R&D in Reactor Core Physics for Generation IV Nuclear Energy Systems

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Type of R&D required in Reactor physics on Generation IV Reactor Cores

R&D required in Reactor physics on Generation IV Reactor Cores concerns different types of assessment

- **Code development**
- **Nuclear data assessment**
- **Thermal – hydraulic assessment**
- **Experimental validation**
- **Uncertainty characteristic definition**

In the following, requests for fast systems are investigated

R&D required in Reactor physics on Gas-Cooled Fast Reactor Cores

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

On code developments :

- Extension of cell codes (like the ECCO code of the ERANOS system) to new fuel sub-assembly geometries (particles/plates/CERCER/CERMET) with some further checks of the ability of the code to treat streaming and water ingress.
- Ability of 3D spatial codes such as to treat voided nodes and have a quite accurate fuel reconstruction scheme within hexagonal sub assemblies

On nuclear data assessment,

- Si and other materials included in CERCER and CERMET fuels
- Refractory materials used in shielding regions

On experimental validation

- Re-assessment of past relevant experiments
- New experimental programme (see ENIGMA)

R&D required in Reactor physics on Gas-Cooled Fast Reactor Cores

R&D is required in VARIANT for a series of developments (existing or planned) answering some of the requests of the reactor core designers (and ADS).

These developments are aiming at giving solutions to the following problems:

1) treatment of voided nodes (problems found in GFR and in ADS (target module)
2) treatment of anisotropy of streaming (and scattering) for GFR
3) treatment of anisotropy of an external source (for ADS)
4) reconstruction of fluxes within hexagonal nodes (problems found when calculating MSM factors in TRADE (for ADS) but of some concern also for GEN IV cores)
5) kinetic core behavior for both absolute reactivity measurements in ADS and for operating transients in GEN IV cores (problems found in MUSE4)
6) local discretization with a de-structured grid

R&D required in Reactor physics on Gas-Cooled Fast Reactor Cores

R&D is required in VARIANT for a series of developments (existing or planned) answering some of the requests of the reactor core designers (and ADS).

There will several presentations at PHYSOR'04 answering these R&D requests and it might be wise to discuss them there in particular in terms of share of efforts (with a split between
R&D required for non mature methodologies
and implementation in VARIANT for mature ones).

ERANOS is now widely used in the world and
the final integration of VARIANT developments within ERANOS
are incorporated at CEA/Cadarache
(and a user club could be organized there),
but coordinating efforts for integrating mature developments
should centered at ANL/Argonne.

R&D required in Reactor physics on Gas-Cooled Fast Reactor Cores

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

The thermal hydraulic heat transfer coefficients (for Helium) have too large uncertainties for designing accurately the core. Experiments should be set up to get assess to better values:

- At FZK (Karlsruhe), use of the HELOKA helium loop (which is designed to test various elements of the ITER circuits).
- At CEA (Cadarache), definition of the ESTHEL programme in which fine instrumentation is being designed.

Modeling of the helium circuits will be (is being) done with RELAP-ATHENA at FZK and with CATHARE at CEA

R&D required for Sodium Cooled Cores

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

- 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 Sodium Cooled Cores

no more UO_2 blankets
replacement by steel zones
external breeding ratio eliminated +0.22 => 0.00

The reason here is coming from different reasons
non proliferation issues (weapon grade plutonium produced in blankets)
economy (blanket manufacturing and reprocessing is costly)

Steel reflectors were studied in the past for reasons (reduction of Pu inventory)
which are no longer consistent with the sustainability

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

A design route should be developed
since only costly reference calculations can overcome numerical difficulties

R&D required 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)

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

R&D required 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

R&D required 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

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)

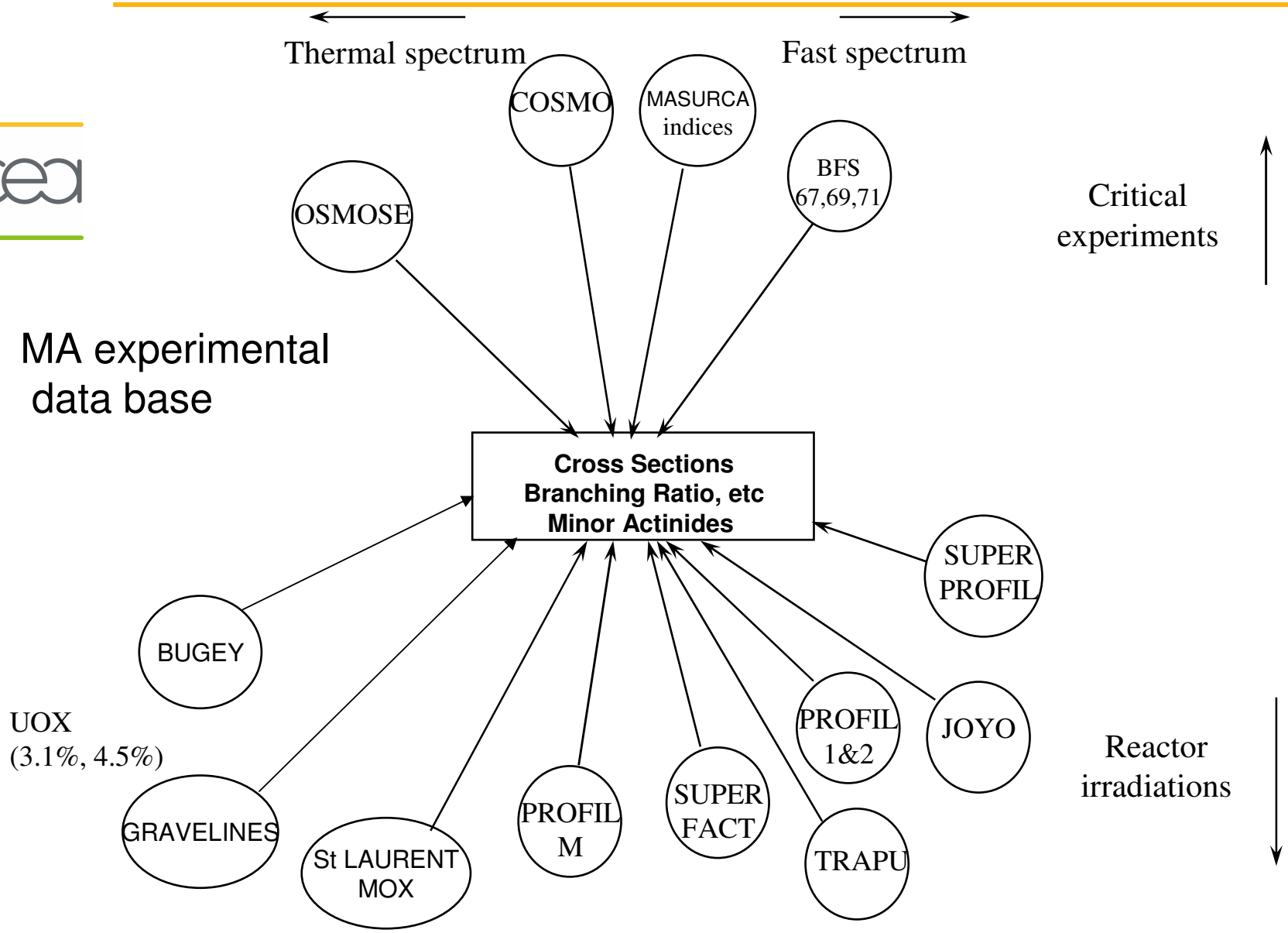
R&D required for closed fuel cycle in fast Cores

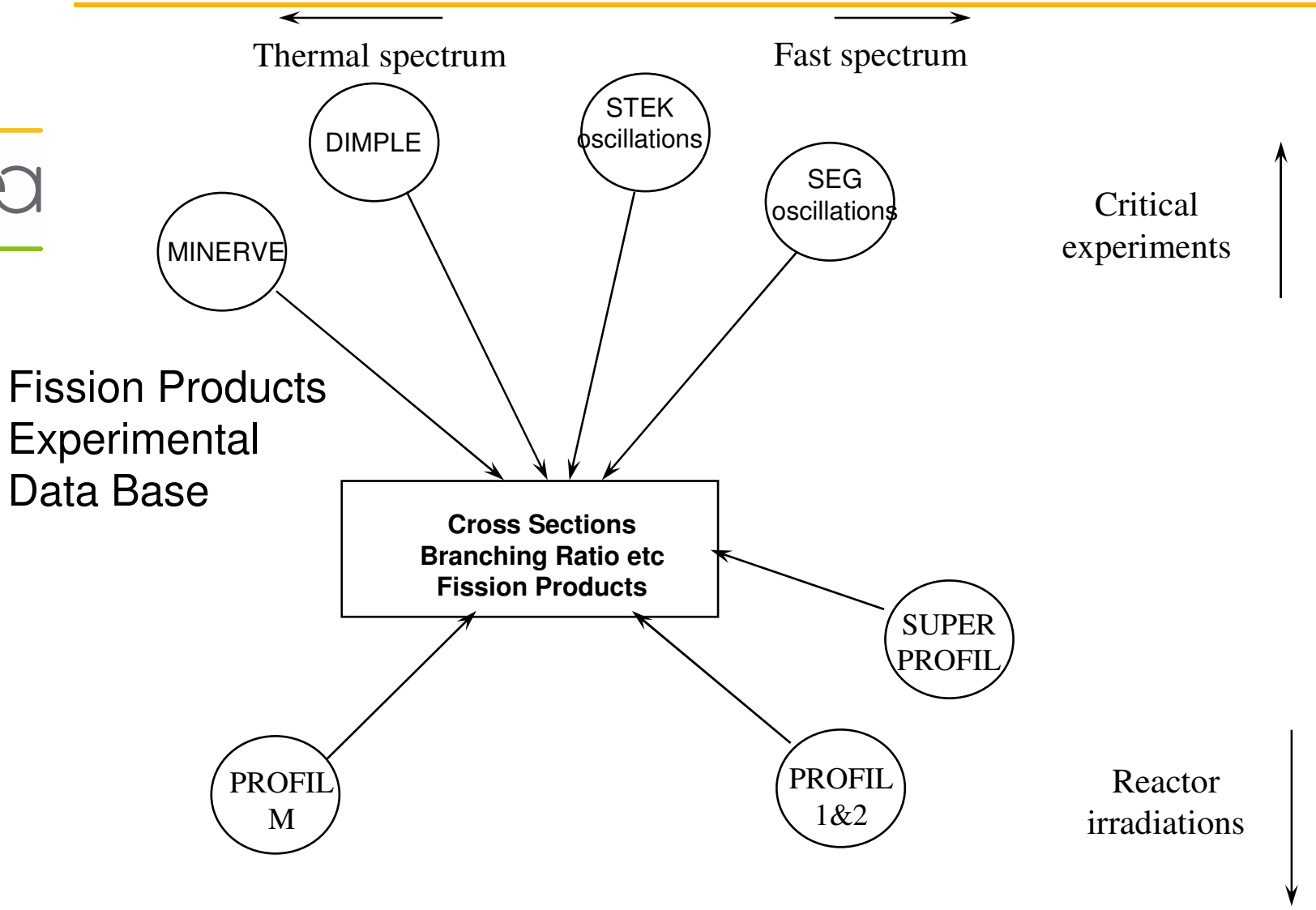
Feedback coefficients and reactivity swing
are very sensitive to the fuel burn up
and hence to the
minor actinides and fission products xs

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


Thermal spectrum
Fast spectrum
COSMO
MASURCA indices
BFS 67,69,71
OSMOSE
Critical experiments
MA experimental data base
Cross Sections
Branching Ratio, etc
Minor Actinides
SUPER PROFIL
BUGEY
UOX (3.1%, 4.5%)
PROFIL 1&2
JOYO
Reactor irradiations
GRAVELINES
St LAURENT MOX
PROFIL M
SUPER FACT
TRAPU


Thermal spectrum
Fast spectrum
DIMPLE
STEK oscillations
SEG oscillations
MINERVE
Critical experiments
Fission Products Experimental Data Base
Cross Sections
Branching Ratio etc
Fission Products
SUPER PROFIL
PROFIL M
PROFIL 1&2
Reactor irradiations