, but avoid headers with empty sections (as is the case in the wiki).
    f. For the content see the section “Assessment” above
    g. Wiki will be considered a working document not for general access
    h. This section will replace the wiki as deliverable for the CRP.

Outlook (Ch.3, Harada, Reifarth)

1. Methods
    a. Differential/TOF (Perhaps: High energy resolution)
    b. Activation and integral, high sensitivity, AMS, … (Quasi mono-energetic and spectral averages)
    c. Surrogate techniques
2. Current state of the art
    a. Demokritos, Bordeaux, Orsay, LANL, IRMM, Russia, Budapest, RPI, ORELA, Kyoto, JAEA, …
    b. Decide on how extensive this should be
3. Experimental options for the future
    a. FRANZ, SARAF, SPIRAL-2/NFS, nELBE, J-PARC, Livermore, upgrade n_TOF
4. Achievable accuracies
    a. General discussion on the basis of earlier results and the prospects for new techniques (facility-related, neutron flux, background conditions, timing, sample production and characterization, decay data)

Progress in Evaluations (Ch.4, 40 pages, Han, Iwamoto, Maslov, Pronyaev)

1. Methods of evaluation of cross sections and secondary neutron spectra, specific for MA
    a. ^{237}Np (^{241}Am, ^{243}Am, …)
    b. ^{239}Pu (^{243}Cm, ^{245}Cm, …)
    c. ^{238}U (^{238}Pu, ^{242}Cm, …)
2. Non-model least-squares (GMA) fits, where applicable
3. Adjustment of model parameters to the non-model fits
    a. Clear-cut cases
    b. Typical MA case
4. Major source of discrepancies in recent evaluations
    a. Model stiffness
    b. Model inadequacy
    c. Arbitrary model parameter adjustments
        i. ^{237}Np (^{241}Am, ^{243}Am, …)
        ii. ^{239}Pu (^{243}Cm, ^{245}Cm, …)
        iii. ^{238}U (^{238}Pu, ^{242}Cm, …)

5. Comparison of the modern evaluations obtained in this approach (JENDL-4.0, Minsk, CENDL, JEFF-3.1.1)
    a. ^{237}Np (^{241}Am, ^{243}Am, …)
    b. ^{239}Pu (^{243}Cm, ^{245}Cm, …)
    c. ^{238}U (^{238}Pu, ^{242}Cm, …)

Conclusions and recommendations (Ch.5, Käppeler, Nagai, Otsuka, Plompen)

1. Repeat the motivation
2. Summary
    a. Detailed investigation of the status
    b. Missing data
    c. Need and limitations of theory
    d. New experimental work
    e. Foreseeable measurement capabilities
3. Recommendations
    a. Evaluations
    b. New experiments
    c. New setups/equipment
    d. EXFOR compilations
        i. Preliminary results are to be avoided
        ii. Multiple entries about one work should be avoided
    e. Documented evaluations (peer review publications)

Appendices

1. List of members (Otsuka)
2. Summary table of the assessment (Otsuka/Zerkin)
3. Summary figures (Energy ranges covered by measurements, Gunsing)
4. Recommended templates for EXFOR compilations (Gunsing TOF, Pointwise data Plompen/Semkova/Reifarth/Harada)

Time table

1. Final report
    a. Deadline final version: 31 December 2011 (Before INDC meeting 2012)
    b. Intermediate drafts: 31 March, 30 June, 30 September 2011
        i. First content in each section 31 March
        ii. First draft (complete) 30 June
        iii. Comments by chapter contributors integrated 30 September
        iv. Final reading and corrections by everyone (31 December)
    c. Reminders sent 45 days before each deadline
2. Wiki
    a. Decide on harmonized content: this week
    b. Harmonization/finalization June 2011.
3. EXFOR templates (job SG-36 or input to SG-36, June 2011)

a. TOF
    i. Transmission
    ii. Capture
    iii. Fission
b. Point wise data
    i. By subfield?

4. Public access to contributions made at the RCMs
    a. Should we do this? No, but sharepoint would be good (limited access)
5. Publication?
    a. NSE, ANE, NDS: Otsuka/Plompen to contact Mike Herman (comprehensive summary of final report)
    b. Conference

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