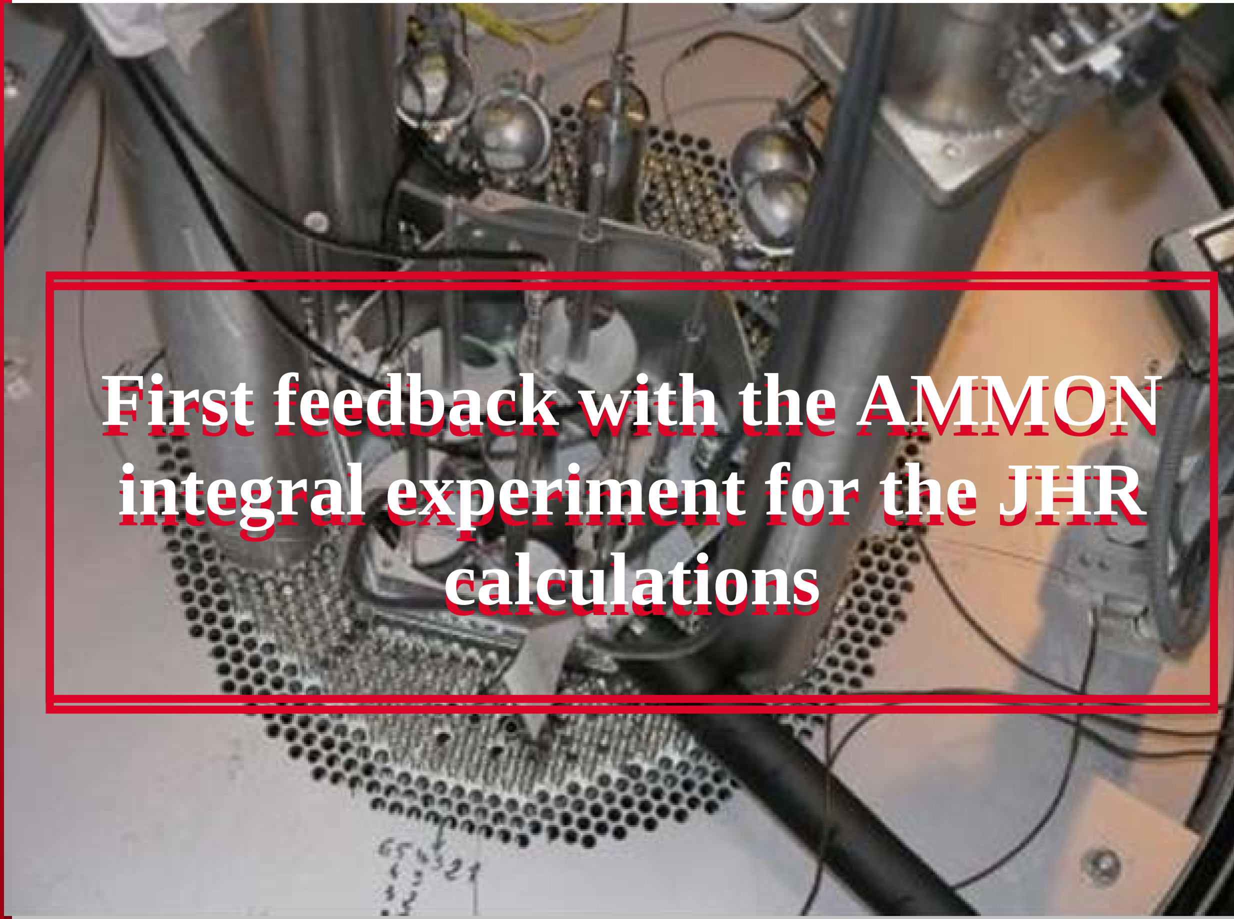
DE LA RECHERCHE À L'INDUSTRIE



First feedback with the AMMON integral experiment for the JHR calculations

C. Vaglio-Gaudard, O. Leray, A.C. Colombier, J.P. Hudelot, M. Lemaire

CEA, DEN, DER/SPRC/LPN CADARACHE

Wonder 2012, Aix-en-Provence, September 27, 2012

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3. Analysis of the AMMON experiment:
   - Reduction of the a priori uncertainty due to ND on JHR calculated reactivity
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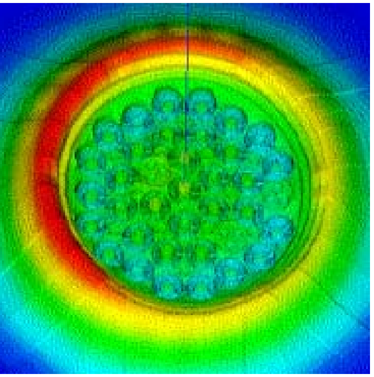
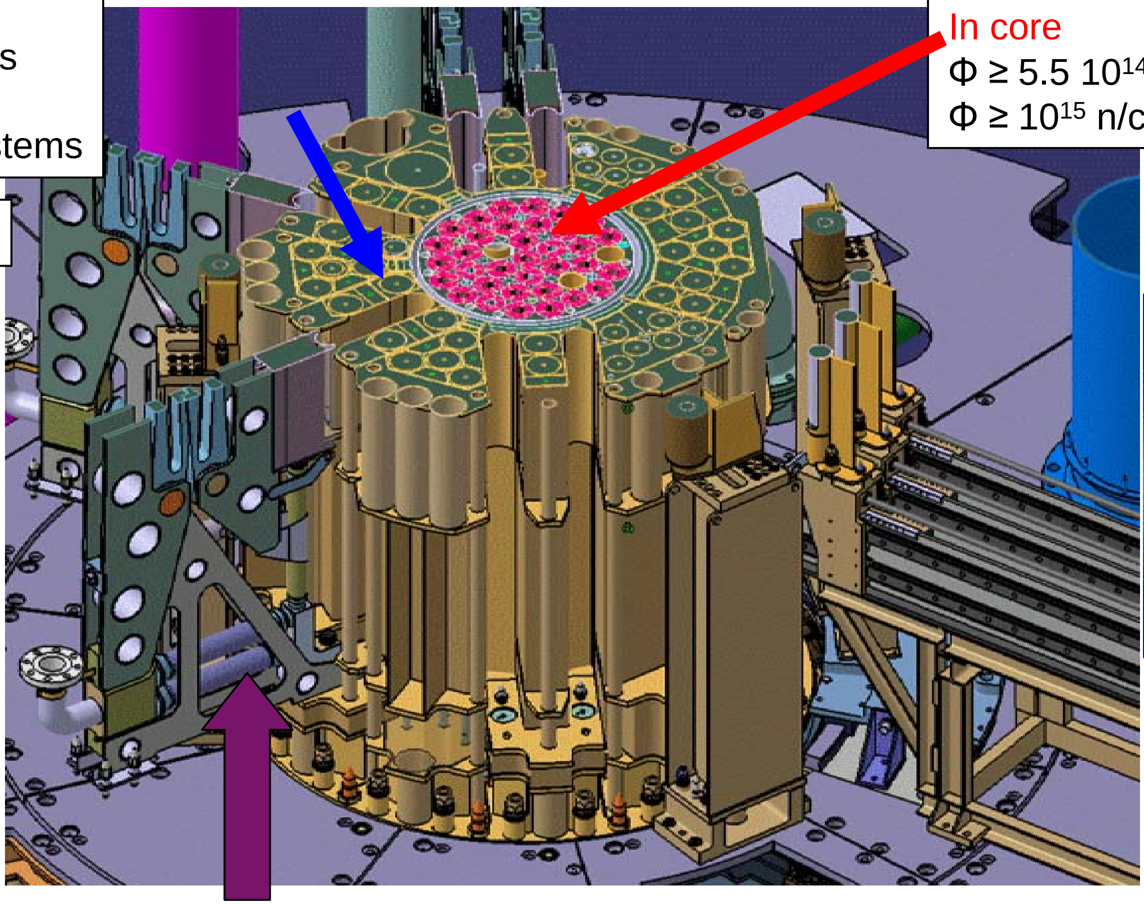
A NEW MTR UNDER CONSTRUCTION: JHR

About 20 experiments at the same time

In reflector
Φ ≥ 5.5 10^{14} n/cm².s
20 fixed positions
6 displacement systems

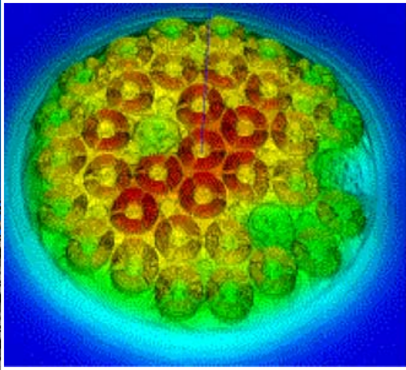
Thermal neutron flux

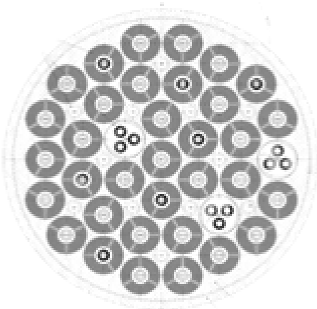




In core
Φ ≥ 5.5 10^{14} n/cm².s > 1 MeV
Φ ≥ 10^{15} n/cm².s > 0.1 MeV

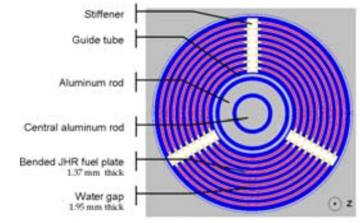
Fast neutron flux





Displacement system :
→Adjustment of power
→Power transient studies

70 MWth / 100 MWth
Cycle between 25 and 30 days
6-7 days between cycles



SOME JHR SPECIFICITIES

- LWR with a spectrum harder than a « standard » PWR/BWR
- Fuel: U_3Si_2 –Al with e% $^{235}U \geq 20\%$
- A high power density
- Presence of specific isotopes: ^{27}Al (fuel matrix, cladding, rack, structure,…)
  ^{9}Be (reflector)
  Hf (control rods)

Example: A priori ND uncertainty propagation on reactivity (BOL) in pcm

	JHR
^{235}U	342
^{238}U	122
H_2O	194
^{27}Al	402
^{9}Be	59
Total	637

NEEDS OF INTEGRAL VALIDATION

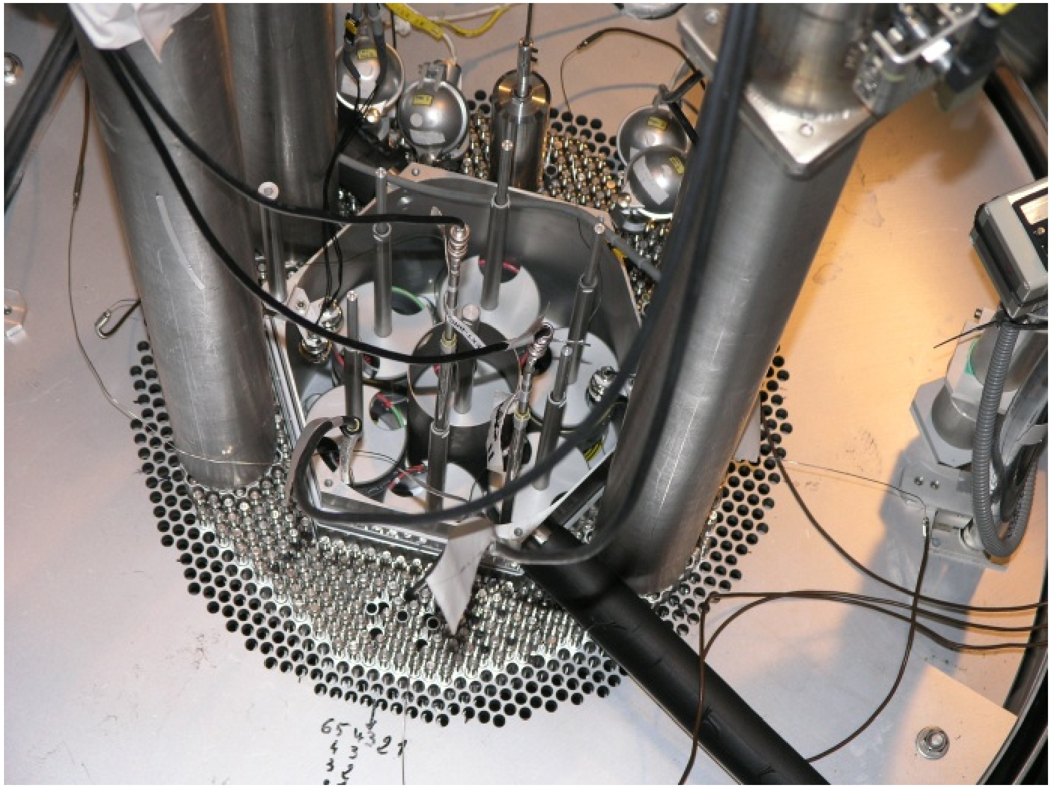
The accuracy of ^{27}Al, ^{9}Be, Hf ND has a direct impact on the accuracy of the calculations of JHR safety and performance parameters (n and γ):

- Few feedback on ^{27}Al ND => important for reactivity calculation

- Few feedback on ^{9}Be ND => important for the calculation of the plate power close to the reflector, radial macroscopic flux shape in the core, neutron flux levels and γ heating in the reflector

- Existing feedback on Hf ND for rod efficiency calculation (French experimental programs in EOLE and AZUR) => extension of the validation field for JHR (harder neutron spectrum)
  Few feedback on Hf ND for γ heating calculation

AMMON EXPERIMENT IN THE EOLE FACILITY

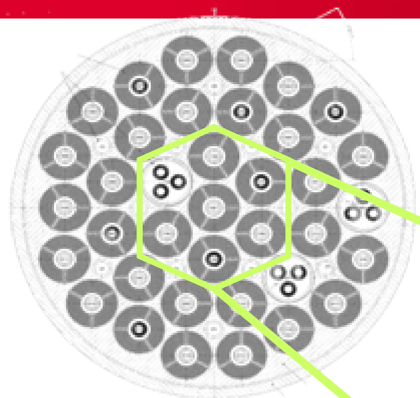


Aims of the AMMON experiment:

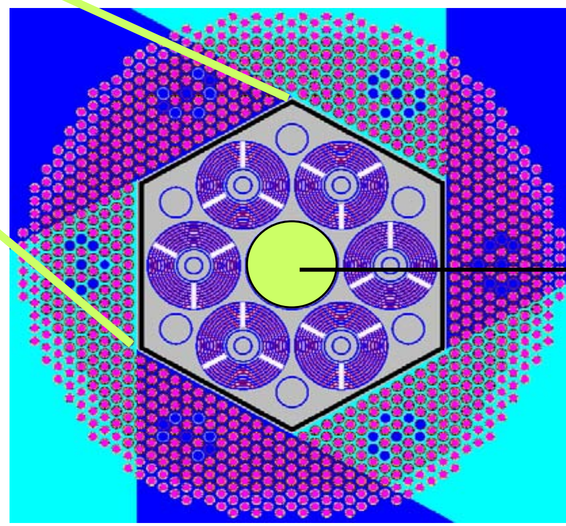
> **Determination of the global calculation bias and uncertainty associated with the JHR calculation formular on neutron / photon parameters such as reactivity, reactivity worth, power distributions, kinetics parameters, spectrum indexes, gamma-ray dose …**

> **Feedback on nuclear data for the JEFF-3.1.1 library: aluminum, beryllium, hafnium for neutron and gamma interactions**

DESCRIPTION OF THE AMMON EXPERIMENT



- **JHR :** daisy flower shaped pattern

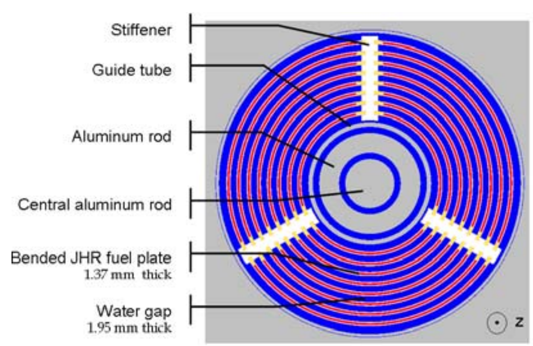


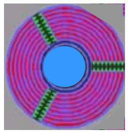
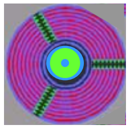
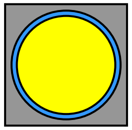
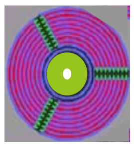
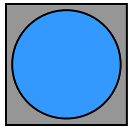
•AMMON-EOLE :

➢*Experimental zone*: aluminum rack hosting U_3Si_2-Al e=27% fuel assemblies

➢*Driver zone*: 500 to 900 UOx e=3.7% fuel pins

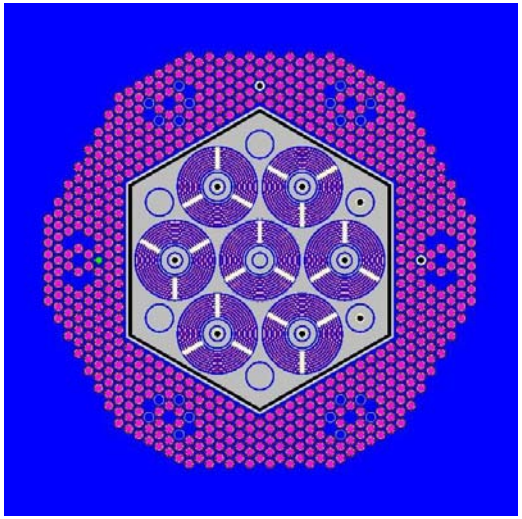
Hexagonal lattice pitch optimized in order to get the same neutron spectrum in EZ/DZ

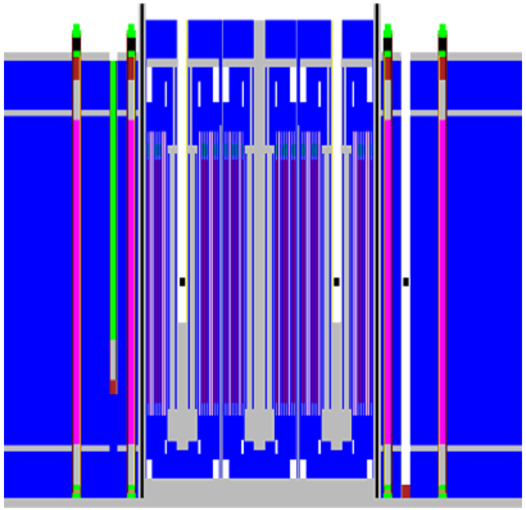


- *Configurations :*
  - Reference core : 7 JHR assemblies 
  - Ejected follower 
  - Hf rod : totally or half inserted 
  - Beryllium block 
  - Voided assembly 
  - Water cell 

ANALYSIS OF THE AMMON EXPERIMENT

- 3D reference continuous-energy calculations with the Monte Carlo TRIPOLI4 code and the JEFF3.1.1 nuclear data library (processed at room temperature)
- Modelling of the 3D-exact geometry with TRIPOLI4
- Simulation of several billions of neutron histories to reach a satisfactory statistical uncertainty





ANALYSIS OF THE RESIDUAL REACTIVITY MEASUREMENT

- Core criticality adjusted with the insertion of an automatic pilot rod
- Measurement of core reactivity with the divergence technique when the pilot rod is withdrawn

Residual reactivity

	AMMON/REF
Measurement	+184 pcm ± 9
TRIPOLI4	+560 pcm ± 3
C-E	+376 pcm ± 340

- **(C-E) value very satisfactory**
- Direct propagation of a priori nuclear data uncertainty on reactivity -> 670 pcm (1σ) uncertainty (360 pcm only comes from ^{27}Al nuclear data)

CALCULATION OF THE RESIDUAL REACTIVITY

Impact of nuclear data libraries on AMMON/REF residual reactivity calculation

	JEFF3.1.1	JEF2.2	ENDF-B/VII.0
TRIPOLI4	+560 pcm ± 3	+1015 pcm ± 3	+652 pcm ± 3

- Significant improvement (270 pcm) due to the new ^{27}Al evaluation in JEFF3
- 100 pcm overestimation when using ENDF/B-VII.0

REPRESENTATIVITY METHODOLOGY (1/3)

Objective: transposition of the bias and uncertainty from AMMON to JHR

A. *The representativity study concerning the reactivity parameter*

Dot product of sensitivity vectors S of the Reactor (R) and the Experiment (E) weighted by the nuclear data covariance matrix M

$$r_{(R,E)} = \frac{S_R^t M S_E}{\sqrt{\left(S_R^t M S_R\right)\left(S_E^t M S_E\right)}}$$

Indication of the relevancy of the Experiment to the Reactor case (for the considered neutron parameter):

For the JHR and AMMON/REF cores:

$r_{(JHR,AMMON/REF)} = 0,95$

Very good representativity (r>0,9) => the bias and uncertainties can be transposed

REPRESENTATIVITY METHODOLOGY (2/3)

B. The Calculation Bias and posterior uncertainty due to nuclear data for JHR

Neutronic weight of the experiment concerning the Reactor: (ratio between the experimental uncertainties and the ND uncertainties)

$$w = \frac{1}{1+\sigma_E^2 / \left(S_E^t M S_E\right)}$$

Bias on the Reactor calculated reactivity as a function of the bias on the Experiment calculated reactivity :

$$\left(\frac{Exp-Cal}{Cal}\right)_{Reactor} = a_E^R \left(\frac{Exp-Cal}{Cal}\right)_{Experiment}$$

With the transfer coefficient : $a_E^R = \frac{r_{(R,E)}}{1+\sigma_E^2 / \left(S_E^t M S_E\right)} \sqrt{\frac{S_R^t M S_R}{S_E^t M S_E}} = w \cdot r_{(R,E)} \cdot \frac{I_R}{I_E}$

From a AMMON/REF$_{ND}$ bias = +376 pcm (1σ), a JHR bias$_{ND}$ = +250 pcm (1σ) is expected

Reduction of the uncertainties due to Nuclear Data (depending of the representativity and the weight):

$$\alpha^2 = \frac{{I_R^*}^2}{I_R^2} = 1 - \frac{{r_{(R,E)}}^2}{1+\sigma_E^2 / \left(S_E^t M S_E\right)} = 1 - w \cdot {r_{(R,E)}}^2 = 0.24$$

From a 597pcm (1σ) prior uncertainty, the reduction gives 328 pcm (1σ) posterior uncertainty on the JHR reactivity

REPRESENTATIVITY METHODOLOGY (3/3)

Synthesis of the transposition for the reactivity parameter

$(C\text{-}E)_{AMMON/REF} = +376 \text{ pcm} \pm 340$

and

A priori uncertainty on ρ_{JHR}=+597 pcm

$\Downarrow$

$\mathbf{(C\text{-}E)_{JHR\text{-}BOL} = +250 \text{ pcm} \pm 328}$

A PRIORI ND UNCERTAINTY PROPAGATION

* Importance to have realistic covariance matrices associated with the ND library used for the calculation

* Origin of the covariance matrices:

- JEFF3.1.1 / JENDL3.3

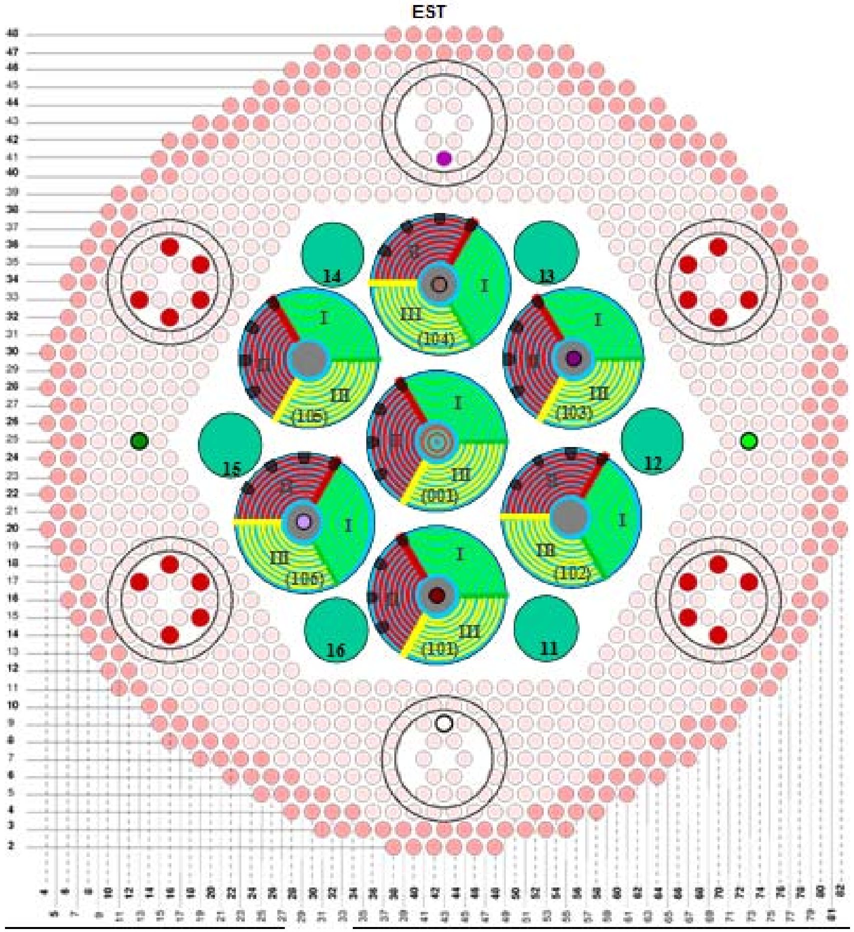
- recommandations of CEA

- determination of a new ^{27}Al covariance matrix (retroactive marginalization technique in the CONRAD code)

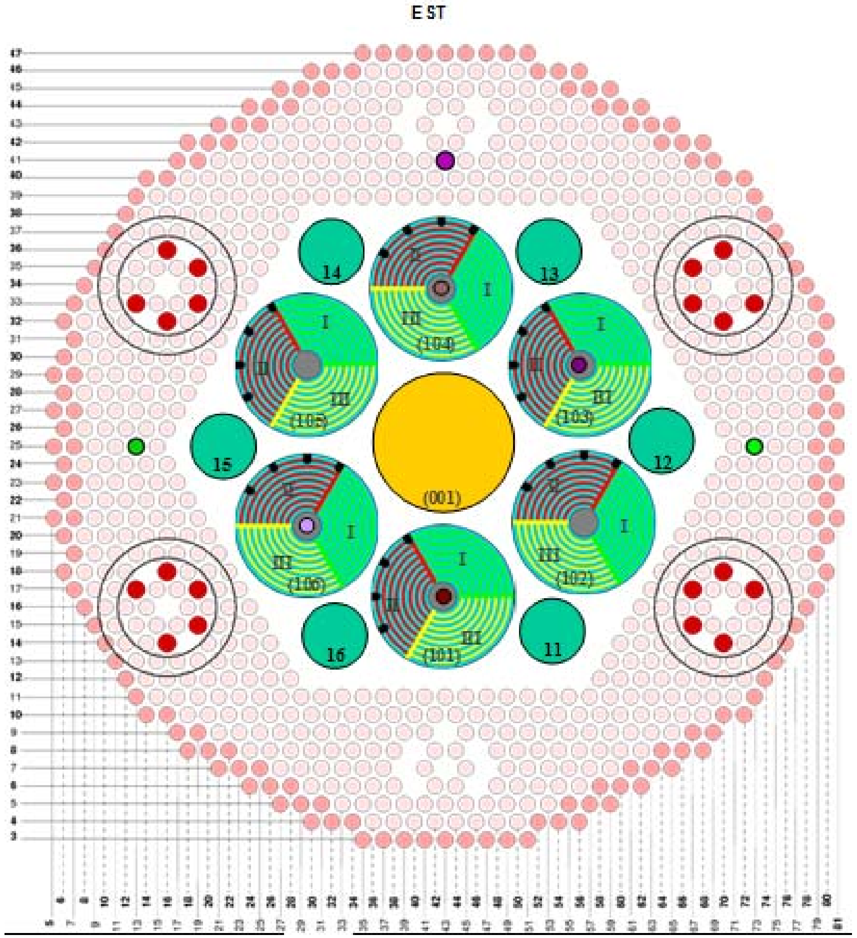
Isotope	Reaction	AMMON Keff uncertainty	JHR Keff uncertainty
^{235}U	Fission	201	133
	ν	336	270
	Capture	187	175
	Scattering	9	13
^{238}U	Fission	130	33
	ν	26	6
	Capture	156	91
	Scattering	58	42
^{27}Al	Capture	177	221
	Elastic	150	153
	Inelastic	272	224
H_2O	Capture	50	49
	Scattering	148	179
^{56}Fe	Capture	82	7
	Scattering	7	4
^{9}Be	Scattering	No Be	60
Total uncertainty (1σ)		**671 pcm**	**597 pcm**

AMMON Hf AND Be CONFIGURATIONS

A hafnium rod inserted in the central assembly



A beryllium block inserted in the rack central cell



ANALYSIS OF BIAS ON THE REATIVITY WORTH

Residual reactivity (analysis of the 3 critical states)

AMMON configuration	**REF**	**Hf**	**Be**
Measurement	+184 pcm ±9	+ 212 pcm ±11	+ 155 pcm ±8
TRIPOLI4	+560 pcm ±3	+ 573 pcm ±2	+ 521 pcm ±2
C-E	+376 pcm	+ 361pcm	+ 366 pcm

$$\frac{\delta\Delta\rho}{\Delta\rho} = \frac{(\rho_{calc}^{Hf/Be} - \rho_{calc}^{REF}) - (\rho_{mes}^{Hf/Be} - \rho_{mes}^{REF})}{\Delta\rho_{mes}}$$

Bias on the reactivity worth

AMMON configuration	**Hf**	**Be**
Experimental worth	-3356 pcm	-2526 pcm
(C-E)/E	**+0.5% ± 1.8%**	**+0.4% ± 2.0%**

- The Bias due to ND (Hf and Be) are within the uncertainty (1σ)
- Preliminary results: to be completed with sensitivity studies…

CONCLUSION/ OUTLOOK

- New measurements in progress in the EOLE facility with the AMMON experimental program => 2 goals: experimental validation of the design and safety calculation formular for JHR + elements of validation for specific ND (Al, Hf, Be)

- Transposition of the bias and uncertainty due to ND from AMMON to JHR thanks to the representatity methodology

- A priori uncertainty on the calculated JHR reactivity reduced by a 2 factor:

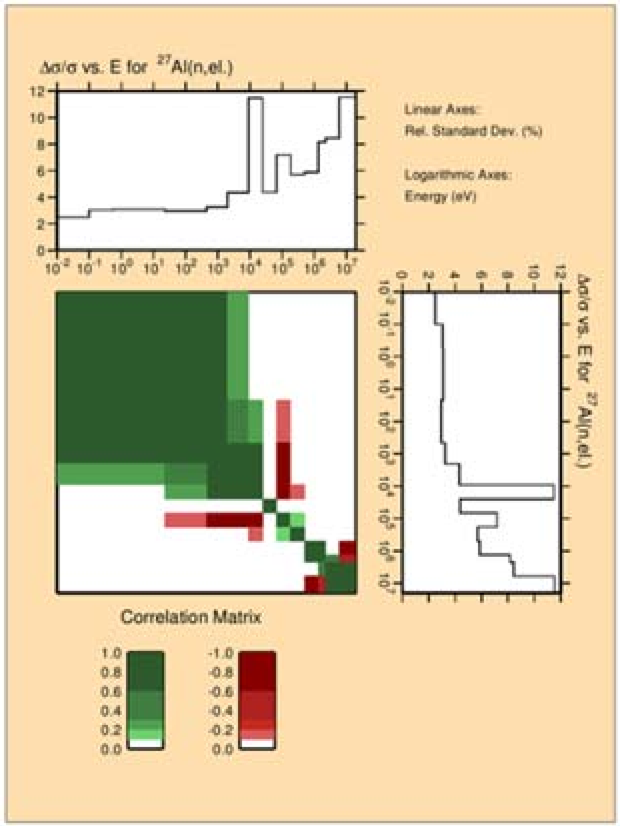
  (C-E) JHR BOL = +250 pcm ±328 (1σ)

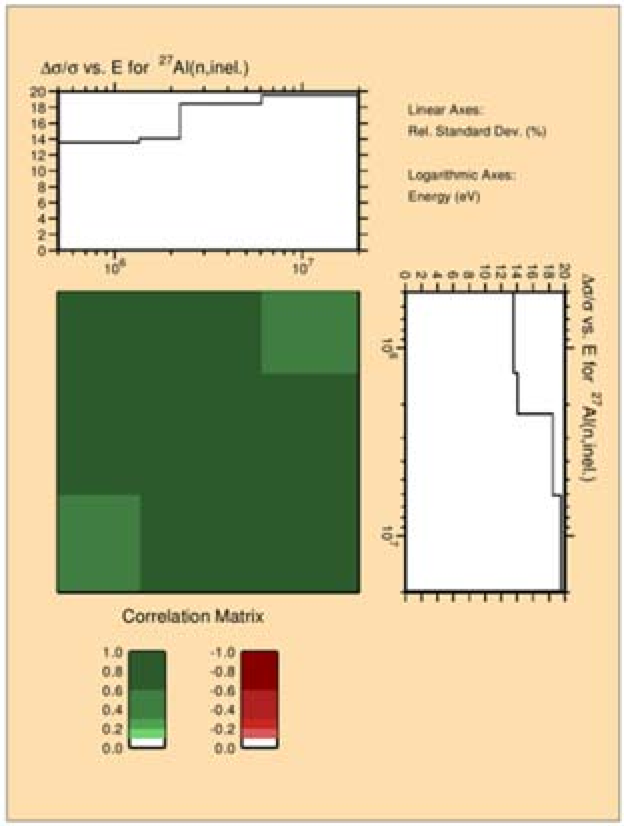
- No bias due to JEFF3.1.1 ND on Hf efficiency and Be reactivity worth

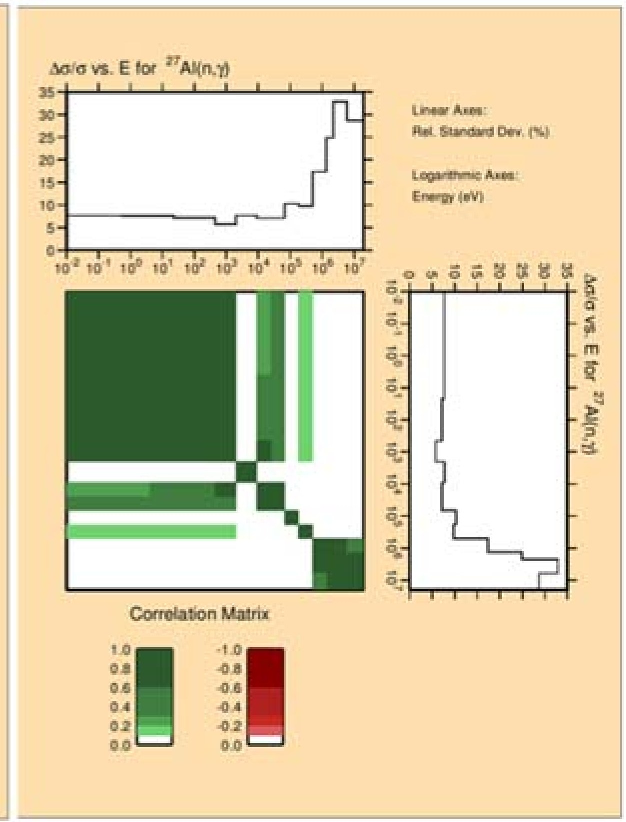
- First feedback which will be completed in the next months:
  - Neutron data: Analysis of spectral indexes with activation foils at the center of the Be block
  - Photon data: analysis of gamma heating in Al, Hf and Be

27Al NEW COVARIANCE MATRIX WITH CONRAD

Elastic cross section *Inelastic cross section* *Capture cross section*







Commissariat à l’énergie atomique et aux énergies alternatives
Centre de Saclay | 91191 Gif-sur-Yvette Cedex
T. +33 (0)1 XX XX XX XX | F. +33 (0)1 XX XX XX XX

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