Workshop on

Nuclear Data for Science & Technology: Accelerator Driven Waste Incineration

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Nuclear Data for Science and Technology: Accelerator Driven Waste Transmutation

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NUCLEAR DATA FOR SCIENCE AND TECHNOLOGY:
ACCELERATOR DRIVEN WASTE TRANS_MUTATION

Outlines of a Workshop

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ICTP Trieste, September 2001
The design of Accelerator Driven Systems (ADS) requires knowledge of Nuclear Data for
- simulation of the spallation process
- radiation heating and damage
- criticality and transmutation rates

The data are needed also for energies above 20 MeV (typical limit for standard nuclear-reactor oriented data libraries)
Experimental Data

Nuclear Data measurements have been classified into two categories

• Low Energy
  *Laurent Tassan-Got*: n_TOF, the new neutron time-of-flight facility operating at CERN.

• High Energy
  *Jan Blomgren*: ongoing experimental activities in high energy cross section measurements.
Neutrons in thermal and fast reactors

- 235U thermal fission
- YAYOI Fast Reactor

Neutron energy [eV] vs. n-yield
Neutrons from Fusion reactions
... and High energies

Neutron and proton emission spectra for 1.5 GeV protons on a heavy nucleus
Nuclear theories and models will be involved in several presentations

- **Overview of nuclear reaction theory**
  *Bret Carlson*

- **Statistical Model of nuclear reactions**
  *Mike Herman*: - implementation of nuclear reaction models at low energies
  - Introduction of a data-base of model parameters for nuclear model calculations (RIPL).
  - Basics of nuclear data evaluations.

- **Nuclear Reactions at high energies**
  *Sylvie Leray*: nuclear reaction mechanisms at high excitation energies.
Particle interaction processes: low energy

Incident particle → TARGET

TARGET → COMPOUND NUCLEUS

COMPOUND NUCLEUS → Fission neutrons, Fission, Emission → light particles & photons

Fission neutrons → Fission Products, Residual nucleus
Particle interaction processes: high energy

Intranuclear cascade

Highly excited nucleus (pre_equilibrium)

Nucleons & other hadrons

Fission neutrons

Fission

Emission

Light particles & photons

Fission Products

COMPOUND NUCLEUS

Fission neutrons

Fission

Emission

light particles & photons

Fission Products

Residual nucleus
Example: $^{233}\text{U}(n,\gamma)$

The diagram shows the cross section (in barns) as a function of incident energy (in MeV) for the reaction $^{233}\text{U}(n,\gamma)$. The graph compares different data sets and models, including ENDF/B-VI, JEF-2, JENDL-3, and experimental data from 1971 Cabell, 1970 Weston, 1968 Weston, 1966 Brooks, and 1962 Hopkins.

The x-axis represents the incident energy in MeV, ranging from $10^{-11}$ to 100 MeV. The y-axis represents the cross section in barns, ranging from $10^{-3}$ to $10^3$ barns. The graph includes a logarithmic scale for both axes.
Example: $n + {^{16}}O$

$^{16}O+n$, reaction cross section

- LLNL evaluation
- Islam (1988)
- Olsson (1990)
- Zanelli (1981)
- Kirby (1966, proton systematics)
- Dejuren (1950, neutron systematics)

--- Optical model calc. (Islam potential, with Madland potential above 50 MeV)
- Carlson (1975, proton data)
Nuclear data libraries come into all possible flavors. From raw experimental data, to evaluated pointwise data files, to energy group processed libraries. Names are important: EXFOR, ENSDF, BROND-2.2, CENDL-2.1, ENDF/B-VI.6, JEF-2.2, JENDL-3.2, ADL-3, EADL-92, EAF-3.1, EEDL-92, EFF-2.4, EPDL-92, FENDL-20, IRDF-90, MENDL-2, UKFY-3.0, UKHEDD-2.1, UKPADD-3, WIND, ...

- **General**
  
  *Andrej Trkov:* data formats of evaluated data libraries (ENDF).
  
  - Processing Nuclear Data libraries.

- **Nuclear Data network**
  
  *Otto Schwerer:* Nuclear data libraries organization at IAEA.

- **Impact of Nuclear Data Libraries on applications**
  
  *G. Palmiotti:* ADS design
  
  *P. Talou:* Validation of Nuclear Data Libraries for ADS
  
  *E. Sartori:* Computer Codes for simulating ADS
Three Computer Codes:

- **EMPIRE**
  
  *EMPIRE-II is a flexible code for calculation of nuclear reactions in the frame of combined Optical, Multistep Direct (TUL), Multistep Compound (NVWY) and statistical (Hauser-Feshbach) models. Incident particle can be a nucleon or any nucleus (Heavy Ion). Isomer ratios, residue production cross sections and emission spectra for neutrons, protons, alpha-particles, gamma-rays, and one type of Light Ion can be calculated. The energy range starts just above the resonance region for neutron induced reactions and extends up to several hundreds of MeV for the Heavy Ion induced reactions.*

- **FLUKA**
  
  *FLUKA is a fully integrated particle physics Monte Carlo simulation package. It has many applications in high energy experimental physics and engineering, shielding, detector and telescope design, cosmic ray studies, dosimetry, medical physics and radio-biology.*

- **MCNP**
  
  *MCNP is a general-purpose, continuous-energy, generalized geometry, time-dependent, coupled neutron-photon-electron Monte Carlo transport code system. MCNPX extends the CCC-660/MCNP4B code to all particles and all energies.*
Priority measurements for ADS

• Accuracy requested (in %) on the Nuclear Data for the reactions involved in the Th cycle

<table>
<thead>
<tr>
<th>Data</th>
<th>$^{232}\text{Th}$</th>
<th>$^{231}\text{Pa}$</th>
<th>$^{233}\text{Pa}$</th>
<th>$^{232}\text{U}$</th>
<th>$^{233}\text{U}$</th>
<th>$^{234}\text{U}$</th>
<th>$^{236}\text{U}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(n,\gamma)$</td>
<td>1-2</td>
<td>10</td>
<td>3-10</td>
<td>50</td>
<td>3</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>$(n,\alpha)$</td>
<td>5</td>
<td>20</td>
<td>20</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

• Neutron spallation mechanisms at intermediate energies ($20 \text{ MeV} \leq E_n \leq 150 \text{ MeV}$). $(n, xn)$, $(n, p)$, $(n, \alpha)$ and other charged-particle emission cross sections are needed for ADS target design materials.

• Cross sections for Long-lived fission products. Examples are: $^{99}\text{Tc}$, $^{151}\text{Sm}$, $^{135}\text{Cs}$, and others.
n_TOF is a spallation driven TOF facility at CERN-PS with an unprecedented neutron flux density in the broad energy range between 1 eV and 250 MeV and with very high energy resolution.