

**Neutron Data Measurements:
Experimental Activities in Europe.**

Report to WPEC

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1. The ADOPT network

(based on a Report by M. Hugon, V. P. Bhatnagar and J. Martin Bermejo (DG Research) to the GLOBAL 2001 Conference, Paris, September 2001)

In the current Fifth Framework Programme (1998-2002) the European Atomic Energy Community (EURATOM) has two specific programmes on nuclear energy, one for indirect research and training actions managed by the Research Directorate General, and the other for direct actions performed by the Joint Research Centre of the European Commission. The indirect program includes several key actions, one of which is on nuclear fission. The research is co-sponsored and managed by DG Research of the EC, but carried out by external public and private organisations as multi-partner projects. Partitioning and Transmutation (P&T) of nuclear waste is one of the large research activities sponsored by this program. A thematic network on ADvanced Options for Partitioning and Transmutation (ADOPT) co-ordinates the R&D activities on P&T. The partners of ADOPT are European research organisations and industries. The Network is organised in five clusters, each of which consisting of several smaller collaborations:

PARTITION:

PYROREP: assessment of flow sheets for pyrometallurgical processing of spent fuels and targets. Two methods are investigated for separating actinides from lanthanides: salt/metal extraction and electrorefining.

PARTNEW: development of solvent extraction processes of minor actinides (MA) in two steps. First co-extraction together with the lanthanides (DIAMEX processes), then separated from the lanthanides (SANEX processes).

CALIXPART: synthesis of more innovative extractants. Functionalized organic compounds, such as calixarenes, are synthesised with the aim of achieving the direct extraction of minor actinides.

FUETRA:

CONFIRM: computer simulations of fuel irradiation up to about 20% burn-up, to optimise pin and pellet designs.

THORIUM: investigation of the irradiation behaviour of Th/Pu fuel at high burn-up. Full core calculations for Th-based fuel with a view to supplying key data related to plutonium and minor actinide burning.

FUTURE: feasibility studies of irradiation of innovative actinide-based oxide fuels for transmutation. These fuels contain compounds of the type (Pu, Am)O₂, (Th, Pu, Am)O₂ and (Pu, Am, Zr)O₂ homogeneously. These compounds are synthesised and characterised, the fabrication processes are tested.

TESTRA:

- SPIRE:** study of irradiation effects on an ADS spallation target. The effects of spallation products on the mechanical properties and microstructure of selected structural steels (e.g. martensitic steels) are investigated by ion beam irradiation and neutron irradiation in reactors (HFR in Petten, BR2 in Mol and BOR 60 in Dimitrovgrad). Data from mixed proton/neutron irradiation are obtained from the analysis of the SING spallation target at the PSI in Villigen.
- TECLA:** assessment of the use of Pb alloys both as a spallation target and as a coolant for an ADS. Three main topics are addressed: corrosion of structural materials, protection of structural materials, and physico-chemistry and technology of liquid Pb alloys.
- MEGAPIE:** development and validation expertise for the design and operation of a heavy liquid metal (Pb-Bi) spallation target producing a high neutron flux. It is planned to be coupled to the ~1W proton beam of the cyclotron accelerator of PSI in Villigen in 2004.

BASTRA:

- MUSE:** development of validated analytical tools for sub-critical neutronics including recommended methods, data and a reference calculation tool for ADS study. The experiments will be carried out by coupling a pulsed neutron generator to the MASURCA facility loaded with different fast neutron multiplying sub-critical configurations.
- HINDAS:** cross-section measurements at different European facilities, nuclear model simulations and data evaluations in the 20-200 MeV energy region and beyond on Fe, Pb and U
- n-TOF-ND-ADS:** measurement, evaluation and dissemination of neutron cross sections for most of the radioisotopes (actinides and long-lived fission products) considered for transmutation in the energy range from 1 eV up to 250 MeV. Measurements are carried out at the TOF facility at CERN, at the GELINA facility in Geel, and using other neutron sources located at different EU laboratories.

PDS-XADS:

Preliminary Design Studies of an European experimental ADS, to select the most promising technical concepts addressing the critical points of the whole system and consolidating the road mapping for its development.

Neutron data measurements are mainly carried out inside the BASTRA cluster in the HINDAS and in the n-TOF-ND-ADS projects .

The **HINDAS** project (High- and Intermediate-energy Nuclear Data for Accelerator-Driven Systems) is a collaboration of 16 European laboratories and 6 large facilities providing neutron and proton beams in the 20-1000 MeV energy range. The experiments focused mainly on Fe, Pb and U, but measurements have also been carried out on, e.g., ^{12}C , ^{27}Al , ^{59}Co , ^{209}Bi . Cross-sections have been measured for both, neutron and proton induced reactions, and with relativistic heavy ion beams in inverse kinematics. The measurements involved double differential cross-sections for light charged particle production (p, d, t, ^3He and α), residual nuclide production, neutron elastic scattering angular distributions, and thick-target neutron spectra. Two workpackages of the HINDAS contract concentrate on the development of model codes, e.g. TALYS in the energy range below 200 MeV (NRG Petten) and INCL at energies above 100 MeV (Univ. Liège).

The **n-TOF** collaboration is a consortium of 27 Institutes and National Agencies and the two international organisations CERN and EC-JRC. Of these collaboration members, 18 institutes participate in the above mentioned n-TOF-ND-ADS indirect action of the Commission, financing part of the installation and experimental equipment. The facility consists of a Pb spallation target installed at the 20 GeV proton synchrotron PS and one flight path of 187 m length. Protons are delivered in 1-4 bunches of 6 ns every PS super-cycle of 16 seconds, with a typical intensity of $7 \cdot 10^{12}$ protons per pulse, resulting in a neutron flux of approx. 10^5 n/cm²/pulse at the experimental area. The useful neutron energy range extends from 1 eV up to 250 MeV. The facility became operational in April 2001 but an unexpectedly high background delayed the experimental program. The main source of the background could be identified as being due to high-energy muons from the spallation target creating neutrons in the vicinity of the experimental area. The shielding of the spallation target was increased and the background could be reduced considerably. The experimental program resumed in May 2002.

2. Activities at IRMM Geel

➤ Capture and total cross sections.

- ^{232}Th (collab. with FZK and INRNE): measurements in the resonance region and in the average region 5-150 keV
- ^{103}Rh : new task in collaboration with CEA Saclay. Subsequent samples may be ^{143}Nd , $^{149,152}\text{Sm}$, ^{153}Eu , etc. (need improvement of measurement station).
- $^{206}\text{Pb}(n,\gamma)$: the experimental setup was upgraded installing two new C_6D_6 detectors. Experiments just started.

➤ $^{129}\text{I}(n,\gamma)$ and σ_{tot}

- Collaboration with CEA Saclay. All capture and transmission measurements on ^{127}I and ^{129}I have been completed. Problem in the sample characterisation due to delays in the analysis (MS at IRMM and PSI, NAA at SCK).

➤ **Doppler broadening of neutron resonances**

- $^{237}\text{NpO}_2$: 20K and 300K measurements completed, analysis ongoing.
- Hf: transmission measurements at 20K, 77K and 300K completed, analysis started.
- New samples of $^{240,242}\text{PuO}_2$ in a graphite matrix have been prepared. Transmission experiments on ^{240}Pu started.
- Higher temperatures: the graphite furnace from ILL is not yet operational.
- Analysis codes: SAMMY has been modified by ORNL (N. Larson) to include the DOPUSH routine. A new version of REFIT has also been developed and is being tested (M.C. Moxon)

➤ **Charged-particle cross sections**

- Measurements at GELINA (collab. with RUG): $^{17}\text{O}(n,\alpha)^{14}\text{C}$ measurements in the resonance region completed. $^{26}\text{Al}(n,\alpha)^{23}\text{Na}$ and $^{36}\text{Cl}(n,p)^{36}\text{S}$ measurements continuing on schedule.
- Measurements at the Van de Graaff (collab. with IPPE): a new time projection chamber and waveform digitizer were used successfully for $^{10}\text{B}(n,\alpha)$ measurements at 1.5-2.8 MeV (see below). Modifications of the DAQ electronics for use of the system at GELINA is under investigation.

➤ **Activation cross sections.**

Collab. with ANL, FZJ, INRNE, Univ. Vienna.

- ^{51}V : cross-sections were obtained for the $^{51}\text{V}(n,p)$, $^{51}\text{V}(n,\alpha)$ and $^{\text{nat}}\text{V}(n,x)^{47}\text{Sc}$ reactions.
- $^{204}\text{Pb}(n,p)^{204}\text{Tl}$: completed.
- Co, Ni : New irradiations started for the $^{60,61,62}\text{Ni}$ isotopes. Seven data points were completed for the $^{60}\text{Ni}(n,p)^{60\text{m}}\text{Co}$ reaction. The data analysis for the $^{61}\text{Ni}(n,xp)$ and the $^{62}\text{Ni}(n,p)^{62\text{m,m}^+\text{g}}\text{Co}$ reactions is ongoing.
- $^{\text{nat}}\text{Mo}(n,x)^{94}\text{Nb}$ ($T_{1/2} = 2 \cdot 10^4$ a): data taking in the HADES underground laboratory completed.
- $^{14}\text{N}(n,p)^{14}\text{C}$: new task in collab. with FZJ, and with the Univ. of Vienna for the AMS analysis.

➤ **High resolution inelastic scattering**

Collab. with Univ. of Debrecen

- ^{58}Ni : Data taking of inelastic events at the new 200 m station was completed. Improvements of the experimental setup and development of the analysis procedure are continuing. An alternative data acquisition technique based on fast digitizers is being tested together with IReS Strasbourg (n-TOF collaboration).
- ^{52}Cr : experiments at the 100 m station are scheduled to start in May.

➤ **$^{233}\text{Pa}(n,f)$**

- Collab. with Univ. of Örebro and Uppsala (Studsvik Lab.). The results of the first experiments have been published: PRL 88, 062502 (2002). A new beamline was installed at the 0m-level in the VdG target hall. A second Pa sample arrived and 5 energy points between 5.0 and 8.5 MeV (around the second-chance fission threshold) could be measured successfully.

➤ $^{234,236}\text{U}(n,f)$

Collab. with RUG, ILL

- Cross-section measurements of ^{234}U at GELINA: a new sample is being prepared, experiments will start in May (100 Hz campaign)
- Fission fragment distributions of ^{234}U at ILL: there persists a problem in the analysis of the fission yield measurements. The obtained mass distribution is still slightly distorted due to asymmetries for both chamber sides.
- Cross-section measurements of ^{236}U at GELINA: a new sample has been prepared, experiments in the resonance region are under preparation.

➤ $^{239}\text{Pu}(n,f)$ and $^{242}\text{Pu}(SF)$

- $^{239}\text{Pu}(n,f)$ in the resonance region: No significant spin dependence observed, in contrast to ^{235}U . A two-dimensional analysis in terms of the multi-modal random-neck rupture model at resonances neutron energies has been finalized. Non-negligible correlations found for mass and TKE and anticorrelation with prompt neutron emission.
- $^{242}\text{Pu}(SF)$, collab. with RUG: the ternary fission measurements have been completed, the data analysis started.

➤ $^{10}\text{B}(n,\alpha)$ branching ratio α_0/α_1

- Measurements at the Van de Graaff: the new time projection chamber and wave-form digitizer were used successfully for $^{10}\text{B}(n,\alpha)$ measurements. Cross-sections and α_0/α_1 ratios have been obtained between 1.5 and 2.8 MeV. The data show a satisfactory agreement with the JENDL-3.2 and strong deviations from the ENDF/B-VI evaluation, respectively. Preliminary results have been obtained for the $^{58}\text{Ni}(n,\alpha)^{55}\text{Fe}$ reaction at $E_n=5.2$ MeV. The α_0 , α_1 , α_2 and α_3 - α_4 particle groups of the reaction have been clearly resolved and identified. The overall angular distribution is in good agreement with results published by other groups.
- Measurements at GELINA: Continuation of the experiment at 60m. Still problems with background.

➤ **Fluence intercomparison BIPM/CCRI**

- IRMM participated in a BIPM Key comparison of neutron fluence measurements organized by the PTB within the frame of BIPM/CCRI key comparison exercises. Measurements at 1.2, 5.0 and 14.8 MeV were carried out at PTB with the IRMM Proton Recoil Telescope. A complete report has been submitted to PTB. This key comparison exercise is registered in the BIPM database at http://kcdb.bipm.fr/BIPM-KCDB//AppendixB/specific_comparison3_4.asp

3. Co-ordination of European activities

In the JEFF project a new subgroup on Experimental Activities has been created. The aim of the subgroup is to enhance the links between evaluators and experimentalists. Continuous information exchange between laboratories measuring microscopic data, laboratories performing integral measurements, and evaluators shall help to better establish priorities. In view of decreasing resources questions of feasibility can better be addressed: provision of adequate samples, planning of measurements at the most adequate facility, accuracy limits that can be achieved, manpower problems.

There have been two meetings of the subgroup, at the general JEFF meetings in December 2001 in Paris and April 2002 in Aix-en-Provence. In-depth discussions on priority requests for new experiments according to the list established by the WPEC Subgroup C have been hampered by the fact that the list was not available to all participants. It is therefore proposed to make the HPRL accessible to the general public, e.g. as a pdf document on the website of the NEA databank.

Similar discussion groups in the other data centres participating to the WPEC could serve as filters for the requests to subgroup C allowing to assess beforehand the feasibility of realising the measurements with the required accuracy.

