AMMON: An experimental program in the EOLE critical facility for the validation of the JHR Neutron and Photon HORUS3D calculation scheme

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The EOLE critical facility of the CEA/Cadarache

Critical facility dedicated to the neutronic studies of water moderated lattices, such as PWR or BWR cores

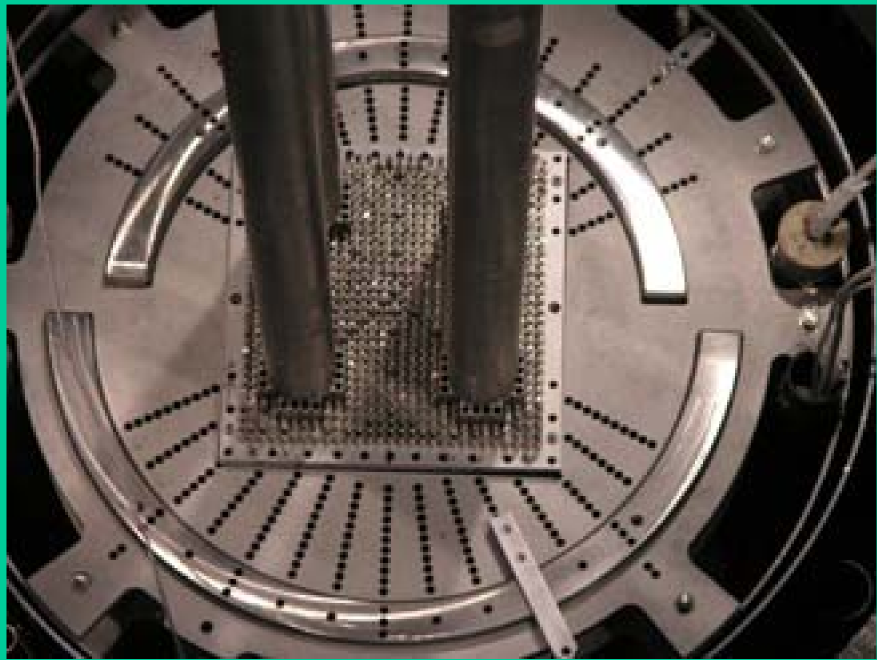
(First criticality 1965)

- Water reactor composed of a cylindrical vessel with an over structure of stainless steel able to contain various types of cores and associated structures.

- Water circuit designed to control the volume, the boron content and the temperature of the moderator.

- Four safety rods and one pilot rod, with different possible designs

- A set of grids allows the insertion of UOx and MOX pins



FLUOLE configuration : *Analysis of the PWR core-reflector boundaries and vessel fluence estimations*

The motivations of the AMMON experimental program

- Specificities of the JHR reactor for the qualification of the calculation scheme:
  - New type of fuel => U_3Si_2 ($\varepsilon \geq 20\%$)… and future UMo/Al ($\varepsilon = 20\%$)
  - New materials : Al in high proportion, Be, Hf
  - Innovative sub-assembly and control rod geometries
  - Irregular core lattice

- The current uncertainties of the calculation scheme for the JHR reactor are based on :
  - **Over-estimated** uncertainties, coming from the elementary qualification and propagation studies
  - **Safety margins** linked to the representativeness of non specific experiments

- A specific qualification is required in order to :
  - **Consolidate and reduce** these over-estimated uncertainties
  - Obtain **validated uncertainties** coming from measurements
  - Eliminate **the supplementary margins** for the representativeness aspects

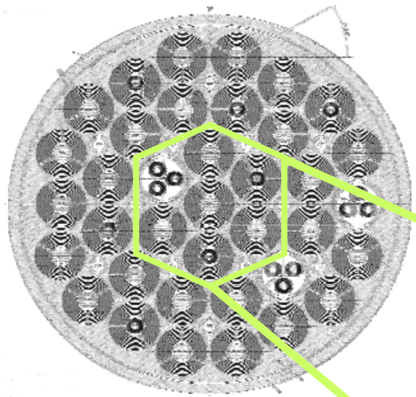
- Safety approach
  - The JHR is an innovative reactor and **few representative measurements exist**
    - Requirement for demonstrating the uncertainties taken into account for the JHR design
  - The calculation schemes are based on new models

- Possibilities of qualifications in EOLE >> possible measurements in the JHR reactor
  - Well known and controlled environment, accessibility, dedicated instrumentation, flexibility

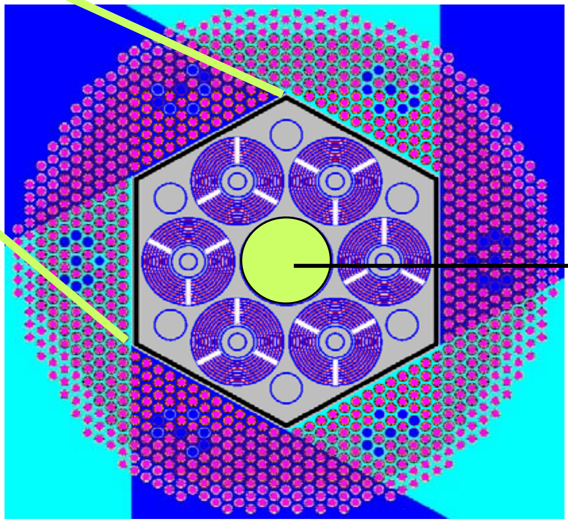
Objectives for the uncertainties of the program

Parameters	Current uncertainties (2σ)	Objectives (2σ)
Reactivity	*±1.6 $*	*±0.6 $*
Power peak	*±8%*	*De ±2 à ± 5%*
Flux	*±20%*	*De ±5 à ± 10%*
Absorbers weight	*±8%*	*±5%*
Exp. devices weight	*±10%*	Depends on the device
Gamma Heating	*±30%*	*<±20%*
Moderator coefficient	5^{E-3} *$/°C*	2.5^{E-3} *to* 4^{E-3} *$/°C*
Kinetics parameters	*Non evaluated*	*±10%*

The AMMON design in EOLE

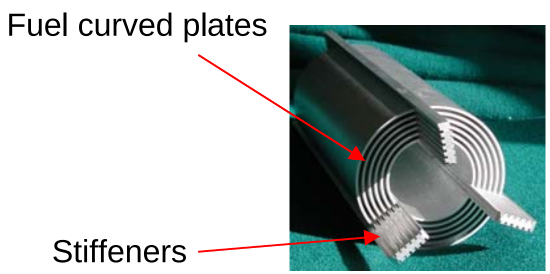


- **JHR :**
  - Core made of Macro-Hexagons

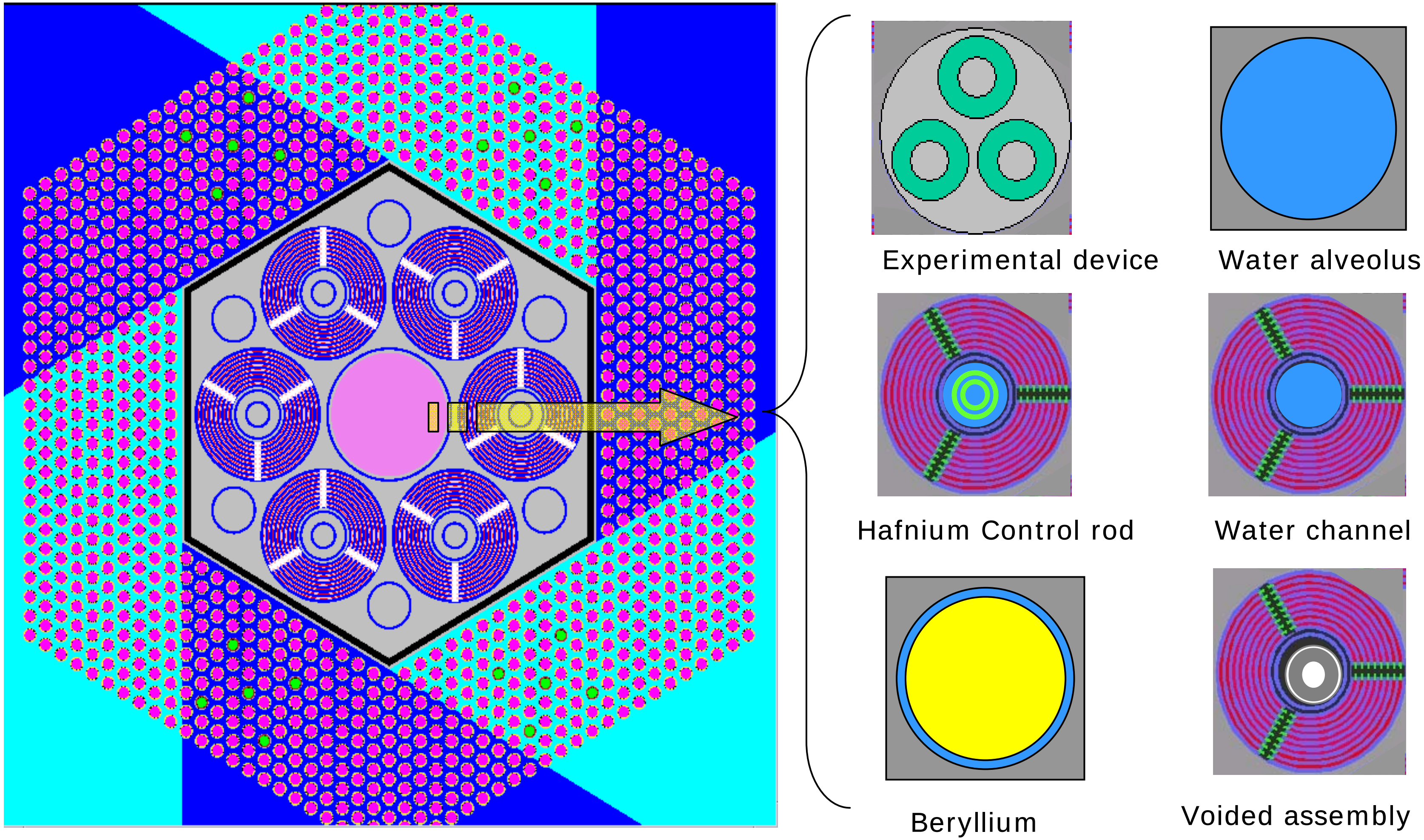


- **AMMON in EOLE :**
  - 1 Macro-Hexagon
  - Driver zone

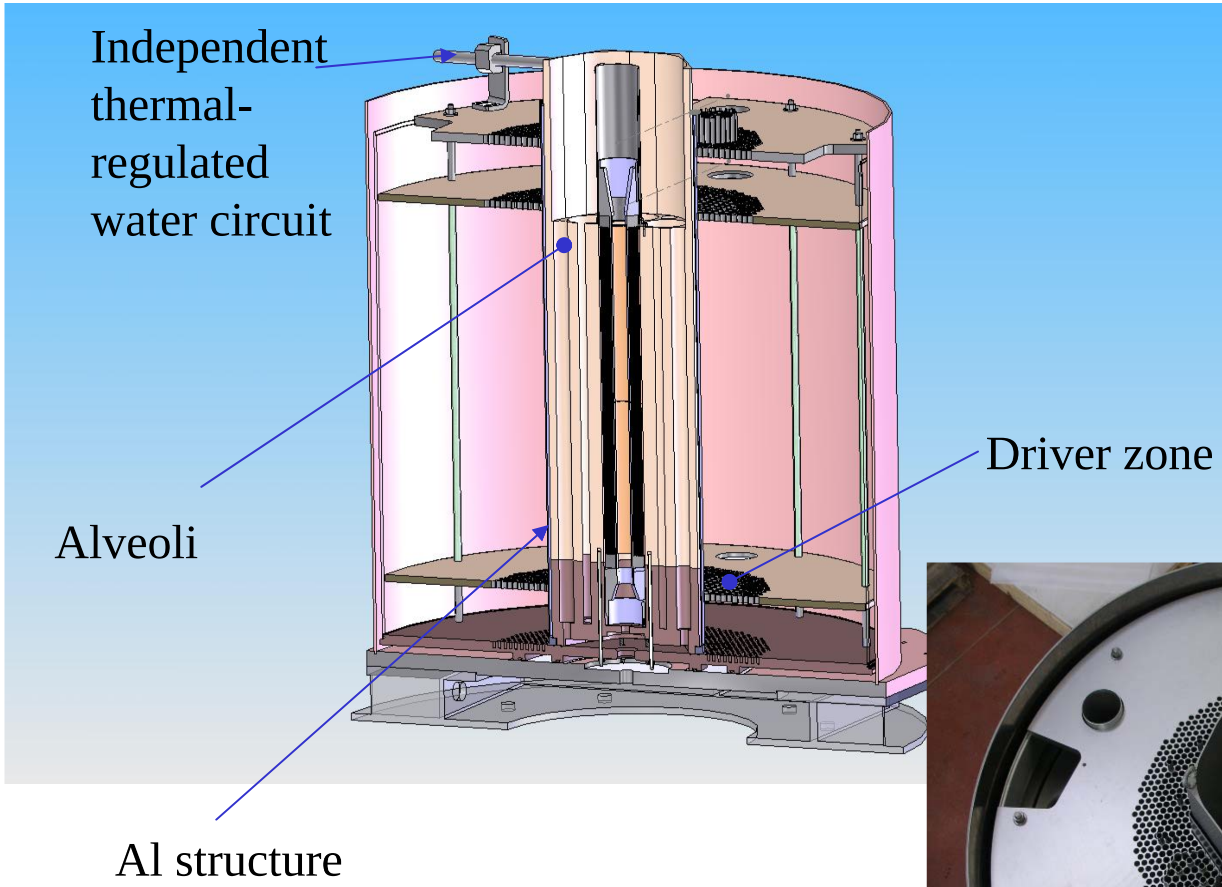
- ***Characteristics :***
  - Central experimental zone : aluminium block with seven alveoli containing the JHR assemblies
  - Driver zone : 500 to 900 UO_2 pins (e=3.7 %)
  - Two independent water regulation circuits

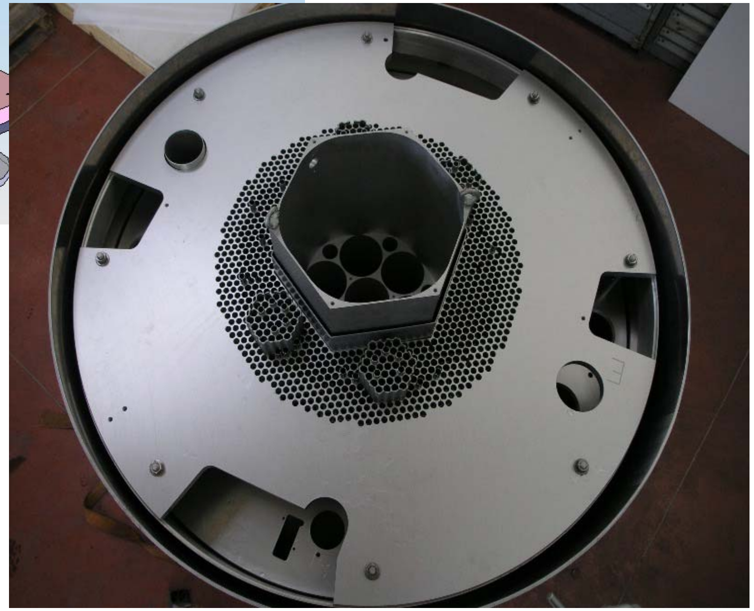


The AMMON alternative configurations



The basis of the AMMON design





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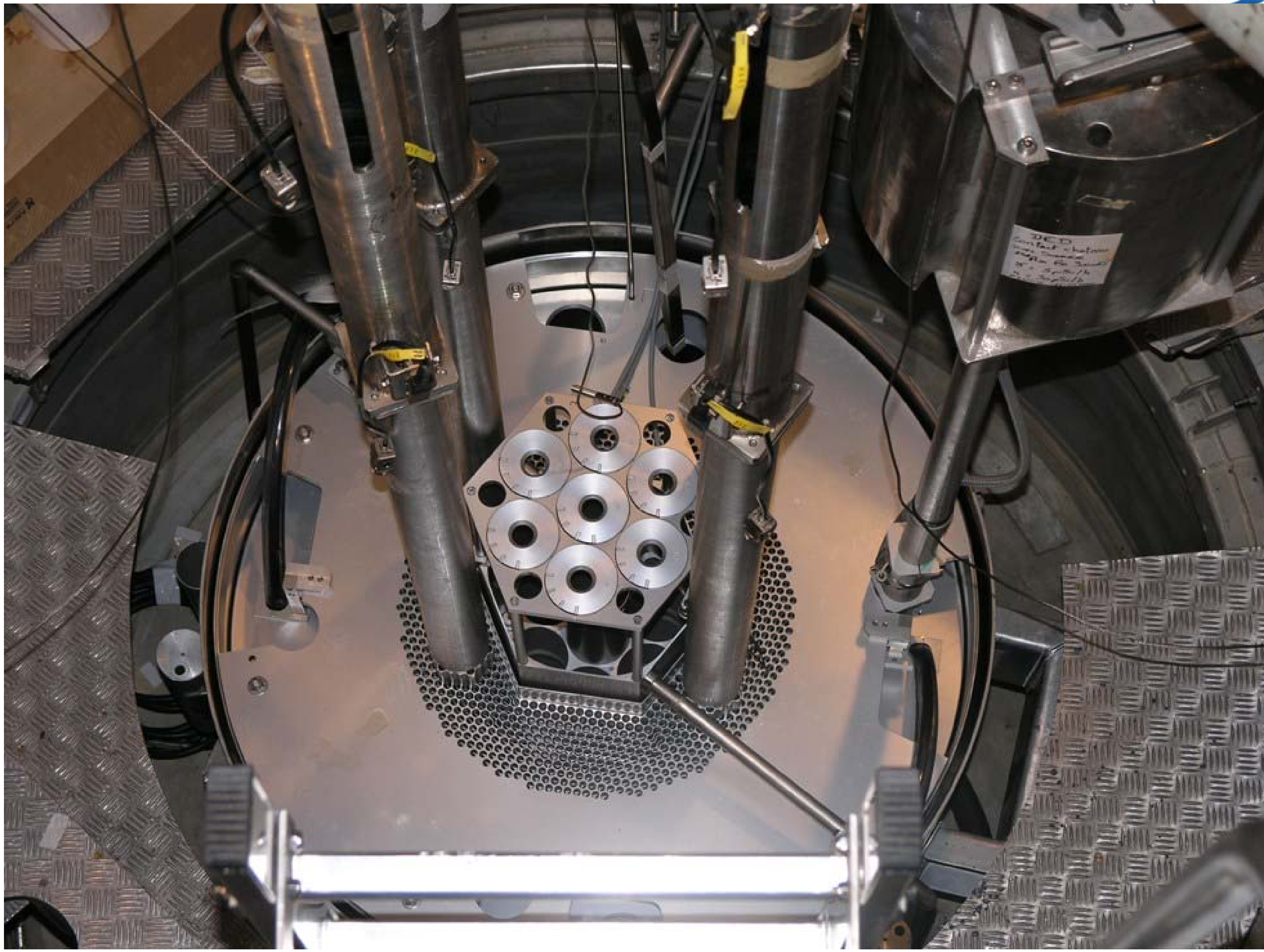


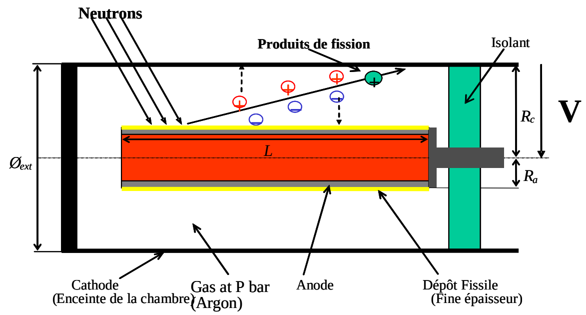
Measurements and associated uncertainties (1/4)

Parameters	Type of measurements	Uncertainty (2σ)	
Reactivity	Doubling time	10 pcm	
Reactivity	ASM subcritical method (All the configurations)	4%	**Reactivity weights absorbers, exp. device**
Spectral indices	Fission U-238/Fission U-235	10%	Flux
	Fission Pu-239/Fission U-235	6%	
	Fission Np-237/Fission U-235	6%	
Neutron Flux	Fission Chambers	4%	Flux
Temperature coefficient	ASM subcritical method	5%	Experimental Zone Steps of 20°C (20° to 80°C)

In-core measurements using **miniature fission chambers** (Ø 4, 8 mm), put in the center of the JHR assemblies and in various positions of the driver zone.

•CEA/Cadarache has been developing the miniature fission chambers technology for more than 40 years :

- ∅ 1.5 mm, 4 mm and ∅ 8 mm for critical mock-up (CEA, ENEA, JAERI,…) :
  - Various fissile materials :
    Th, Np-237, Am-241, U isotopes, Pu isotopes
- ∅ 4.7 mm for "in-core" neutron flux measurements

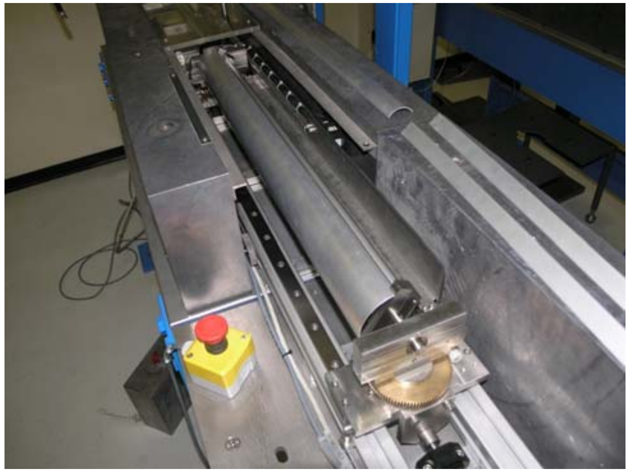


Measurements and associated uncertainties (2/4)

Parameters	Type of measurements	Uncertainty (2σ)	
Conversion ratio	Capture U-238/Total Fission	4%	Burn up performances
Distribution of total fission rates (power)	γ-scanning (All the configurations)	2%	**Power peak** Azimuthally, axially, total / plate total / assembly
Axial buckling	Total Fission (spectro γ)	1.50%	Leakage

Gamma spectrometry used to measure the **fission rates** arising in the fuel pins and assemblies:

- ***the integral γ-scanning technique***, used for axial and radial fission rate distributions of the JHR assemblies and UO_2 fuel pins
- ***the particular peak check measurement***, used to “renormalize” these integral distributions for the two types of fuel



1 assembly with removable plates

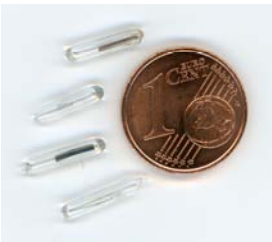
Measurements and associated uncertainties (3/4)

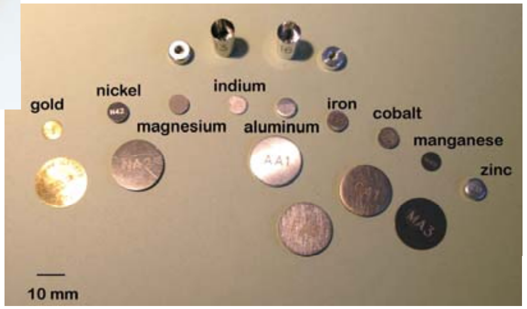
Parameters	Type of measurements	Uncertainty (2σ)	
Neutron Flux	Dosimeters	4%	Flux
Axial Distribution	Dosimeters (Au)	2%	

Dosimeters

- Determination of the neutron distribution as a function of the energy by irradiating:
  - activation wires between with the fuel removable plates
  - activation disks in the center of the JHR assemblies and in various positions of the driver zone

- Measurement of the gamma emitters in the **MADERE platform** – presented in this conference





Measurements and associated uncertainties (4/4)

Parameters	Type of measurements	Uncertainty (2σ)	
Total γ heating *(Dose γ)*	TLD (Al block, Hf, exp. device)	15%	Γ heating

Thermoluminescent detectors

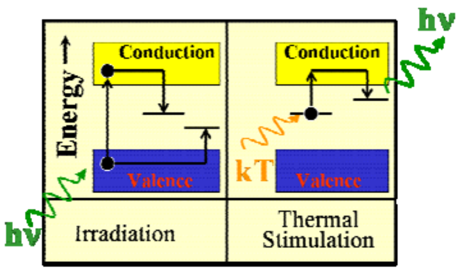
– Objective: measure the heating in a material of interest

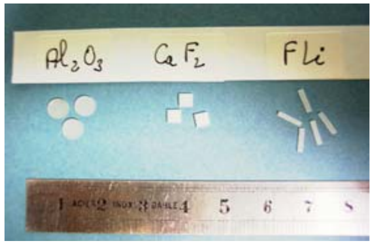
⇒ Needs a detector which will integrate the energy of the particles (or the dose)

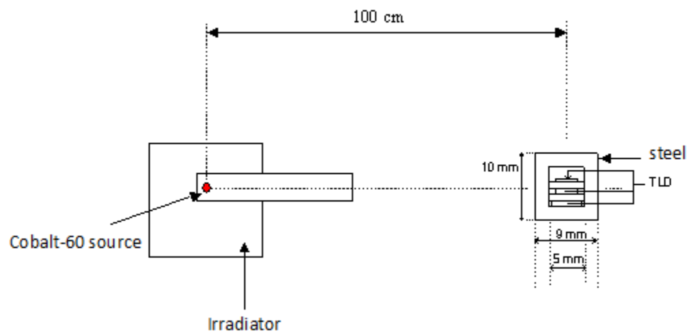
– Irradiation of thermoluminescent detectors (TLD) => integrated dose in the material

– The absolute dose is obtained after a calibration step of the TLDs (calibrated source):
the TLD response is proportional to the dose received

– In order to be representative, the TLD are put in specific boxes, designed for the program (Hafnium and Beryllium boxes)







Conclusions

- AMMON experimental program: carried out in the EOLE facility to provide experimental results for the validation of the Jules Horowitz Reactor HORUS3D neutronics and photonics calculation scheme.

- Design of the program based on a core composed of an experimental central zone with 7 JHR assemblies and an outer driver zone made of standard UO2 PWR pins.

- Several configurations representative of the JHR core in normal operation or accidental situations : successive insertions of a Hafnium control rod, a Beryllium block, an experimental device, a water hole and the voiding of a JHR assembly.

- The flexibility of the EOLE critical facility has allowed the design of this very innovative experimental program:
  - use of *new type of fuel* (JHR assemblies with U_3Si_2 fuel curved plates),
  - modifications of the gamma-scanning devices for measuring curved plates,
  - modification of EOLE to receive a second independent water circuit.

- Large number of measurements planned, using different experimental techniques: characterization of global and local physical parameters => reactivity worth, fine power distributions, spectral indices, gamma heating and temperature coefficient.