Nuclear Data Needs
for Generation IV Nuclear Energy Systems

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Generation IV Reactor Cores

Six Reactor Concepts have been selected by the Generation IV International Forum (GIF) countries to meet challenging technology goals in four areas:
- Sustainability
- Economics
- Safety and reliability
- Proliferation resistance and physical protection.

Among the six selected systems,
- 5 (SFR, GFR, LFR, SCWR, MSR) are fast systems
- while 3 (SCWR, MSR, VHTR) are thermal ones

This implies some consequences on nuclear data needs
Generic Nuclear Data Needs for Generation IV Reactor Cores

Nuclear Data Needs for the six selected Generation IV systems should undergo a sensitivity analysis for selecting those data which are important. But it must be recognized straight from the beginning that evaluated nuclear data cannot as such meet the requirements, especially for the fast systems.

Past experience should therefore be used.

This will be done using experience:
• on SFR for the 5 (SFR, GFR, LFR, SCWR, MSR) and
• on PWR for the 3 (SCWR, MSR, VHTR) thermal ones.

And nuclear data needs will therefore be restricted to:
• those needs that have been left behind in previous designs and
• those specific elements which are new in these designs.
### STATUS OF VALIDATION FOR SUPER-PHENIX

<table>
<thead>
<tr>
<th>Measurement</th>
<th>(E-C)/C</th>
<th>Particular Points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Critical Mass</strong></td>
<td>&lt; 100 pcm</td>
<td>Direct Run (No Corrections)</td>
</tr>
<tr>
<td><strong>Control Rod Worth</strong></td>
<td>&lt; 5%</td>
<td>SPX CMP and PX (REACTIVIX)</td>
</tr>
<tr>
<td><strong>Power Map distribution</strong></td>
<td>Residual Discrepancy of 5%</td>
<td>SPX CMP</td>
</tr>
<tr>
<td><strong>γ Heating</strong></td>
<td>Residual Discrepancy of 10%</td>
<td>Measurements in critical facilities RACINE and CIRANO programmes in MASURCA</td>
</tr>
<tr>
<td><strong>Burn-up Swing</strong></td>
<td>- 5%</td>
<td>Possible compensation effects between MA and FP</td>
</tr>
<tr>
<td><strong>β_{eff}</strong></td>
<td>dispersion de 6.5%</td>
<td>Measurements in critical facilities BERENICE programme in MASURCA</td>
</tr>
<tr>
<td><strong>Doppler Constant</strong></td>
<td>0%</td>
<td>SPX CMP (Debye correction necessary)</td>
</tr>
<tr>
<td><strong>Sodium Void</strong></td>
<td>Correction factor of 1.1 for the leakage component due to an incorrect total xs 10%</td>
<td>Correction confirmed by a new Na evaluation Measurements performed in MASURCA</td>
</tr>
</tbody>
</table>
R&D required for Sodium Cooled Cores

VALIDATION METHODOLOGY

- Numerical validation of individual algorithms

- Analysis of clean experiments (Beginning of Life, Simple to model)

- Sensitivity calculations and variance-covariance matrices

- Nuclear data adjustments
  ⇒ production of the ERALIB1 adjusted library

- Analysis of measurements performed in reactors
  (SUPER-PHENIX Start-up Measurements)

- Determination of uncertainties on reactor values including fuel cycle

- Analysis of experiments specific to safety
  SNEAK 12A&B
  CONRAD safety configurations
R&D required for closed fuel cycle in fast Cores

In Fast Spectrum, whatever the GEN IV core envisaged, there will be a strong incentive to assess the core characteristics through the fuel cycle since

- the breeding gain should be near zero to achieve sustainability goals
- the safety criteria are very much associated to the Minor Actinide content in the fuel
  - either in an equilibrium state where only depleted Uranium is provided to the fuel cycle
  - or by addition of both Pu and MA coming from pre - GEN IV cores

Hence, a better control of the fuel cycle characteristics is needed

At present, only partial assessment has been done and need to be completed

New reassessment of fission and capture xs for the long decay chain going from Np237 to Cf252 (for Pu fuel cycles)
R&D required for closed fuel cycle in fast Cores

Feedback coefficients and reactivity swing are very sensitive to the fuel burn up and hence to the minor actinides and fission products $x_s$

These data have an insufficient quality and would require adjustment on integral experiments.

When they exist, these experiments can be sample worth experiments or irradiated sample experiments or analyses of irradiated pins.

To take profit of these experiments, developments of perturbation method for the Boltzmann equation under its integral form (collision probabilities) and for burnt elements using coupled Batemann and Boltzmann equations are required.
MA experimental data base

Cross Sections
Branching Ratio, etc
Minor Actinides

Thermal spectrum
Fast spectrum

COSMO
MASURCA indices
BFS 67, 69, 71

OSMOSE

Critical experiments

Critical experiments
Reactor irradiations

SUPER PROFIL

PROFIL 1 & 2

JOYO

TRAPU

PROFIL

SUPER FACT

St LAURENT MOX

GRAVELINES

UOX (3.1%, 4.5%)

BUGEY

UOX (3.1%, 4.5%)

UOX (3.1%, 4.5%)
Fission Products
Experimental Data Base

Cross Sections
Branching Ratio etc
Fission Products

Thermal spectrum

Fast spectrum

Critical experiments

Reactor irradiations

MINERVE

STEK oscillations

SEG oscillations

DIMPLE

SUPER PROFIL

PROFIL M

PROFIL 1&2
**Nuclear Data Needs for Fast Reactor Cores**

**D-1 Target accuracy of MA nuclear data**

* from Shigeo OHKI (JNC)
* influential MA nuclear data selected are:
  - Am-241 Capture
  - Am-241 Isomeric Ratio
  - Am-243 Capture
  - Cm-242 Capture
  - Cm-244 Capture

**Irradiation Experiment Analysis for XS validation**

* from G. Palmiotti (ANL), PHYSOR’04

**Contribution to the Validation of JEF-2 Actinide Nuclear Data:**

* Analysis of Fuel and Sample Irradiation Experiments in PHENIX,
  From R. Soule and E. Fort, GLOBAL’97, Yokoyama, 1997
Nuclear Data Needs for Sodium Cooled Cores

Realisation and Performance of the Adjusted Nuclear Data Library
ERALIB1 for calculating fast reactor neutronics
from E. Fort, W. Assal, G. Rimpault et al. ,PHYSOR96
September 1996, MITO, IBARAKI, JAPAN

Preliminary Analysis of JEFF-3.0/GP Trends in Fast Spectrum Experiments
from E. Dupont (CEA) JEFF-DOC-956, JEFF meeting, April 2003

Although some obvious improvements appear on some xs (Na, Pu240, Cr52)
the overall goal is not achieved and JEFF-3 does not meet the
SFR requirements as it was the case for JEF-2

Similar approaches at JNC and INEEL do not lead to similar trends
everywhere
=> coordinate work trends to better identify difficulties

Analysis of the JUPITER Fast Reactor Experiments using the ERANOS
and JNC Code Systems from K. Sugino, G. Rimpault
PHYSOR'00 , Pittsburgh, Pennsylvania, USA (May 2000)
**Nuclear Data Needs for Sodium Cooled Cores**

No more $\text{UO}_2$ blankets
replacement by steel zones
external breeding ratio eliminated $+0.22 \Rightarrow 0.00$

For different reasons
- Non-proliferation issues (weapon grade plutonium produced in blankets)
- Economy (blanket manufacturing and reprocessing is costly)

Experiments in CIRANO and in some other experiments BFS, FCA show difficulties in representing fluxes and hence reflection gain

Nuclear data pointed out, in particular
Steel isotopes and in particular their scattering anisotropy in the 100 KeV- 1KeV range

- Experimental Validation of Nuclear Data and Methods for Steel Reflected Plutonium Burning Fast Reactors from G. Rimpault et al, PHYSOR96, September 1996, MITO, IBARAKI, JAPAN
- Développement et qualification d’un formulaire adapté à SuperPhenix avec Réflecteurs from J.C. Bosq, PhD thesis, University of Provence, 1998
- Fast Reactor Core-Reflector Interface Effects Revisited, from J.F. Lebrat et al (CEA), PHYSOR’02, Seoul, Korea, October 2002
Nuclear Data Needs for Gas-Cooled Fast Reactor Cores

Exploratory Studies on Helium-Cooled Fast Reactor Cores have been undertaken and shown that R&D is required

On nuclear data assessment,
• Si and other materials included in CERCER and CERMET fuels
• Refractory materials used in shielding regions

• Methodologies for a large gas cooled fast reactor core design and Associated Neutronic Uncertainties, from J.C. Bosq, A. Conti, G. Rimpault, J.C. Garnier, PHYSOR’04, April 2004, Chicago, Illinois, USA

• Analysis of the ZPR9 Gas Cooled Fast Reactor Experiments using JEF2.2 data and the ERANOS code system from J. Tommasi, PHYSOR’04, April 2004, Chicago, Illinois, USA
Nuclear Data Needs for Lead Bismuth Cores

Lead and Bismuth require an overall assessment

Integral experiments are very scarce, they (MUSE4 for instance) show that JEF2 evaluation are leading to reasonable results if partial xs used (total ≠ sum of partials)

Sensitivity calculations (PSI) show large core characteristic uncertainties due to:
Lead:
reevaluation of natural lead xs;
evaluation of isotopic xs : Pb204 ; Pb206 ; Pb207 ; Pb208.

Bismuth:
Less important in capture but Polonium (coming from Bi activation is a problem)

Attention to the high energy xs activated by the spallation source (for ADS)

PDS-XADS LBE and Gas Cooled Concepts Neutronic Comparison from Sandro Pelloni, PHYSOR’04, April 2004, Chicago, Illinois, USA
R&D required for Lead Bismuth Cores

Lead and Bismuth require an overall assessment.

Integral experiments are very scarce, and

**ISTC proposals provide an opportunity to extend the data base**

**ISTC 2661 BFS experiments for BREST 300:**
Analytical and Experimental Substantiation of Neutron-Physical Characteristics of Fast reactors with Lead Coolant

**ISTC 2884 BFS experiment in support of MA transmutation**
"Integral Experiment at BFS Critical facility for Justification of Minor Actinides Transmutation and their Analysis
1\textsuperscript{st} core Lead Core
2\textsuperscript{nd} core Molten Salt
Nuclear Data Needs for Molten Salt Cores

In fast spectra
chloride:
reevaluation of natural chromium;
**evaluation of isotopic xs:** Cl35 et Cl37.
feasibility aspect very much associated to their capture xs level

In Thermal spectrum
Fluoride capture xs as well as thermal matrices
(possible inconsistency in the current evaluations)
Heavy isotopes:
**evaluation of fission and capture xs** for: U232, Pa231, Th230, Th231, Th232 and
(n,2n), (n,3n) xs for Th232
Nuclear Data Needs for Super Critical Water Cores

In Thermal spectra
thermal matrices of hydrogen
for large temperatures (above 350°C)

with H binding effects in water
(attention should be given
to the impact of high pressure 250 bars?)

and in Yttrium, Zirconium and Calcium hydrides

No integral experiments available for the new design
and for water densities ranging from 0.3 to 0.7
Acute problem for the fast versions of SCWR for which
voiding is a sensitive issue

Experiments planed in EOLE and PROTEUS by 2008

Core Design Feature Studies and Research Needs for HPLWR
from G. Rimpault et al., ICAPP’03, Cordoba, Spain, May 2003
Nuclear Data Needs for VHTR

At the moment, nuclear data requests hidden for method difficulties.

Nuclear data requests are those of PWR plus
thermal matrices of carbide
for large temperatures

with H binding effects in graphite
## Generic Nuclear Data Needs for SCR and VHTR

At the moment, nuclear data requests hidden for method difficulties. Nuclear data requests are those of PWR

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Nuclear data</th>
<th>Justification</th>
</tr>
</thead>
</table>
| Hf177   | Capture: T.V and RR | Longstanding systematic discrepancies in Naval reactor studies [1]  
 Priority [1 eV-100 eV]  
 Accuracy: 2% |
| Hf178   | Capture: T.V and RR | Longstanding systematic discrepancies in Naval reactor studies [1]  
 Priority [1 eV-100 eV]  
 Accuracy: 2% |
| Hf179   | Capture: T.V and RR | Longstanding systematic discrepancies in Naval reactor studies [1]  
 Priority [1 eV-100 eV]  
 Accuracy: 2% |
| U235    | Prompt neutron spectrum (thermal fission)  
 [100keV-0 MeV]  
 Accuracy: high resolution  
 If possible: Prompt γ spec. | WPEC/SG-9 [2] and SG-22 [3]:  
 γ heating calculation [4] |
| Pu239   | Thermal shape of Capture and fission: [0.01 eV – 0.5 eV]  
 Accuracy: 2% on α(E) shape | Reactivity Temperature Coefficient in Mixed Oxide[5] |
| Am      | Am241 capture: RR  
 Am242m abs. RR  
 Branching ratios | Large discrepancies in the prediction of Am2m and Cm build-up in PWR [6] [7] |
| Gd155 Gd157 | Capture: T.V and R.R  
 Capture thermal shape | PWR and Naval reactor application |
| U238    | Capture: T.V and R.R  
 Priority [therm – 120 eV]  
 Accuracy: 2% | WPEC/SG-22 [3] |
Generic Nuclear Data Needs for SCR and VHTR

References:
[4] JEF/DOC-747 Recommendations for basic data evaluation deduced from the validation of gamma-heating calculations against experiments in Masurca. Anton Luthi