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# INDC International Nuclear Data Committee

Summary Report of Consultants Meeting on

## Minor Actinide Nuclear Reaction Data (MANREAD)

International Atomic Energy Agency (IAEA)
Vienna, Austria

23 and 24 November 2006

Prepared by

Arjan Plompen
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and

Alberto Mengoni
IAEA Nuclear Data Section, Vienna, Austria

October 2007

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

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## Abstract

A Consultant Meeting on reaction cross section data for minor actinides was held at the IAEA Headquarter, in Vienna on 23 and 24 November, 2007. The main objective of the initiative was to define the detailed plan for the Co-ordinated Research Project on minor actinide neutron reaction data (MANREAD) CRP. The details of the discussions which took place at the reported meeting include a review of the current activities in the field, a list of recommendations and a proposed timescale for the CRP.

October 2007

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# 1. INTRODUCTION

Neutron-induced nuclear reaction data for minor actinides (MA) play a key role in studies of waste transmutation and Generation-IV systems. Various options for partitioning and transmutation are under investigation which aims towards substantial reductions of the requirements for repositories of high level radioactive waste. These options involve new reactors using fuels with minor actinide concentrations that are well above those of present day reactors and the sodium-cooled fast breeder reactor. As a result, engineering studies place increased emphasis on the completeness and accuracy of neutron-induced nuclear reaction data for minor actinides. These demands are not met by the currently available experimental database which shows important gaps as well as discrepancies among measured data.
New state-of-the-art measurements are required to improve the evaluated nuclear data libraries. In view of the difficulty of such measurements, it is important to coordinate efforts and stimulate collaborations and new initiatives. Thus, the present Consultants Meeting was organized to determine whether a Coordinated Research Project organized by the Nuclear Data Section could lead to an important step forward in terms of bringing together new measurements, assessing the origin of discrepancies, and providing guidance to future efforts.

Following adoption of the agenda, the goals of the meeting were introduced by the Head of the Nuclear Data Section (NDS), A. Nichols. The participants were requested to review the field of minor actinide measurements and the merit of Nuclear Data Section involvement and to recommend on the appropriateness and content of a near term Coordinated Research Project (CRP) and longer-term activities.

A. Mengoni (NDS) introduced the proposed CRP Minor Actinide Neutron Reaction Data (MANREAD). A short summary of the relevance of minor actinides in High Level nuclear Waste (HLW), the potential of transmuting such HLW in fast neutron spectra and the need of nuclear data to facilitate studies of waste management was presented. Some prominent examples of discrepant data sets for Minor Actinides were shown. Emphasis was placed on the need for an accurate and reliable neutron-induced reaction cross section database with adequate uncertainty and covariance information. A time table for the proposed CRP was presented, starting in the first half of 2007 and concluding with the final report in 2010 (Table Appendix A)

The agenda for the Consultants Meeting was adopted, and is given in Appendix B.

The participants of the meeting elected F. Käppeler, FZK, Karlsruhe, Germany as chairman of the meeting and A. Plompen, EC-JRC IRMM, Geel, Belgium, as secretary. The list of participants is given in Appendix C. E. Gonzalez Romero, CIEMAT, Madrid, Spain was not able to attend.

# 2. PRESENTATIONS

The participants provided an overview of planned, ongoing and recently completed experimental efforts in their countries in the form of their various presentations. Short summaries of these presentations are given below, and a summary of experiments relevant to MANREAD is given as a table in Appendix D.

**R. Reifarth,** Los Alamos National Laboratory (LANL), USA.

Experiments and plans were reported for LANL, TUNL and LLNL/LBNL. At LANL minor actinides measurements are carried out at two time-of-flight facilities that together cover the energy range from the meV range up to 200 MeV. The range is split in two parts. Up to about 0.5 MeV the moderated spectrum of the LANSCE facility is used and above this energy the un-moderated WNR facility is employed. At LANSCE, capture cross section measurements and fission tagged capture measurements are performed with the DANCE $BaF_2$ array with the possible addition of parallel plate avalanche counters. Fission cross sections are studied with ionisation chambers at LANSCE and WNR to effectively cover the full energy range mentioned above. Fission cross sections on very small sample material can be studied with the lead slowing down spectrometer that will be driven by 800 MeV protons from the Proton Storage Ring. A proof of principle was carried out by the study of the $^{239}$Pu(n,f) cross section.
At TUNL a 10 MV tandem accelerator has been used to study (n,2n) reactions on 241Am with neutrons from the $^{2}$H(d,n)$^{3}$He reaction. At LLNL surrogate reactions are employed to study the usefulness of charged-particle induced transfer reactions in determining key parameters of neutron-induced cross sections for reactions that are difficult to study with direct techniques. Experimental work takes place at LBNL. It was not checked if related activities take place at RPI and ORNL. An impressive amount of work, which is of relevance to MANREAD, is ongoing at LANL, and is most effectively summarized by means of the Table of Appendix D.

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

At IRMM most minor actinide related activities take place at the GELINA neutron time-of-flight facility. Here transmission measurements were recently carried out for $^{240,242}$Pu and for $^{237}$Np in the frame of the n_TOF project, while new work is planned for $^{241}$Am. Capture measurements with $C_6D_6$ detectors were carried out for $^{236}$U for the n_TOF project for analysis at CEA and are planned for $^{241}$Am. Fission measurements were carried out for $^{234,236}$U by University of Gent and final results will be shown early 2007. There are plans for measurements of the $^{245}$Cm(n,f) cross section. For n+$^{234}$U the existence of a fission isomer is being investigated at the Van de Graaff accelerator. At the same laboratory CENBG has measured the fission cross section of $^{243}$Am.

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

Technologies that demand new nuclear data for minor actinides are high burnup in all types of reactors, utilization of accumulated plutonium, recycling of nuclear fuel (closed fuel cycle) and transmutation of minor actinides. For a fast burner reactor a table with achieved and desired accuracies for fission, capture and inelastic scattering cross sections on minor actinides was presented. In most cases substantial improvements of the accuracies are required. A large number of slides were shown to demonstrate the status of fission cross sections studies on minor actinides, providing a more detailed overview of achievements and deficiencies than was presented earlier by A. Mengoni.
A program of planned measurements of minor actinide fission cross sections was presented. Facilities involved are the Lead Slowing Down Spectrometer (LSDS) at INR RAS (Troitsk) and the IPPE pulsed-tandem EGP-15. Samples will be prepared at IPPE by chemical techniques with material from Sarov. Target materials include $^{238}$Pu, $^{241,242m,243}$Am, $^{243-238}$Cm. Critical testing at VNIIF in Sarov was presented as a possible contribution.

**F. Gunsing**, CEA, Saclay, France

The Nuclear Physics Division of CEA/Saclay (DAPNIA) is involved in neutron-induced reaction cross section measurements at the n_TOF facility in CERN, the GELINA facility in GEEL, the tandem of ORSAY (surrogate neutrons), and ILL. Activities of interest to MANREAD are the determination of the cross section for the $^{234}$U(n,$\gamma$)$^{235}$U and

$^{237}$Np(n,γ)$^{238}$Np reactions at n_TOF, the involvement in transmission, capture and (n,2n) studies for $^{241}$Am studies at IRMM, the involvement in transfer reaction studies at Orsay with CENBG which are of relevance to n+$^{242}$Cm, n+$^{243}$Cm, n+$^{244}$Cm and n+$^{242}$Am. Finally, it has been mentioned that activities at the high-flux research reactor of the Institute Laue-Langevin (ILL) in Grenoble are presently going on and several results concerning fission cross sections, fission yields, and other relevant quantities were obtained in the recent years and they are of interest for MANREAD activities.

**Y. Nagai,** RCNP, Osaka, Japan

The Japanese current experimental activities using established facilities, planned activities on new facilities and the Asia ADS network were presented. Current experimental activities include efforts by JAEA, KUR at Kyoto University and the Tokyo Institute of Technology. New beam lines for capture and fission measurements are planned at Kyoto University and at the J-PARC 3 GeV spallation neutron source of JAEA. Experimental work was subdivided in four energy ranges, thermal, 1-100 eV, 10-80 keV and, at J-PARC, below 100 keV.
The Japanese efforts are predominantly aimed at capture measurements using spectroscopic techniques that, except for thermal energies, rely on gamma-ray detection. A variety of detector systems is employed for gamma-detection, such as an annular BGO detector, a single Compton-suppressed Ge detector or a compact array of High Purity Germanium (HPGe) detectors. Nuclides of interest to MANREAD include $^{237,238}$Np, $^{241,243}$Am, $^{244,246,248}$Cm. The importance of reliable methods, high purity samples and a proper understanding of systematic uncertainties were stressed.

**F. Käppeler**, FZK, Karlsruhe, Germany

At FZK, FZR, and PTB five experimental facilities exist where differential neutron-induced reactions may be studied. However, it was noted that INDC reports on Nuclear Data Research in Germany show no evidence of work of importance to MANREAD since 2000. In contrast, new work is being planned for the $^{241}$Am(n,γ)$^{242m,g}$Am isomer ratio at FZK in conjunction with CEA and IRMM, and FZK was deeply involved in the measurement program at the CERN based n_TOF facility (see below). The potential of the new high current 2.2 MeV RFQ at Frankfurt University has highlighted where radioactive samples can be studied. At FZR the ELBE, a new neutron time-of-flight facility with a fast spectrum and short base line and a high-power neutron generator are coming online. All facilities are part of the European Facilities for NUclear DAta for Transmutation (EFNUDAT) Integrated Infrastructure Initiative and measurements of minor actinides cross sections can be proposed to the common Program Advisory Committee of this initiative.

**N. Colonna**, INFN, Bari, Italy

INFN Bari has been involved in measurements of the neutron-induced fission cross section at the CERN bases N_TOF facility. The fission ionization chamber (FIC) was used and INFN participated in measurements of the $^{241,243}$Am cross sections. Measurements are made relative to the fission cross section of $^{235}$U and various steps of the measurement and analysis process were shown.

**A. Mengoni**, IAEA Nuclear Data Section, Vienna, Austria

Results of the data taking campaigns of the n_TOF project were shown. Measurement campaigns took place from 2001 to 2004 and concern capture and fission cross section measurements. Capture cross section measurements have been performed with both $C_6D_6$ detectors and with a $BaF_2$ calorimeter. All results on minor actinides were obtained with the latter. Nuclides of interest to MANREAD include $^{234}$U, $^{237}$Np, $^{240}$Pu and $^{243}$Am.

Fission cross sections have been studied with two setups. The first is a Parallel Plate Avalanche Counter (PPAC) and the second is the above-mentioned FIC. In both setups multiple samples can be studied simultaneously. Cross sections are measured relative to that of the well known $^{235}$U(n,f) cross section. Targets of interest to MANREAD are $^{234,236}$U, $^{237}$Np, $^{241,243}$Am and $^{245}$Cm. Data analysis is in various stages of completion (see Appendix D).
n_TOF phase-2 aims at a new measurement program at CERN starting in the summer of 2007. A new neutron-production target was designed and construction work should finish by the end of June 2007. Several measurements have already been proposed and were accepted by the CERN scientific committee INTC.

**A. Wallner,** VERA-IIK U. Wien, Vienna, Austria

The VERA facility at the University of Vienna is an Accelerator Mass Spectrometer (AMS) with which isotope ratios at the level of $10^{-12}$ to $10^{-14}$ may be measured. The application of this and a spectrometer in Munich to neutron-induced cross measurements was pioneered and the pros and cons of these studies were reported. An open point of this exciting new technique is the potential of its application to neutron-induced reaction cross sections in the actinide region. A pioneering study of the $^{235}$U(n,$\gamma$)$^{236}$U cross section will be made with irradiations performed at FZK. It will be of interest to see if the technique can be of use to studies on minor actinide targets. AMS is used in a variety of applications in other domains of research.

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

Subgroup 26 of the Working Party on Evaluation Co-operation of the OECD Nuclear Energy Agency is currently investigating nuclear data needs associated with Generation-IV reactors. The latter have a closed fuel cycle with integrated HLW recycling as an important objective and the study is therefore of relevance to MANREAD. The subgroup is led by M. Salvatores and follows the methodology of establishing target nuclear data uncertainties from established target uncertainties for key reactor and fuel cycle parameters. The methodology involves a systematic approach to sensitivity analysis. Preliminary results confirm that important minor actinide data need to be studied better to improve the accuracy of cross sections. The work also stresses the need for improved data for major actinides. It will be important to follow up on the work in this Subgroup for guidance and motivation of MANREAD.

## 3. DISCUSSIONS AND RECOMMENDATIONS

*Discussion*

The participants to the meeting acknowledged the large amount of recently completed, ongoing and planned activities on minor actinides measurements and agreed that co-ordination and focusing of the efforts through a coordinated research project starting in 2007 was appropriate. The general aim of the MANREAD CRP is to deliver a well-documented set of experimental data that form a reference database for evaluators of minor actinide data. The discussion was then focused on the actual recommendations.

*Recommendations*

Recommendations concern the actinides that should be the subject of the MANREAD CRP together with proposed objectives.

The suggested list of MAs to be considered by the CRP is as follows:

| | |
|---|---|
| Uranium | $^{234,236}$U |
| Neptunium | $^{237}$Np |
| Plutonium | $^{238,240,241,242}$Pu |
| Americium | $^{241,242m,243}$Am |
| Curium | $^{243,244,245,246,247,248}$Cm. |

These will henceforth be referred to as the MAs.

The following objectives were suggested.

1) Assessment of the available experimental data on the MAs for the total, capture, fission and (n,xn) cross sections.
2) A documented compilation of neutron cross section data and their uncertainties for measurements performed by CRP participants on the MAs with focus on information of relevance to evaluators.
3) Assessment of evaluated nuclear data for the MAs from the major libraries, including information on data uncertainties and covariances.
4) Assessment of achievable accuracies with contemporary measurement facilities and methodologies for the MAs.
5) Exploration of the potential of new experimental techniques and facilities for neutron cross section measurements, such as AMS and ICPMS, new neutron sources (J-PARC, Frankfurt RFQ, ELBE, and others) and of indirect methods (surrogate neutrons).

A list of participants was suggested which includes the present consultants together with a number of additional scientists who will be contacted by the CRP coordinator.

Consultants Meeting on

# Minor Actinide Nuclear Reaction Data (MANREAD)

International Atomic Energy Agency (IAEA)
Vienna, Austria
23 and 24 November 2006
Meeting Room ACV-03-C-252-0

## AGENDA

## Thursday, 23 November

**Welcome and Introduction -**
**IAEA activities and interest on Minor Actinide data**

**Experimental activities on MA Nuclear Data at Labs/Countries by each participant**
(45 minutes each including discussion, considering 30 minutes for presentation)

## Friday, 24 November

**Discussion on the objectives and program layout of the CRP on MA (MANREAD)**
**Drafting of the meeting report**
**Close**

Consultants Meeting on

# Minor Actinide Nuclear Reaction Data (MANREAD)

International Atomic Energy Agency (IAEA)
Vienna, Austria
23 and 24 November 2006

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## Proposed timetable for MANREAD activities

| Activity | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|
| Selection of participants | O | | | | |
| Organize 1st RCM to coordinate work programme | O | | | | |
| Organize 2nd RCM to review work plan, tune to meet CRP objectives | | | O | | |
| Organize 3rd RCM to review the results obtained, assess the CRP accomplishments, adopt action plan to produce final report | | | | O | |
| Prepare Final Report | | | | O | O |
| Inclusion of results into IAEA Nuclear Data Services | | | | | O |

# Summary of experiments relevant to MANREAD

| Target | Element | Institute | Facility | Quantity | Energy range | Method | Status |
|---|---|---|---|---|---|---|---|
| 240Am | Am | LANL | LANSCE | n,f | 1 eV - 100 keV | LSDS, IC | planned |
| 241Am | Am | IRMM | GELINA | n,tot | 0-20 eV | Transmission | planned |
| 241Am | Am | IRMM | GELINA | n,g | | C6D6 | planned |
| 241Am | Am | IRMM | GELINA | (n,2n) | Thr. 20MeV | Activation | planned |
| 241Am | Am | IRMM/FZK/CEA | VdG/chem | (n,g) m/g | 30-500 keV | Activation | planned |
| 241Am | Am | CENBG | Orsay | n,f | <10 MeV | Surrogate 243Am(3He,4He) | ongoing |
| 241Am | Am | IPPE | VdG | n,f | 5-20 MeV | Ionisation ch. | planned |
| 241Am | Am | IPPE/INR | LSDS | n,f | 1eV-30 keV | Ionisation ch. | planned |
| 241Am | Am | JAEA | Kyoto, KUR | n,g | Th | Activation | To analyse |
| 241Am | Am | JAEA | Kyoto, linac | n,g | 1-100 eV | Ge | planned |
| 241Am | Am | CERN | N_TOF | n,g | <100 keV | BaF2 | planned |
| 241Am | Am | CERN | N_TOF | n,f | <250 MeV | Ppac/fic | To analyse |
| 241Am | Am | LANL | LANSCE | n,g | <200 keV | DANCE/PPAC | planned |
| 241Am | Am | TUNL | VdG | n,2n | Thr.-10 MeV | Activation | done |
| 242mAm | Am | IPPE | VdG | n,f | 5-20 MeV | Ionisation ch. | planned |
| 242mAm | Am | IPPE/INR | LSDS | n,f | 1eV-30 keV | Ionisation ch. | planned |
| 242mAm | Am | LANL | LANSCE | n,g | <200 keV | DANCE/PPAC | planned |
| 243Am | Am | CENBG | VdG | n,f | Thr.-8MeV | Ionisation ch. | Done, more points |
| 243Am | Am | IPPE | VdG | n,f | 5-20 MeV | Ionisation ch. | planned |
| 243Am | Am | IPPE/INR | LSDS | n,f | 1eV-30 keV | Ionisation ch. | planned |
| 243Am | Am | JAEA | Kyoto, KUR | n,g | Th | Activation | Done |
| 243Am | Am | JAEA | Kyoto, linac | n,g | 1-100 eV | Ge | planned |
| 243Am | Am | CERN | N_TOF | n,g | <100 keV | BaF2 | To analyse |
| 243Am | Am | CERN | N_TOF | n,f | <250 MeV | Ppac/fic | To analyse |
| 243Am | Am | LANL | LANSCE | n,g | <200 keV | DANCE/PPAC | planned |
| 242Cm | Cm | CENBG | Orsay | n,f | <10 MeV | Surrogate 243Am(3He,t) | ongoing |
| 243Cm | Cm | CENBG | Orsay | n,f | <10 MeV | Surrogate 243Am(3He,d) | ongoing |
| 243Cm | Cm | IPPE | VdG | n,f | 5-20 MeV | Ionisation ch. | planned |
| 243Cm | Cm | IPPE/INR | LSDS | n,f | 1eV-30 keV | Ionisation ch. | planned |

| Target | Element | Institute | Facility | Quantity | Energy range | Method | Status |
|---|---|---|---|---|---|---|---|
| 244Cm | Cm | CENBG | Orsay | n,f | <10 MeV | Surrogate 243Am(3He,p) | ongoing |
| 244Cm | Cm | IPPE | VdG | n,f | 5-20 MeV | Ionisation ch. | planned |
| 244Cm | Cm | IPPE/INR | LSDS | n,f | 1eV-30 keV | Ionisation ch. | planned |
| 244Cm | Cm | JAEA | J-PARC | n,g | <100 keV | Ge | Planned |
| 245Cm | Cm | IRMM | GELINA | n,f | < 10 keV | Ionisation ch. | planned |
| 245Cm | Cm | IPPE | VdG | n,f | 5-20 MeV | Ionisation ch. | planned |
| 245Cm | Cm | IPPE/INR | LSDS | n,f | 1eV-30 keV | Ionisation ch. | planned |
| 245Cm | Cm | CERN | N_TOF | n,f | <250 MeV | Ppac/fic | To analyse |
| 246Cm | Cm | IPPE | VdG | n,f | 5-20 MeV | Ionisation ch. | planned |
| 246Cm | Cm | IPPE/INR | LSDS | n,f | 1eV-30 keV | Ionisation ch. | planned |
| 246Cm | Cm | JAEA | J-PARC | n,g | <100 keV | Ge | Planned |
| 247Cm | Cm | IPPE | VdG | n,f | 5-20 MeV | Ionisation ch. | planned |
| 247Cm | Cm | IPPE/INR | LSDS | n,f | 1eV-30 keV | Ionisation ch. | planned |
| 248Cm | Cm | IPPE | VdG | n,f | 5-20 MeV | Ionisation ch. | planned |
| 248Cm | Cm | IPPE/INR | LSDS | n,f | 1eV-30 keV | Ionisation ch. | planned |
| 248Cm | Cm | JAEA | J-PARC | n,g | <100 keV | Ge | Planned |
| 237Np | Np | IRMM/CEA | GELINA | N,tot | <500 keV | Transmission | Done/to eval. |
| 237Np | Np | IRMM/CEA | GELINA | n,g | <500 keV | C6D6 | Done/to eval. |
| 237Np | Np | JAEA | Kyoto, KUR | n,g | Th. | activation | done |
| 237Np | Np | JAEA | Kyoto, linac | n,g | 1-100 eV | BGO | done |
| 237Np | Np | JAEA | Kyoto, linac | n,g | 1-100 eV | Ge | planned |
| 237Np | Np | TIT | Pelletron | n,g | 10-80 keV | NaI | Done, to analyse |
| 237Np | Np | CERN | N_TOF | n,g | <100 keV | BaF2 | To analyse |
| 237Np | Np | CERN | N_TOF | n,f | <250 MeV | Ppac/fic | To analyse |
| 237Np | Np | LANL | LANSCE | n,g | <200 keV | DANCE | done |
| 237Np | Np | LANL | LANSCE+ WNR | n,f | Th.-100 MeV | Ionisation ch. | done |
| 238Np | Np | JAEA | Kyoto, KUR | n,g | Th | Double neutron capture activation | done |
| 238Pu | Pu | IPPE | VdG | n,f | 5-20 MeV | Ionisation ch. | planned |
| 238Pu | Pu | IPPE/INR | LSDS | n,f | 1eV-30 keV | Ionisation ch. | planned |
| 238Pu | Pu | LANL | LANSCE | n,g | <200 keV | DANCE/PPAC | planned |
| 240Pu | Pu | IRMM | GELINA | Tot | < 20 eV | Transmission | Done/redo? |
| 240Pu | Pu | CERN | N_TOF | n,g | <100 keV | BaF2 | To analyse |
| 240Pu | Pu | LANL | LANSCE | n,g | <200 keV | DANCE | done |

| Target | Element | Institute | Facility | Quantity | Energy range | Method | Status |
|---|---|---|---|---|---|---|---|
| 240Pu | Pu | LANL | LANSCE+ WNR | n,f | Th.-100 MeV | Ionisation ch. | done |
| 241Pu | Pu | LANL | LANSCE | n,g | <200 keV | DANCE/PPAC | planned |
| 241Pu | Pu | LANL | LANSCE+ WNR | n,f | Th.-100 MeV | Ionisation ch. | Planned |
| 242Pu | Pu | IRMM | GELINA | n,tot | < 20 eV | Transmission | Done/redo? |
| 242Pu | Pu | CERN | N_TOF | n,g | <100 keV | BaF2 | planned |
| 242Pu | Pu | LANL | LANSCE | n,g | <200 keV | DANCE | done |
| 242Pu | Pu | LANL | LANSCE+ WNR | n,f | Th.-100 MeV | Ionisation ch. | done |
| 234U | U | IRMM | VdG | f-isomer | < 3MeV | Ionisation ch. | To analyse/follow up |
| 234U | U | CERN | N_TOF | n,g | <100 keV | BaF2 | To analyse |
| 234U | U | CERN | N_TOF | n,f | <250 MeV | Ppac/fic | To analyse |
| 234U | U | LANL | LANSCE | n,g | <200 keV | DANCE | done |
| 236U | U | IRMM | GELINA | (n,f) | 0-… keV | Ionisation ch. | ongoing |
| 236U | U | IRMM | GELINA | (n,g) | <500 keV | C6D6 | To analyse |
| 236U | U | CERN | N_TOF | n,f | <250 MeV | Ppac/fic | To analyse |
| 236U | U | LANL | LANSCE | n,g | <200 keV | DANCE | done |
| 237U | U | LLNL | LBNL cyclotron | n,f | 0.2-20 MeV | surrogate | done |
| 237U | U | LLNL | LBNL cyclotron | n,2n | 0.2-20 MeV | surrogate | done |
| 237U | U | LLNL | LBNL cyclotron | n,g | 0.2-20 MeV | surrogate | done |

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