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 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

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

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

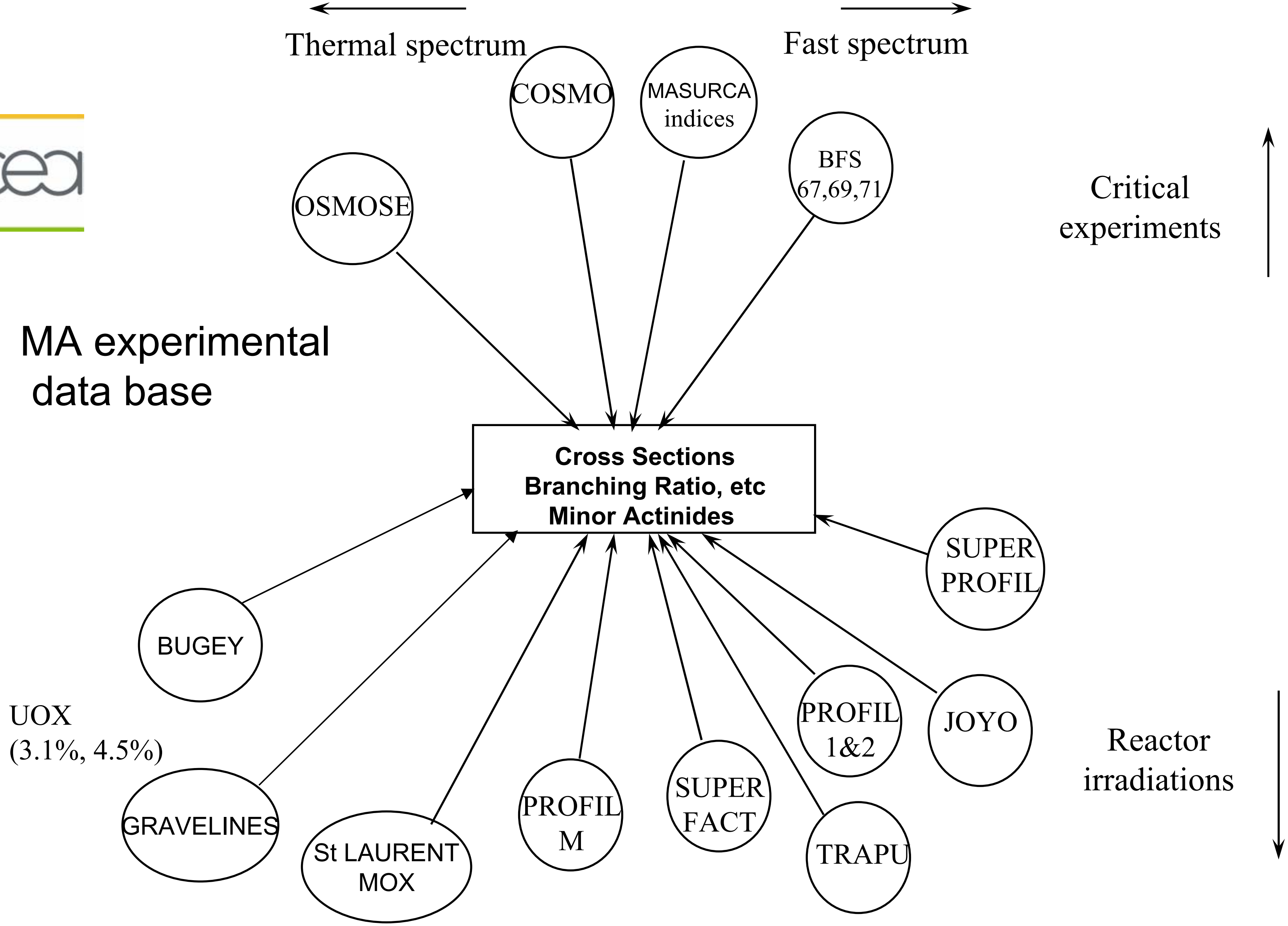
Feedback coefficients and reactivity swing
are very sensitive to the fuel burn up
and hence to the
minor actinides and fission products xs

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

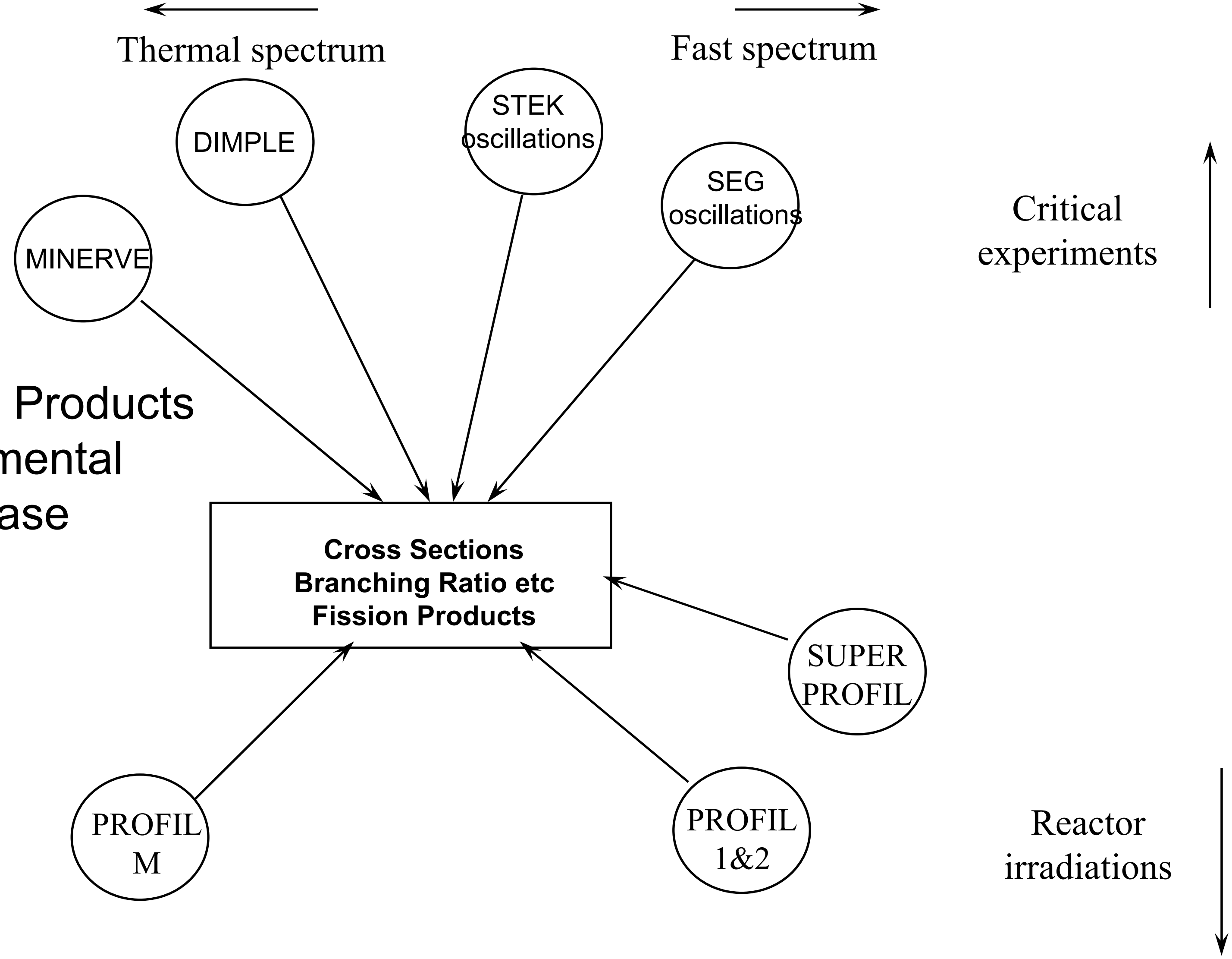
When they exist, these experiments can be
sample worth experiments or
irradiated sample experiments or
analyses of irradiated pins

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



Fission Products Experimental Data Base



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 UO_2 blankets

replacement by steel zones

external breeding ratio eliminated +0.22 => 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
- Developpement 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

- **Methoologies 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

1st core Lead Core
2nd 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

Isotope	Nuclear data	Justification
Hf177 Hf178 Hf179	**Capture : T.V and RR** Priority [1 eV-100 eV] *Accuracy : 2%*	• Longstanding systematic discrepancies in **Naval reactor studies [1]** • **PWR-BWR applications**
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 $\alpha(E)$ shape*	**R**eactivity **T**emperature **C**oefficient in Mixed Oxide**[5]**
Am	Am241 **capture : RR** Am242m **abs. RR** Branching ratios	Large discrepencies 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:
[1] JEFDOC-924 : Current status and proposal concerning Hf evaluated nuclear data for JEFF3. Jean-Marc Palau
[2] NEA/NSC/WPEC/DOC-288 (2003) Subgroup-9 final report : Fission Neutron Spectra D. Madland
[3] NEA/NSC/WPEC/DOC-293 (2003) Summary report of the WPEC sub-group-22; "Nuclear data for improved LEU-LWR reactivity prediction" A. Courcelle
[4] JEF/DOC-747 Recommendations for basic data evaluation deduced from the validation of gamma-heating calculations against experiments in Masurca. Anton Luthi
[5] Nucl. Sci. and Eng Vol 144, 47-74 (2003) . The reactivity temperature coefficient analysis in light water moderated UO2 and UO2-PuO2 lattices. L. Erradi, A. Santamarina and O. Litaize
[6] Trends in nuclear data derived from integral experiments in t hermal and epithermal reactors. C. Chabert, A. Santamarina, P. Bioux, International Conference on Nuclear Data for Science and Technology, Oct.7-12, 2001 Tsukuba Japan
[7] JEFDOC-931 Motivation for new Am241 measurements. O Bouland