IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Epithermal Data Needs for Criticality Safety Assessment in IRSN

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TEX Feasibility Meeting

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Summary

- Introduction
- Data needs through Criticality Assessment feedback
- Low moderated MOX powders
- The structural materials (extension of MIRTE program)

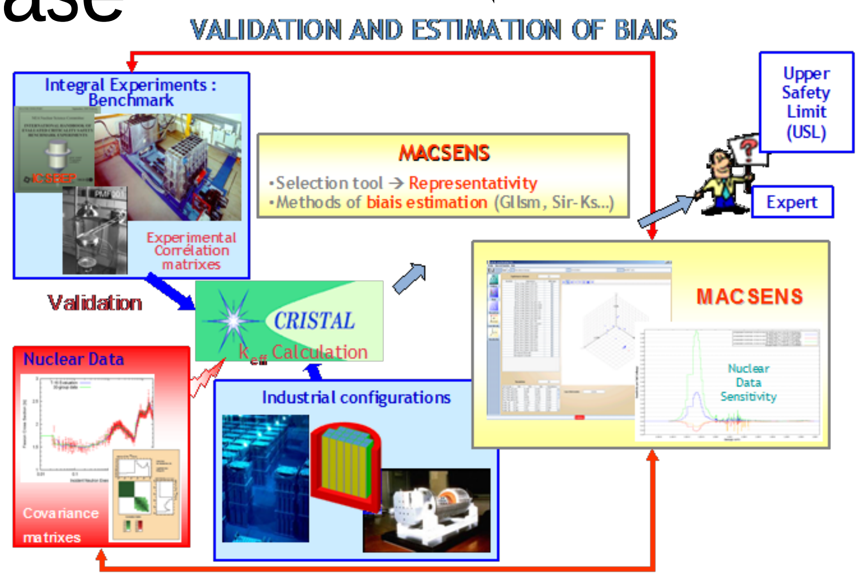
Introduction
IRSN role - Data needs

Criticality Safety Assessment

Criticality safety assessment should demonstrate that operations are sub-critical under all operational states (*i.e.* normal and abnormal operations)

Code Validation Database

IRSN feedback to JEFF (OECD) and technical exchanges with CEA



Nuclear Data needs

- Quality of data, uncertainties, processing …
- GLLSM feedback

Criticality Safety Assessment

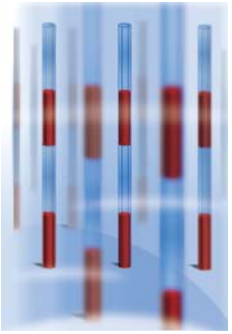
- For both operational states (*i.e.* **normal and abnormal operations**), it's necessary to consider neutron interaction phenomena, which importance increases with the complexity of the studied systems

- In french approach, key role of parametric studies, particularly with the **variation of water density** (0 to 1)

- **Low density water (steam)** can cover presence of water (flooding, coolant, condensation, leaks…), but also can cover the presence of materials that induce neutron interactions

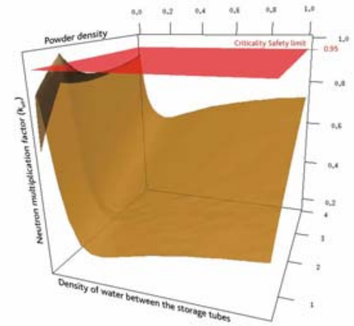
  Nota : we can also consider the presence of water space surrounding the materials in place of water steam (according to the scenario encountered)

- **Extension of the energy range of interest** (from thermal/fast to epithermal)



Example of an interim storage of dry PuO2 powder,
Main parameters to study are:

- **the density of the powder within the storage cans (normally around 1.5 g.cm-3 and up to 4 g.cm-3),**
- **the possible flooding of the storage (leading to an interstitial moderation of the neutrons interacting from a storage tube to another one).**



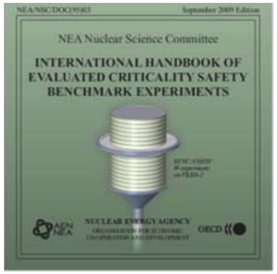
IRSN Proposals for Future Experimental Programs (1/2)

Experimental programme (5-year plan)	Identified needs	
	Engineering justification	Basic Physics/Validation
Experiments with minor actinides	Reprocessing	Cross-section & Doppler coefficient validation
Study of burnable and other absorbers in thermal and resonance spectra (Gd, Hf, Er, …)	Use of different structure materials and absorbers to increase efficiency of casks loading	Cross-section validation
Study of structure materials in thermal and resonance spectra (Si, Ca , Mo, innovative stainless steels and others …)	Fuel transport and storage	Cross-section validation
Homogeneous and heterogeneous water density and temperature effects (steam, water boiling…) for various kinds of fuel	Fuel transport and storage	Kinetic parameters, Cross-section & $S(\alpha, \beta)$ data validation
Moderator with low hydrogen content (fire extinguisher powders, vinyl…)	Fuel transport and storage	

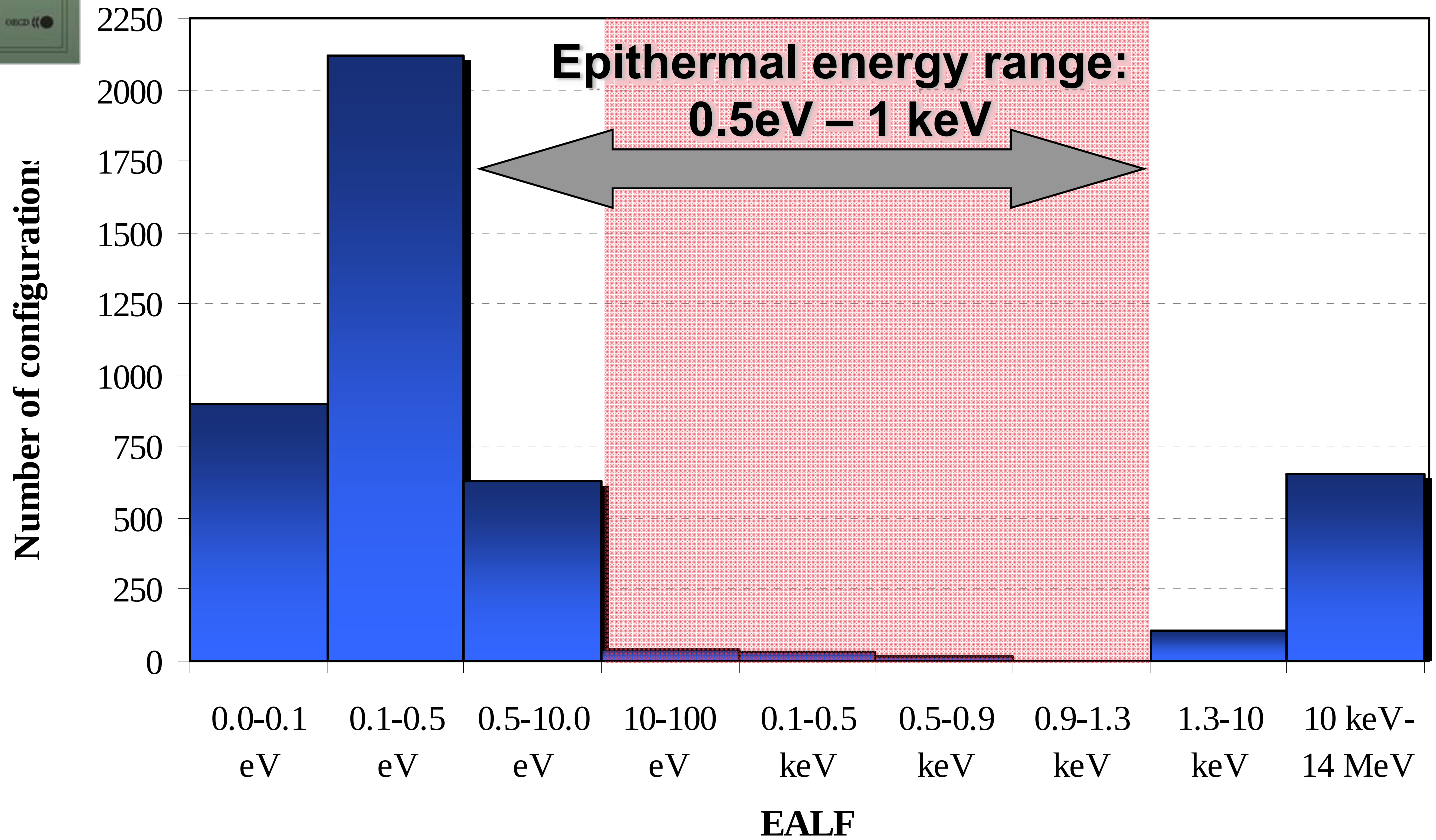
IRSN Proposals for Future Experimental Programs (2/2)

Experimental programme (5-year plan)	Identified needs	
	Engineering justification	Basic Physics/Validation
MOX Rods in U-Pu solutions with high Pu content (> 15%) and high ^{240}Pu content (> 20%)	Reprocessing: MOX fuel dissolution	
Calibration of cores for characterisation of Pu solutions (delayed and prompt criticality)	Operator Training	Kinetic parameters & Cross-section validation
Excursions with Pu solutions having various ^{240}Pu concentrations and temperatures (excursions in the three SILENE kinetic modes)	CAAS qualifications & Operator Training	Kinetic parameters
Calibration of cores for characterisation of mixed U and Pu solutions (delayed and prompt criticality)	Operator Training	Kinetic parameters & Cross-section validation
Excursions with mixed U and Pu solutions having different molarities and temperature	CAAS qualifications & Operator Training	Kinetic parameters
International dosimetry exercises one time a year (2 weeks a year)	Dosimetry exercises, Operator training	

Need: ICSBEP Handbook Data



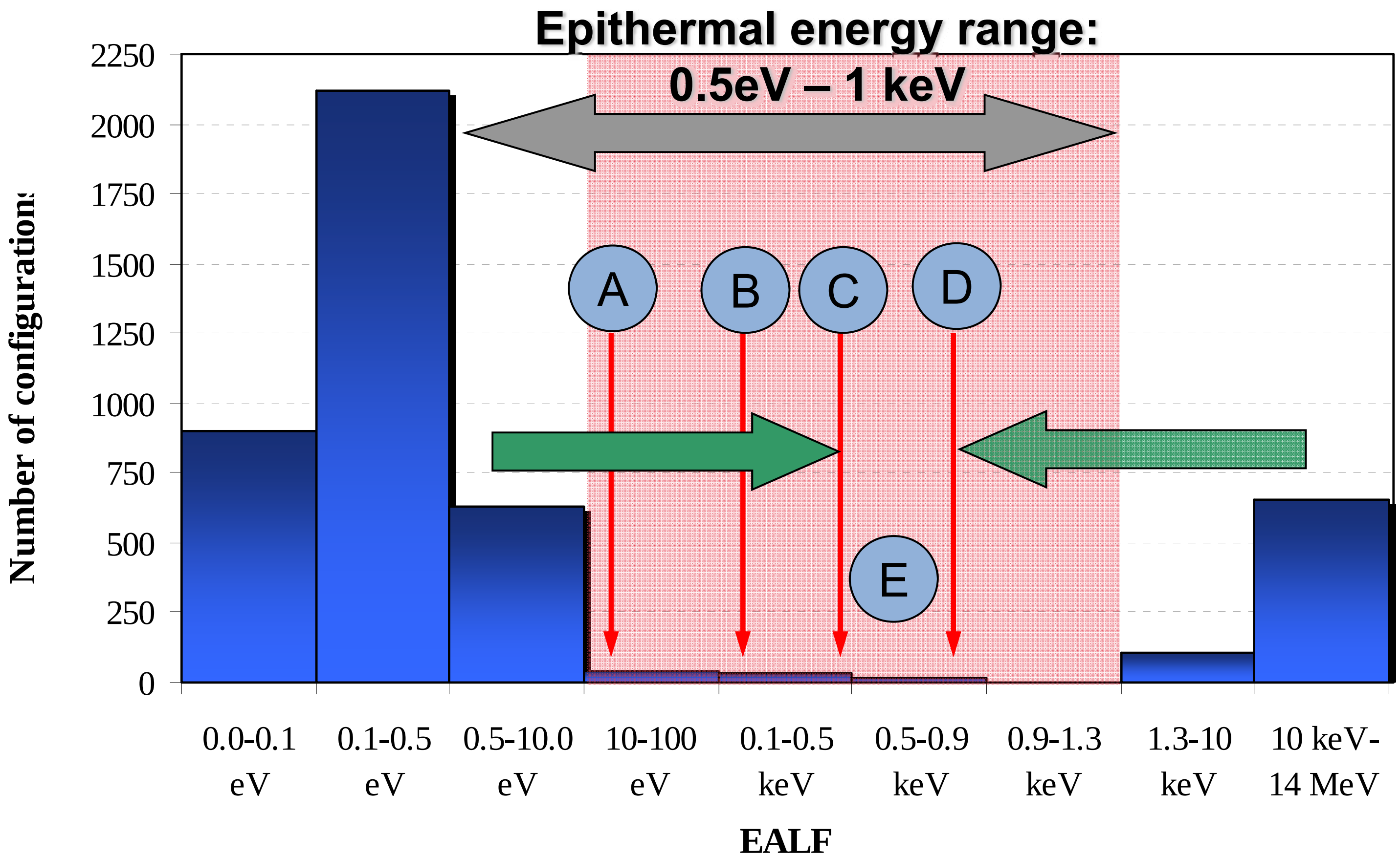
EALF* from 10eV to 1.3keV:
Very limited or <u>NO</u> experiments



*EALF data presented in the ICSBEP Handbook DVD 2010 (DICE)

Need - Scenarios for Safety Assessment

Scenarios considering normal and abnormal conditions –
(**water steam** in fuel storages and transport casks/others ...)



Configuration A : storage of containers with PuO_2 or $UPuO_2$ dry powder

Typical configuration encountered in reprocessing or fuel fabrication facilities

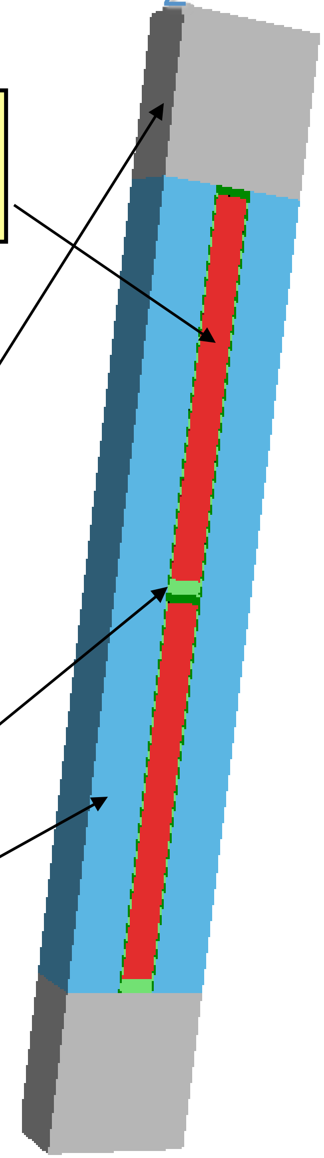
Fissile content: *principally* ***^{235}U, ^{239}Pu, ^{240}Pu, ^{241}Pu & ^{242}Pu***

Conceptual model:
Infinite plane array of wells

Materials – reflection:
Concrete

Materials – interaction:
- ***Steel (containers)***
- ***Water steam***

EALF = 15 eV



Configuration B : limit on allowable fissionable mass and moderation (standard data)

Typical configuration encountered for fuel fabrication facilities or for waste management and decommissioning

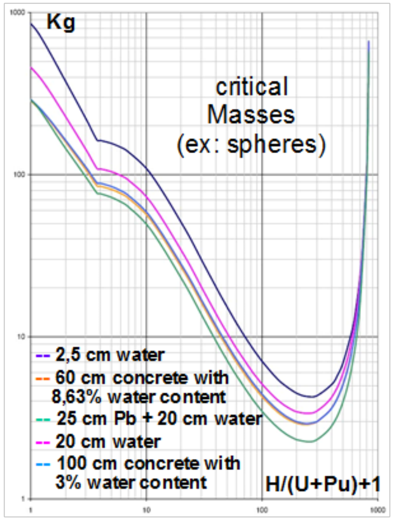
Fissile content: ***^{235}U, ^{239}Pu …***

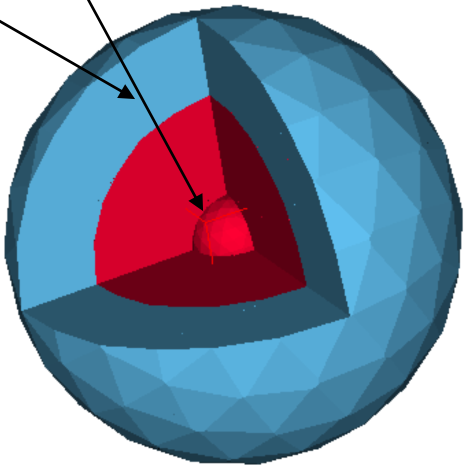
Conceptual model:
Spherical mass with heterogeneity moderation

Materials – reflection:
Water, lead, concrete…

Materials – interaction: *none*

EALF = 150 eV





Configuration C : cask for transport of PuO_2 or $UPuO_2$ dry powder

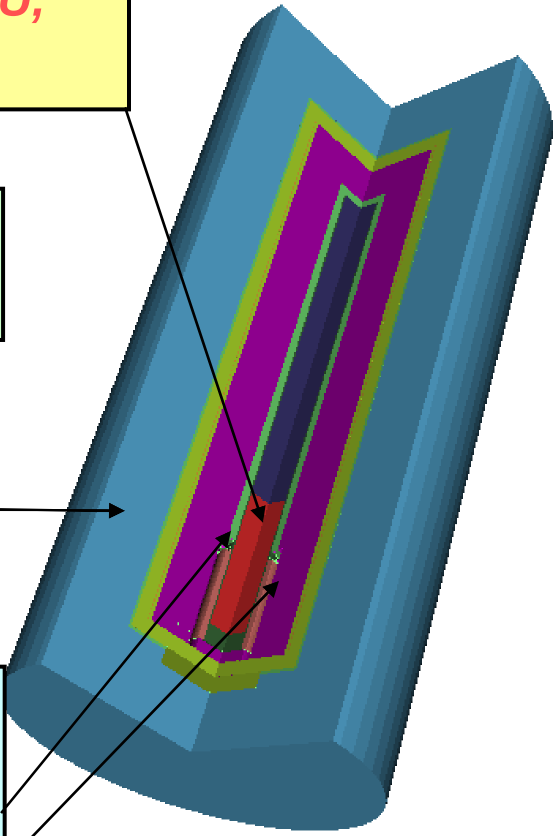
Configuration related for transport of fissionable material

Fissile content: *principally ^{235}U, ^{239}Pu, ^{240}Pu, ^{241}Pu & ^{242}Pu*

Conceptual model:
Geometry of the cask

Materials – reflection:
Water

Materials – interaction:
- *Steel*
- *Fixed absorbers (resins)*
- *Water steam*



EALF = 450 eV

Configuration D : metal single unit of Pu

Typical configuration encountered in metallurgy facilities

Fissile content: *principally* ^{239}**Pu**

Conceptual model:
Spherical mass

Materials – reflection:
Water

Materials – interaction: *None*

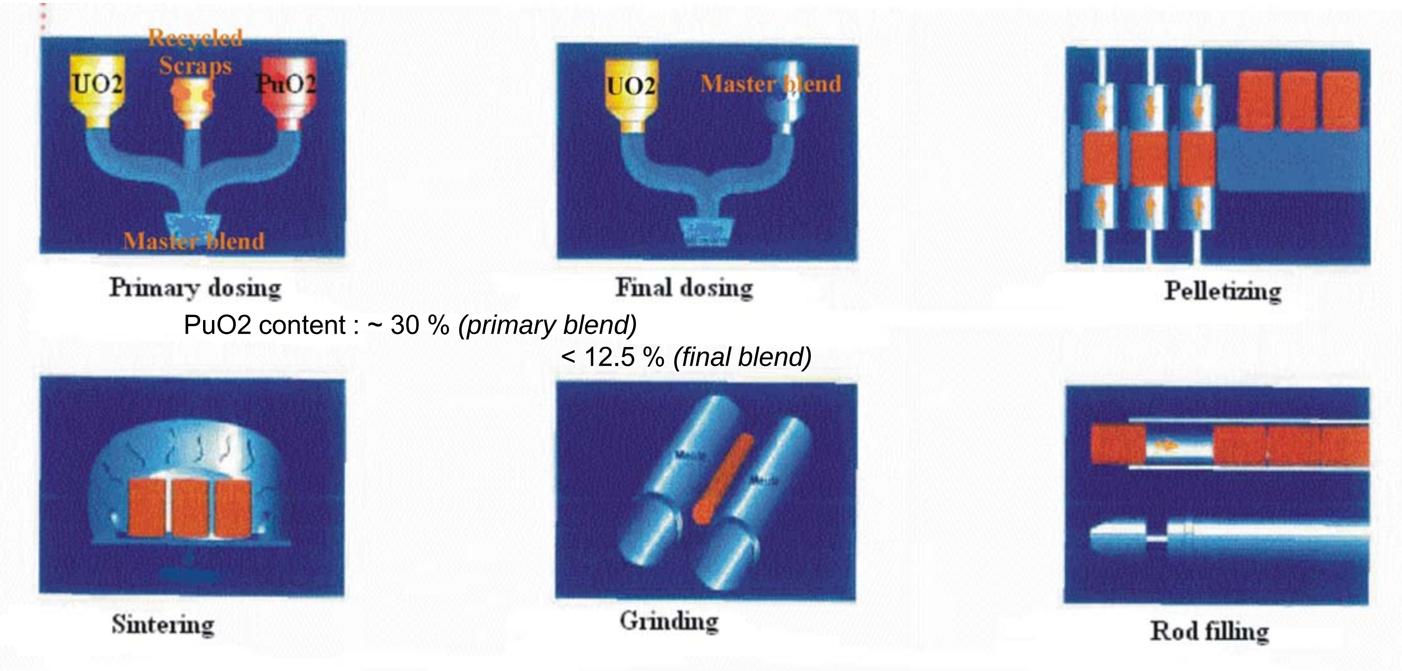
EALF = 770 eV

Configuration E : low moderated MOX powder

Major steps of MOX fabrication process

MELOX plant

- Powder master blend and final blend production
- Pellet production
- Rod production
- Fuel rod assembly



PuO2 content : ~ 30 % *(primary blend)*

< 12.5 % *(final blend)*

Configuration E : low moderated MOX powder

Major steps of MOX fabrication process

- MOX powder with varying UO_2-PuO_2 content, ^{240}Pu content, density and water content

MOX media used for criticality safety studies

- ^{235}U: 1.2%
- ^{240}Pu: 17%
- PuO_2 content: 30% (primary blend)
  12.5% (final blend)
- Powder density: 3.5 to 5.5 g/cm^3
- Water content: 1% (normal conditions), 5% (abnormal conditions)

- Criticality control modes: Mass + Moderation

  ➪ Need of validation due to the reduction of design safety margins (increase of the powder density from 3.5 g/cm^3 to 5.5 g/cm^3)

Configuration E : low moderated MOX powder

OECD Workshop - MOX media encountered in the fuel cycle

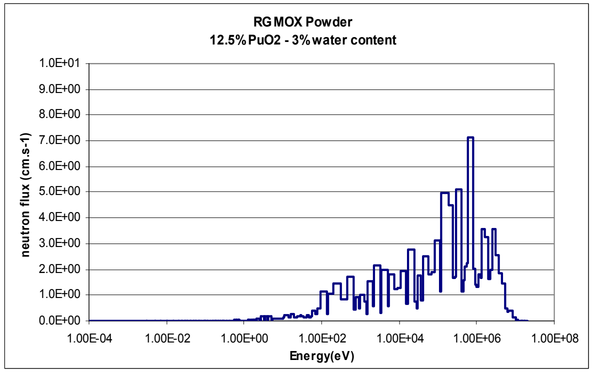
Reactor-Grade (RG) Plutonium
(French fabrication plant MELOX)

- ^{240}Pu > 17 %
- PuO_2 content : ~ 30 % *(primary blend)*
  < 12.5 % *(final blend)*
- Powder density : 4.6 and 5.5 g/cm^3
- Water content : 1% - 5 % (normal -abnormal)

Weapons-Grade (WG) Plutonium
(US fabrication plant)

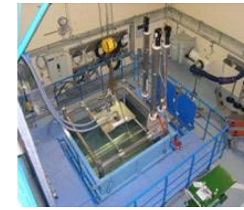
- ^{240}Pu ~ 4 %
- PuO_2 content : 22 % *(primary blend)*
  6.5 % *(final blend)*
- Powder density : 5.5 g/cm^3
- Water content : 1% - 5 %

EALF = 20 to 770 eV

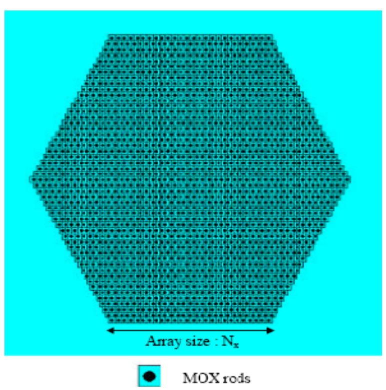


Configuration E : low moderated MOX powder

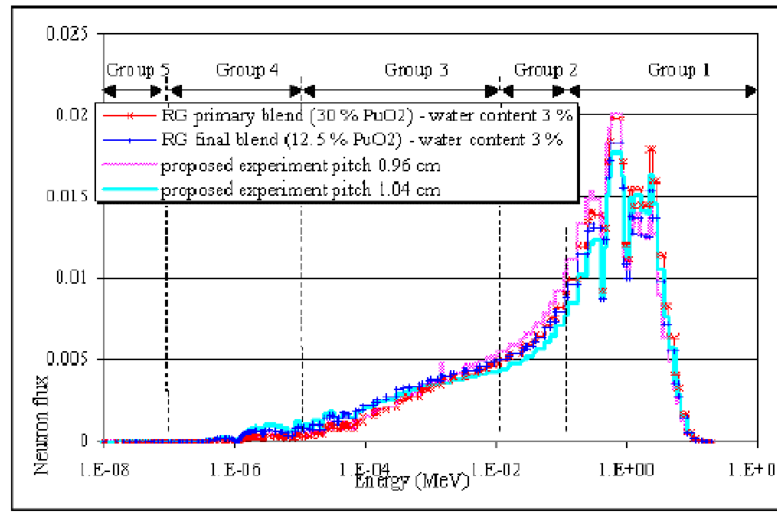
OECD Workshop on experimental needs (2004)



- IRSN proposed experiments
  - Tightly packed MOX rods
    - PuO_2 content: 27.5%,
    - Hexagonal pitch: 0.96 to 1.04 cm,
    - V_{H2O}/V_{MOX}: 0.325 and 0.572 (2.4 to 5.4% H_2O)
    - q_{4eV}: 0.043 to 0.152
    - Average energy: 32.115 to 142.75 eV



Neutron spectrum in infinite media



Isotopic content

Isotope	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am	^{235}U	^{238}U
Weight %	0.26	69.31	25.08	1.88	1.01	2.46	0.25	99.75

Extension on MIRTE program in epithermal range

MIRTE 1 program

- STRUCTURAL MATERIAL EXPERIMENTAL (MIRTE) PROGRAM [2007-2010]

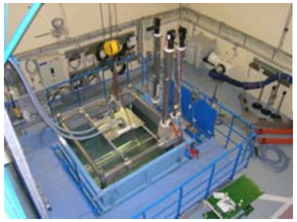
AREVA ANDRA U.S. DEPARTMENT OF ENERGY NNSA

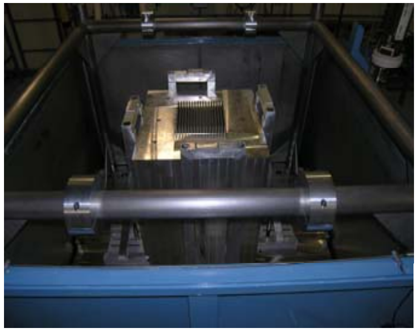
Criticality calculations take into account more and more realistic configurations in particular by modelling the structural material, which ensure sub-criticality of facilities and transport packages

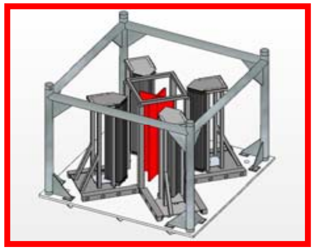
Need for the criticality calculation codes validation and nuclear data validation

- **Extension from thermal to epithermal range for fissile and non fissile Materials**

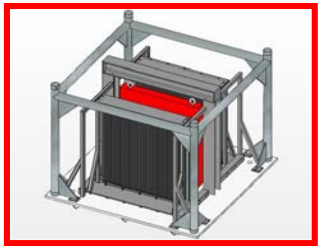
List: **Iron, Nickel, Copper, Lead, Zirconium, Aluminum, Concrete, Glass(SiO_2), Titanium**



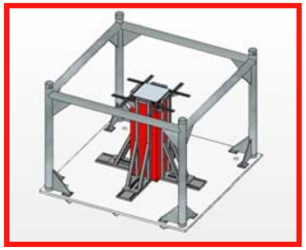




Interaction – thin plates



Interaction - large screens



Reflection

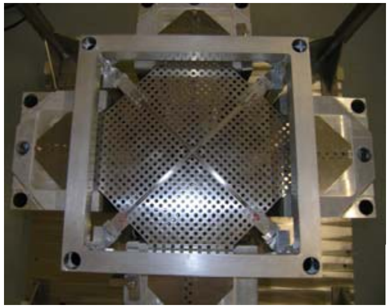
Extension on MIRTE program in epithermal range

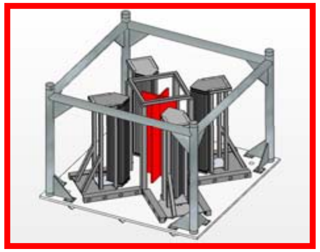
MIRTE 2 program

- The first phase - MIRTE 2.1 - began in January 2011 with reproducibility experiments of MIRTE 1
- The second phase - MIRTE 2.2 - will involve new material in the same kind of interacting configurations as for MIRTE 1 and is planned to begin in 2012
- A third phase with slight changes in the device could begin in 2013 and end before 2014 because of Apparatus B refurbishment

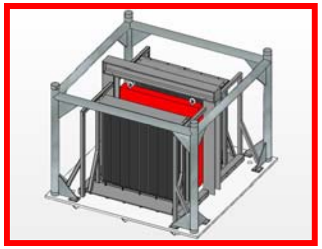
- **<u>Extension from thermal to epithermal</u> range for fissile and structural materials**

List: **Chromium, Molybdenum, Manganese, Chlorine, Rhodium, BORA and VYAL-B resins**



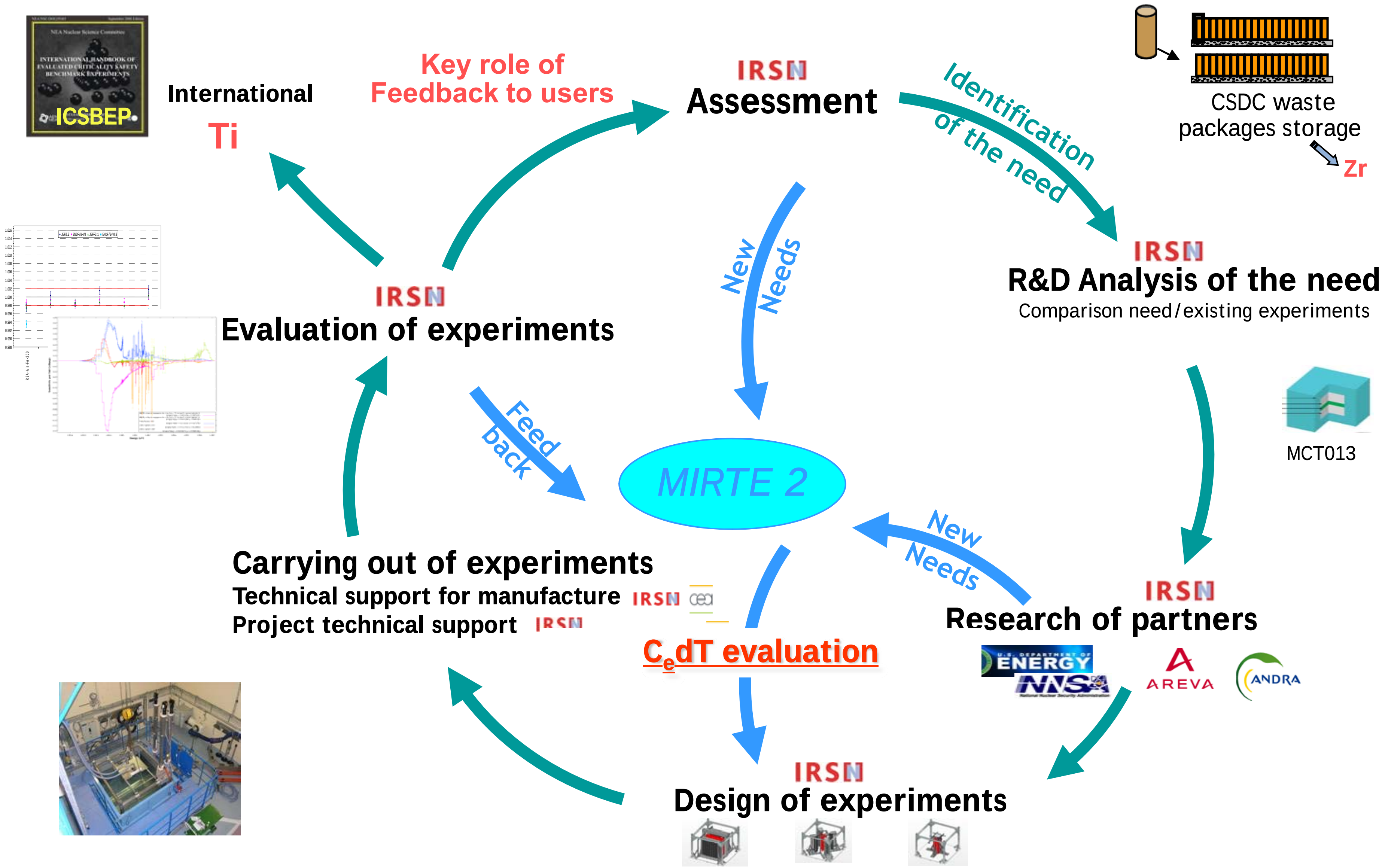


Interaction – thin plates

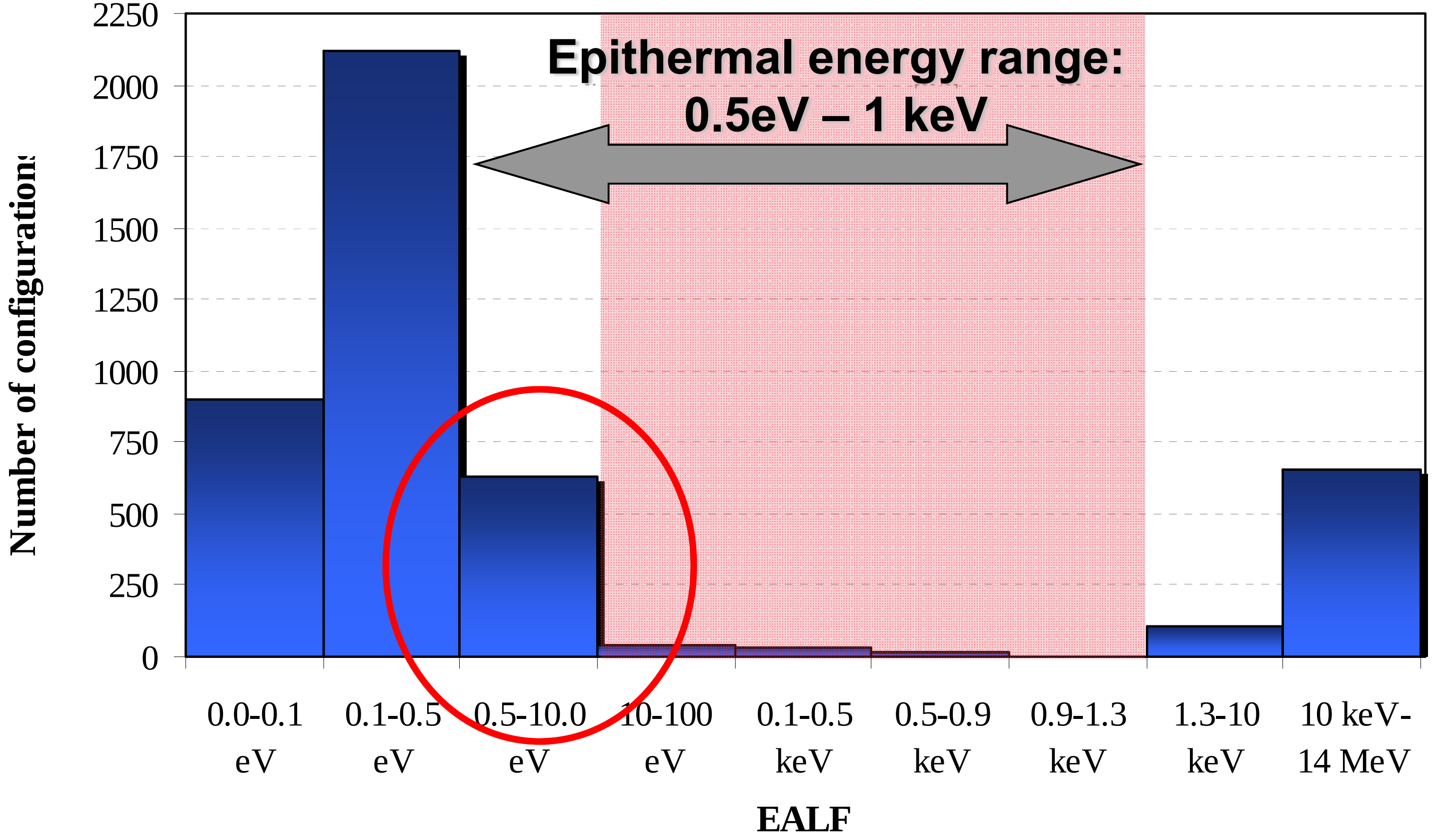


Interaction - large screens

MIRTE 1 program

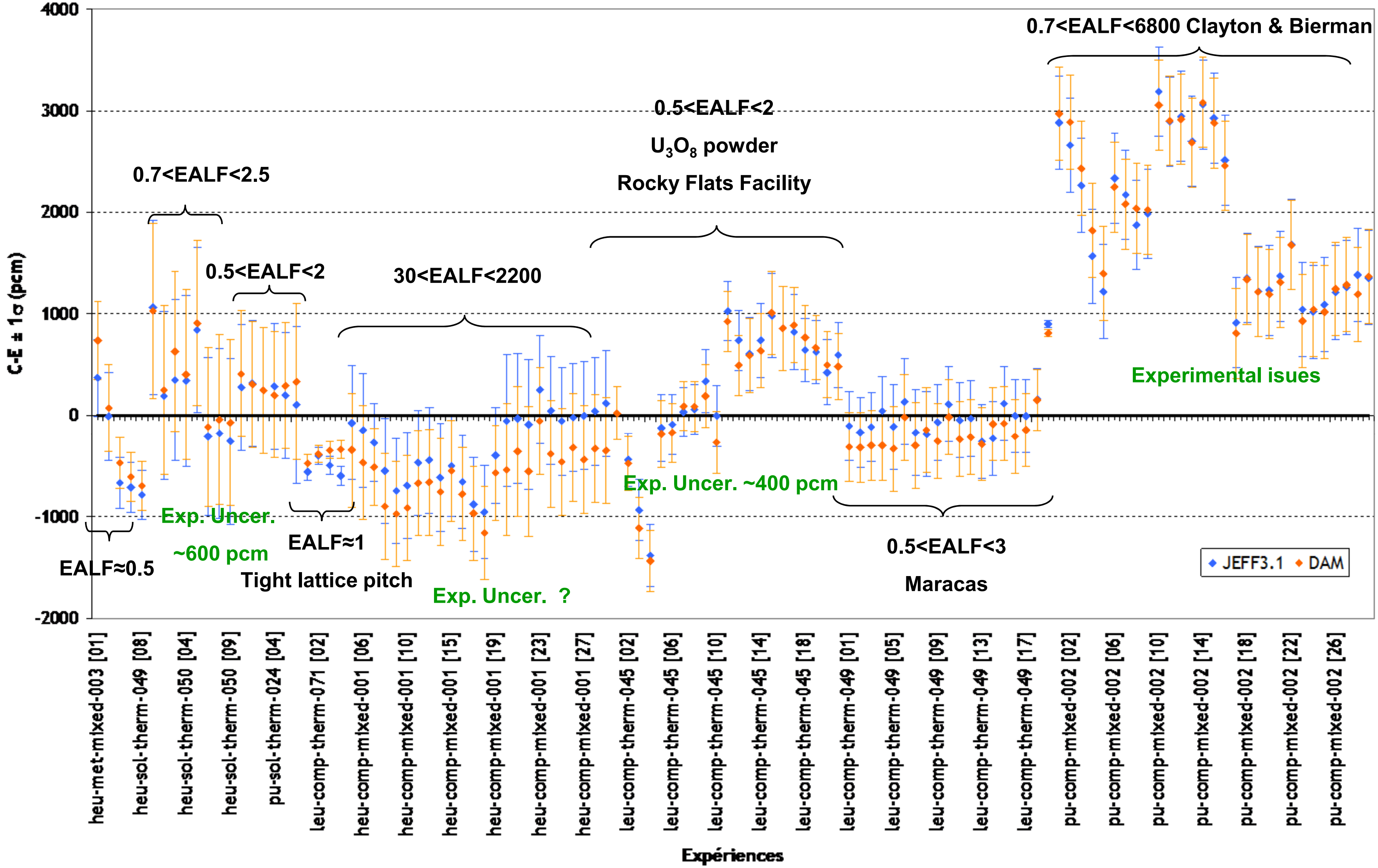


Need: ICSBEP Handbook Data



*EALF data presented in the ICSBEP Handbook DVD 2010 (DICE)

Criticality validation Database – JEFF feedback



Conclusion

- Epithermal data needs through Criticality Assessment feedback

- Extension of the structural materials needs in the epithermal energy range

- Design of experiments must be consistent with the analysis methods to meet the feedback to final users in a practical form

Thanks for your attention…

Status of available experiments

Low moderated powders

- MARACAS experiments (LEU-COMP-THERM-049) - MOX powders with low H/U (2, 2.5, 3)
  - EALF: 0.899 to 2.78 eV
  - q_{4ev}: 0.34 to 0.4
- Rocky flats experiments: LEU-COMP-THERM-045 - U_3O_8 powder (H/U = 0.77)
  - EALF: 0.5 to 2.54 eV, more than 64% of fissions in thermal energy range
- Clayton & Bierman experiments (Pu, MOX)
  - PU-COMP-MIXED-001, 002 and MIX-COMP-THERM-012
  - EALF: 0.75 to 10^6 eV (Pu), 0.07 to 0.26 eV (MOX)
  - q_{4ev}: 0 to 0.53 (Pu), 0.56 to 0.65 (MOX)
    - Experimental data are weak or missing
    - High dispersion of k_{eff} results

Status of available experiments

Other experiments

- Experiments taken from ERANOS validation database
  - ↳ First sensitivity calculations confirm the need
- ERASME/S experiments (MIX-COMP-INTER-005) in EOLE reactor:
  - ↳ 11% PuO_2, $V_{mod}/V_{ox} = 0.5$,
  - ↳ EALF: 180 eV, 54.2% of fissions between 0.625 eV and 100 keV
- BFS experiments (Pu content: 10-22%), Russia
  - ↳ H_2O content: 0 to 3.4%
  - ↳ EALF: 1880 to 5960 eV
  - ↳ 42.8% of fission between 0.625 eV and 100 keV

↳ Except BFS experiments, no quality experiments in the epithermal energy range

Terminology

Energy ranges

Thermal: 0.025eV - 0.5eV

Epithermal : 0.5eV - 1keV

Intermediate: 1keV – 0.5MeV

Fast: 0.5MeV – 50MeV

EALF (Definition derived from DICE Glossary)

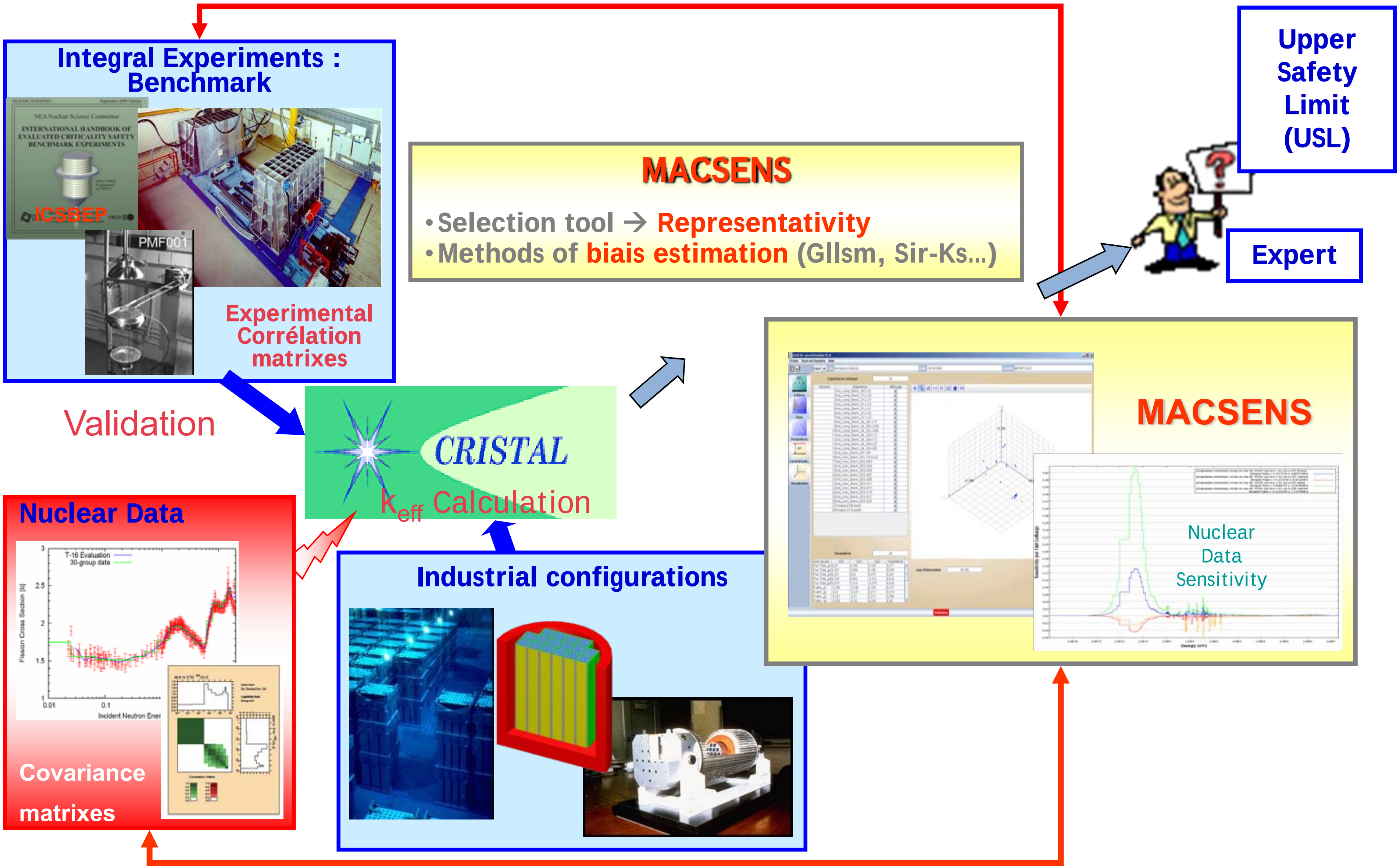
The energy corresponding to the average neutron lethargy causing fission, *EALF (eV)*, defined by:

$$EALF = \frac{E_0}{e^{\bar{u}_g}}$$

where $\bar{u}_g$ is the midpoint of the g^{th} lethargy group; E_0 indicates maximum neutron energy, in this case, 10 MeV.

Sensitivity coefficients

VALIDATION AND ESTIMATION OF BIAIS



IRSN

Experimental plan programme (10-year plan)	Identified needs	
	Engineering justification	Basic Physics/Validation
Mixed U and Pu solutions having molarities as a function of temperature	**Innovative reprocessing & CAAS qualifications & Operator training**	**Kinetic parameters& Cross-section & S(α, β) data validation**
U and Pu solutions with working fluid type constituents in matrix: experiments to assess an impact of each of the following components in the solution matrix: H, Li, Be, C, O, N, F, Na, Cl, K, Zr	**Innovative reprocessing**	**Cross-section validation**
U and Pu solution systems with Np, Am, Cm	**Innovative reprocessing**	**Cross-section & Kinetic parameters & Doppler coefficient validation**
U and Pu solution systems with key FP	**Innovative reprocessing**	**Cross-section & Kinetic parameters validation**
Experiments with new fissile matrices (UPuC, UN, and others)	**Fuel manufacturing & transport & storage & reprocessing**	**Cross-section validation**
Experiments with fuel rods having variable content of Pu in MOX, high enriched fuel, and minor actinides in fuel	**Fuel manufacturing & transport & storage & reprocessing**	**Cross-section & Kinetic parameters & Doppler coefficient validation**