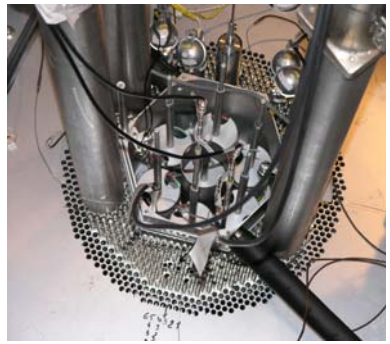
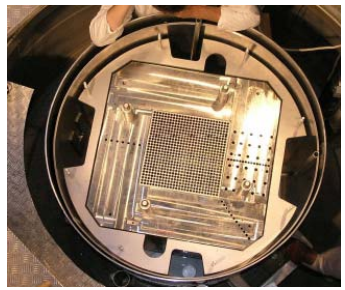
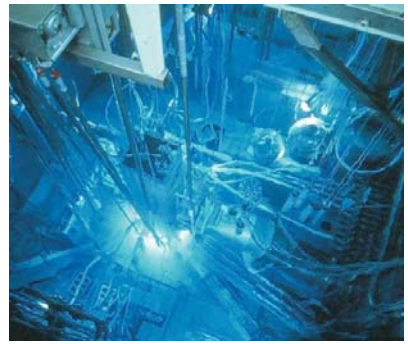
DE LA RECHERCHE À L'INDUSTRIE

NUCLEAR DATA PRODUCTION, CALCULATION AND MEASUREMENT: A GLOBAL OVERVIEW OF THE GAMMA HEATING ISSUE







WONDER-2012| A.C. Colombier, H. Amharrak, D. Fourmentel, S. Ravaux, D. Régnier, O. Gueton, J.P. Hudelot, M. Lemaire

CEA, DEN,DER, Cadarache

25-28 september 2012

www.cea.fr

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1. CONTEXT

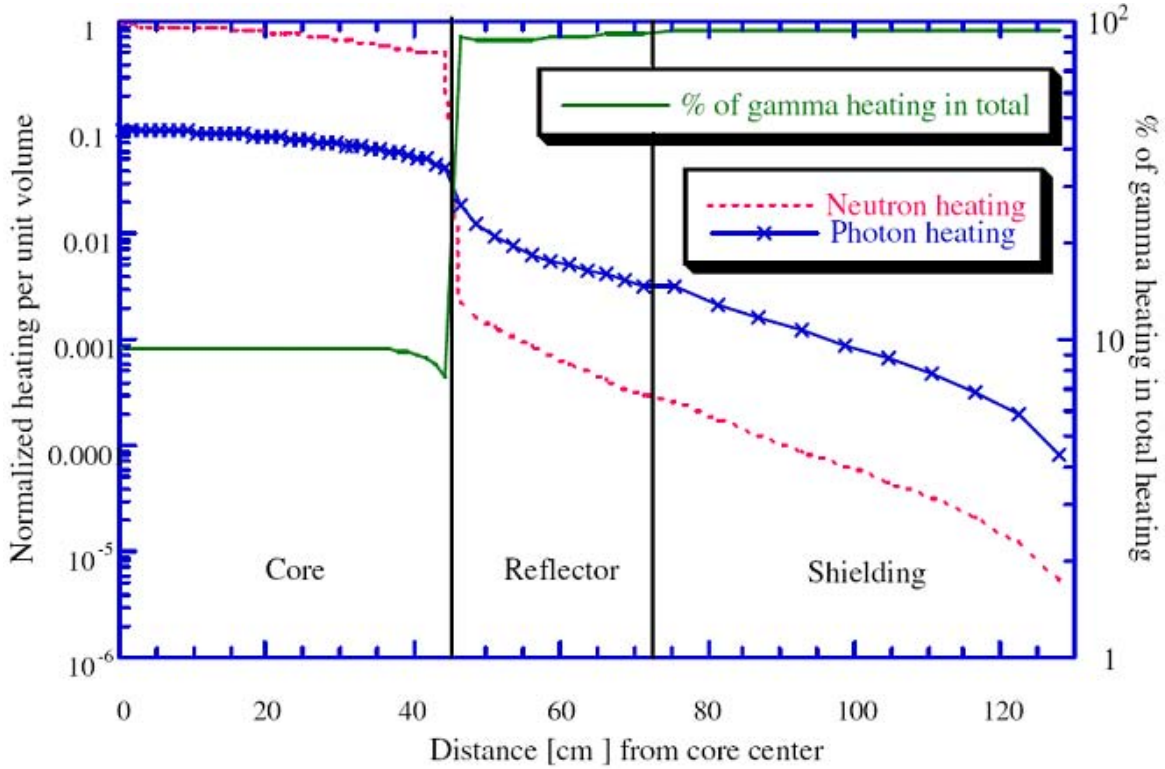
CONTEXT – Nuclear heating in power reactor

Nuclear heating

- Energy deposition :
  charged particles (α, proton, $e^{\pm}$), ions from n & γ interactions

- Photon production :
  . neutron interactions (fission, radiative capture, inelastic scattering)
  . fission products decay

- Photon interactions :
  . photoelectric effect
  . Compton scattering
  . pair production



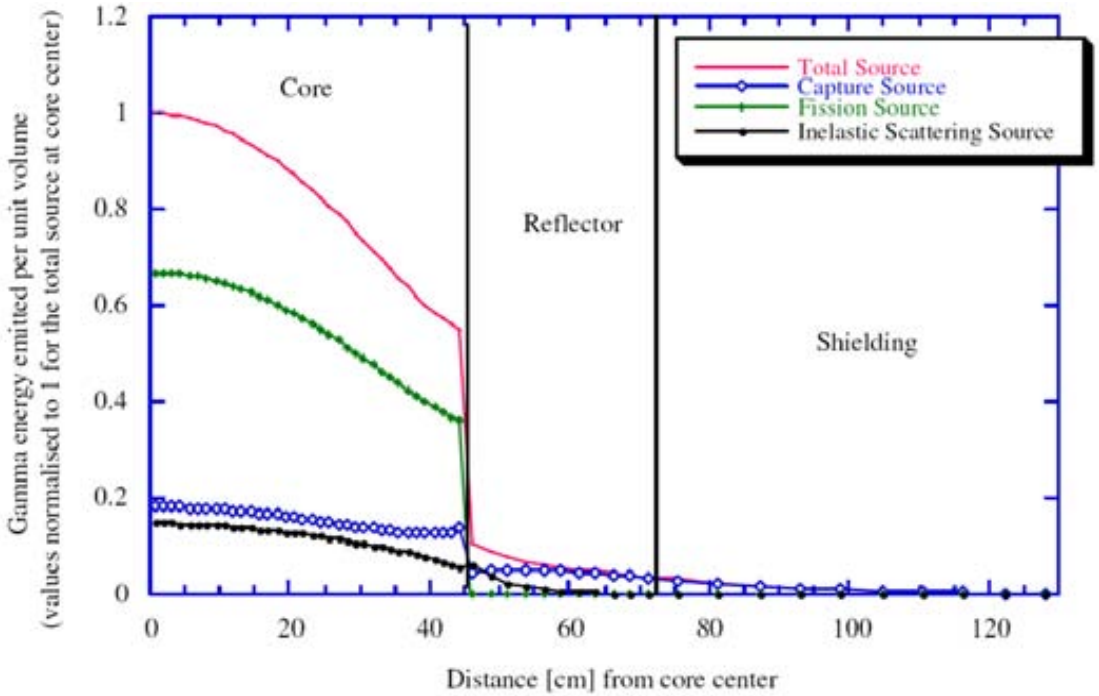
- In the core : > 90% -> neutron (local deposite)
- In the reflector : > 90% -> photon

CONTEXT – Nuclear γ heating in power reactor

Relative contribution in a fast reactor

- Fission : 70% (~ 30% delayed gamma)
- Radiative capture : about 20%
- Inelastic scattering : the rest

} Depending on the reactor material balance



CONTEXT – New reactor concepts

New concept

New design

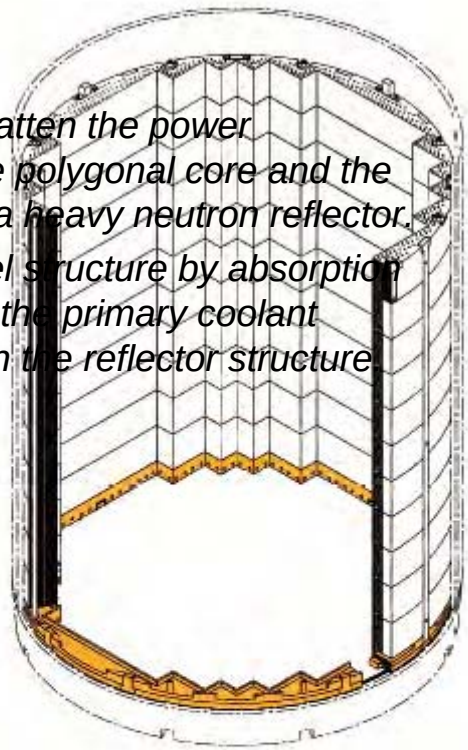
- PWR – GEN III$^+$:
  stainless steal heavy reflector
  Burnable poison (UO_2-**Gd**$_2O_3$ pins for PWR…)

- GEN IV – Fast Reactor :
  steal control rod followers and diluent

- MTR – JHR :
  Hf control rods
  Aluminium structure
  Beryllium reflector
  Cd shielding
  design of experimental devices

To reduce neutron leakages and flatten the power distribution, the space between the polygonal core and the cylindrical core barrel is filled with a heavy neutron reflector.

The heat generated inside the steel structure by absorption of gamma radiation is removed by the primary coolant through holes and gaps provided in the reflector structure.



safety

lifetime

performance

Cooling system

CONTEXT – so what ?

- Nuclear data evaluations
- Experimental measurement uncertainties
- ➔ better description & simulation

➡ **5 PhD works at**

➡ **1 collaboration : McMaster University (Canada)**

2009 : Gamma heating Working Group

2. NUCLEAR DATA PRODUCTION

NUCLEAR DATA PRODUCTION

Nuclear data library : JEFF3.1.1

- Missing data for all n interactions[1] : Gd, Cd, Ag, In, …
- Incoherent Q_γ for (n,γ)[1] : ^{54,56,57,58}Fe, ^{62}Ni
- *Old fashioned* or missing data for prompt gamma fission production[2] : ^{235}U, $^{239, 241}$Pu

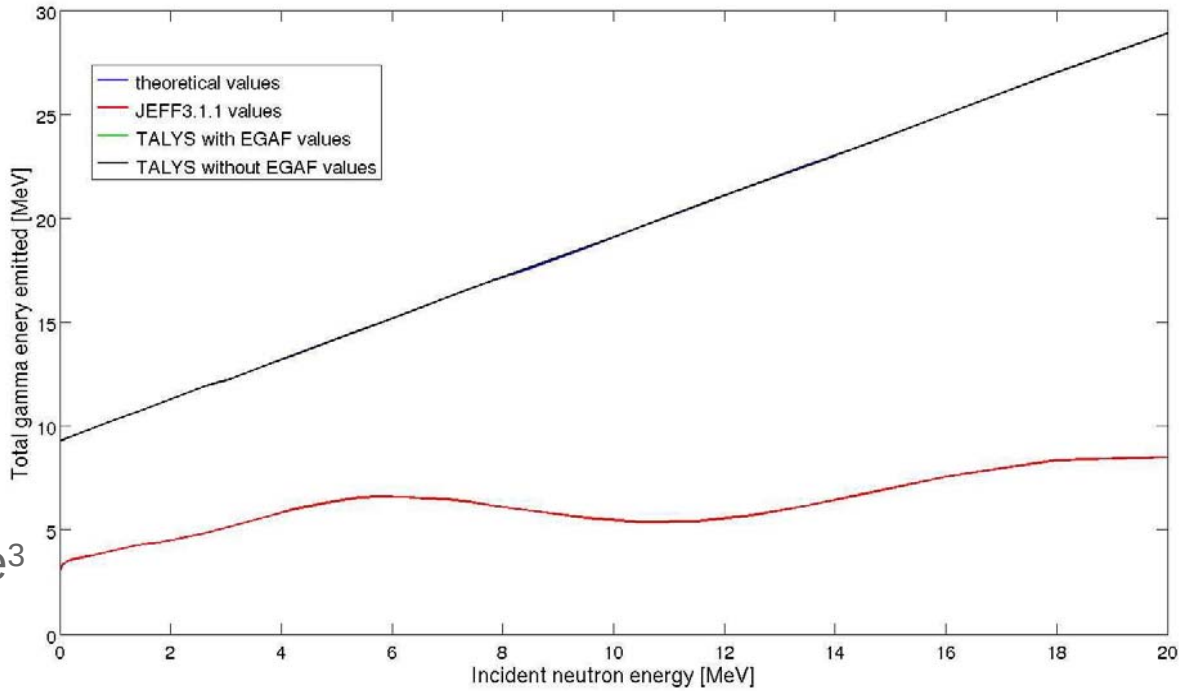
New evalutions

- (n,γ) (n,n')[1] : gamma emission spectrum
  . Discrete level : EGAF/ENSDF libraries
  . Contiunum (A>70) : nuclear reaction code TALYS (RIPL3.0 param. library)
- Monte Carlo simulation code : FIFRELIN[2]

[1] *S. Ravaux, D. Bernard, A. Santamarina, New evaluation of photon production for JEFF3, Conf. PHYTRA2, (2011)*
[2] *D. Regnier, O. Litaize, O. Serot, Monte Carlo simulation of prompt fission gamma emission, Phys. Proc. 31, 59-65, (2012)*

NUCLEAR DATA PRODUCTION : ^{54}Fe example

Integrated gamma production spectra : (n,γ) ^{54}Fe



Descrepancy > 50% !

➢ 16 stable isotopes available[3]

[3] *S. Ravaux, D. Bernard, NEA Data bank, JEFDOC-1404 (2011)*

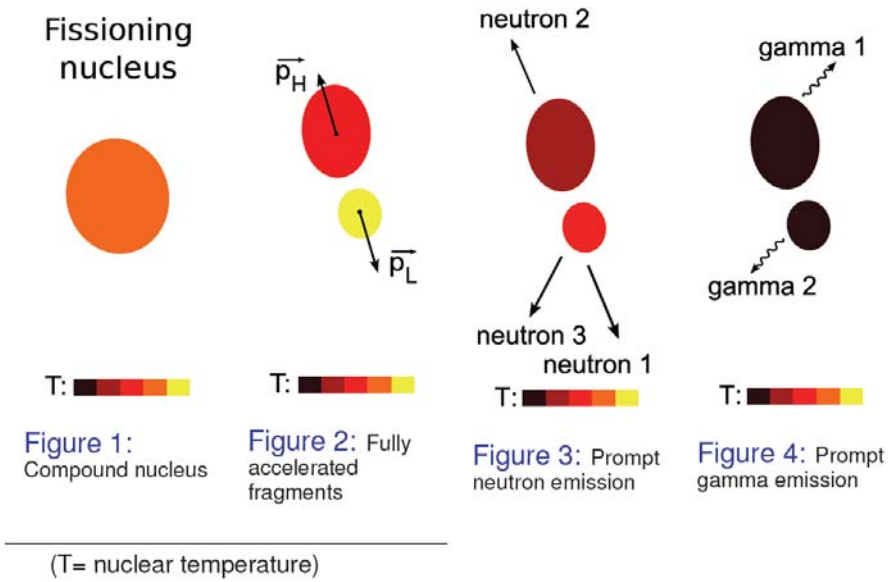
FIFRELIN: Monte Carlo simulation of fission fragments evaporation

+ new module :
de-excitation gamma cascade simulation

- density level distribution model
- strengh function

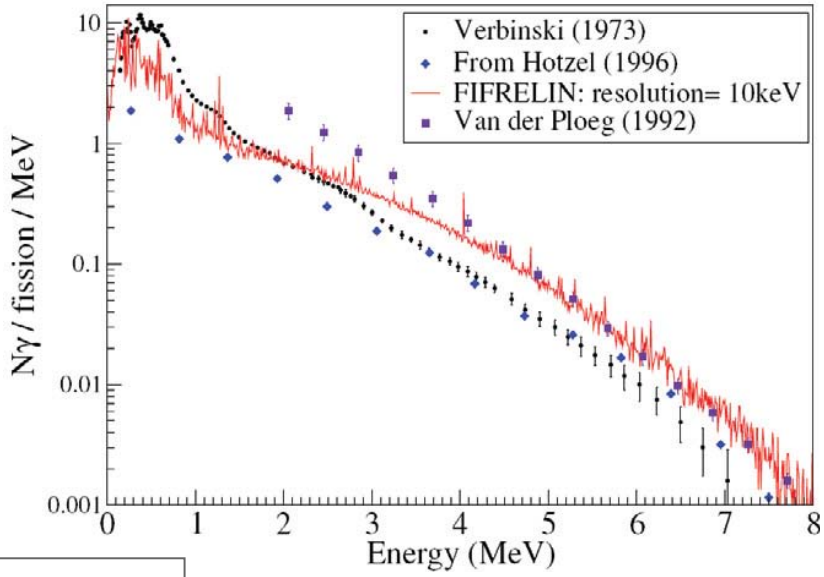
+ preliminary tests :

- ^{55}Mn (n,γ)
- ^{144}Ba fission fragment de-excitation
- ^{252}Cf spontaneous fission



NUCLEAR DATA PRODUCTION : ^{252}Cf

^{252}Cf prompt gamma spectrum



+ preliminary results :

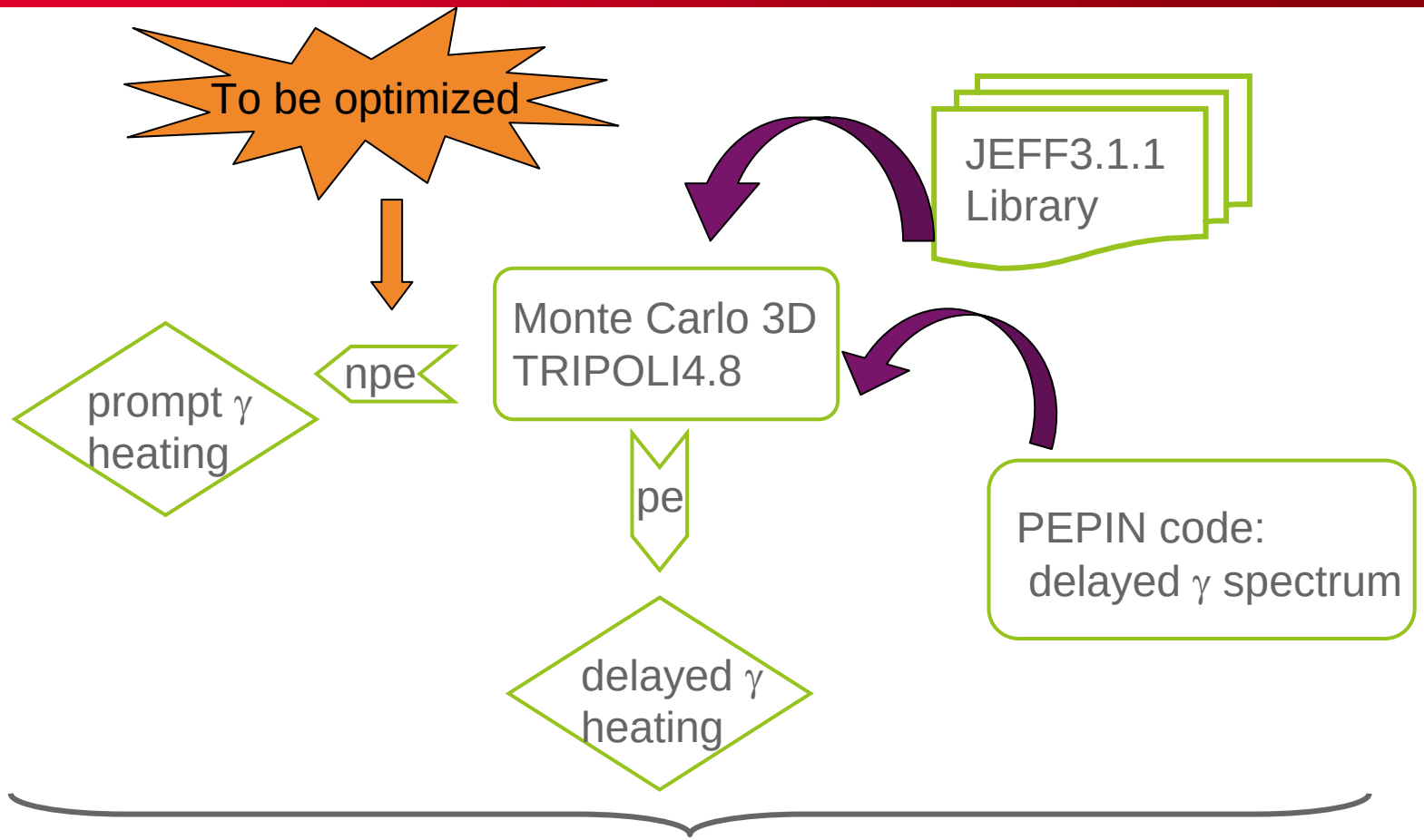
- Discrepancy source :

density level distribution model > strengh function

- Qualitative agreement : good
- Quantitative analisys: systematic overestimation

3. SIMULATION CODE

SIMULATION CODE

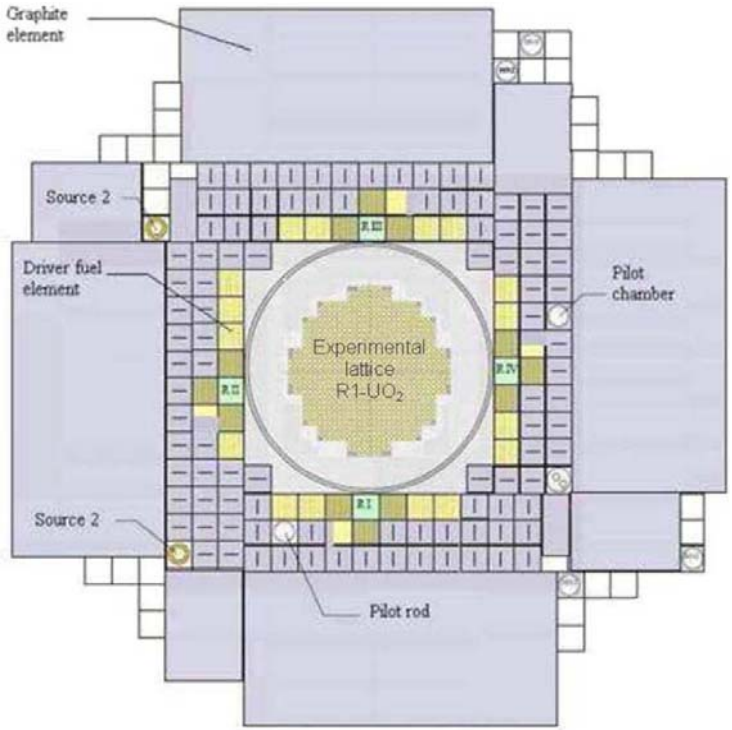


np APOLLO2-MOC QUALIFICATION

4. INTEGRAL EXPERIMENTS AND INSTRUMENTATION

INTEGRAL EXPERIMENTS AND INSTRUMENTATION : ADAPH+ in Minerve

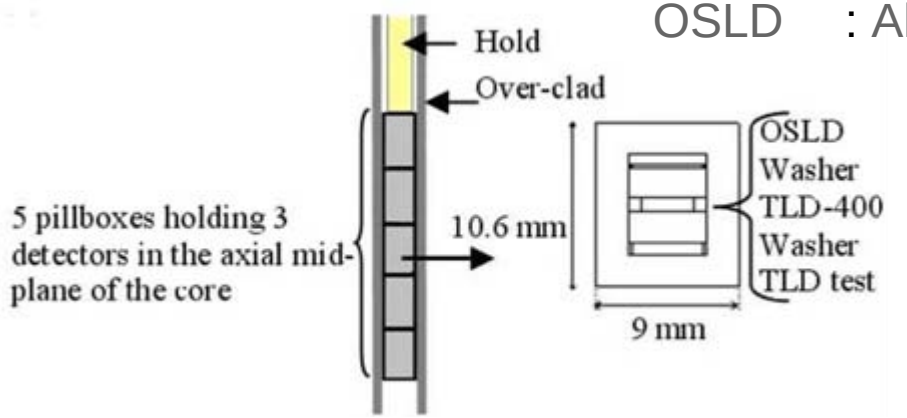
MINERVE facility : R1-UO_2
PWR standard spectrum



γ heating measurement in zero power reactor

-
- Thermo-Luminescent Detector TLD
- Optically Stimulated Detector OSLD

TLD-400 : CaF_2:Mn
OSLD : Al_2O_3:C

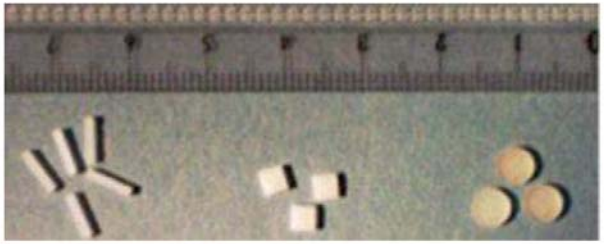


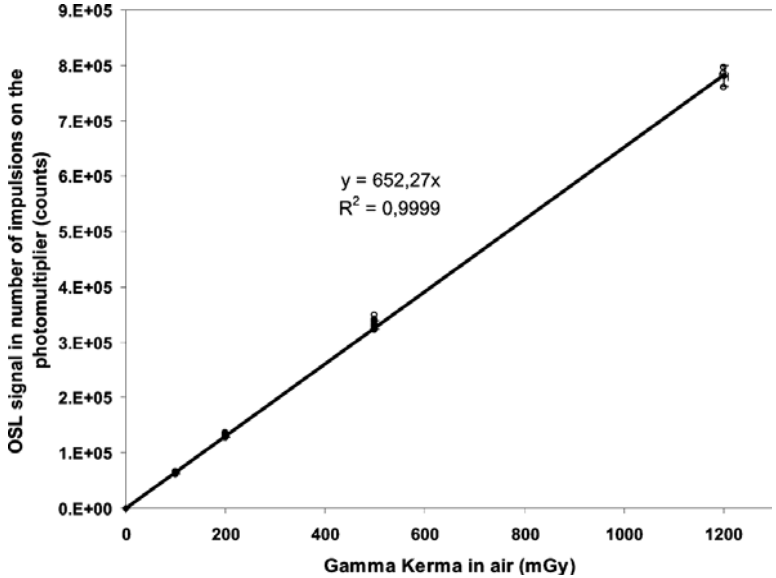
H. Amharrak and al., Analysis and Recent Advances in Gamma Heating Measurements in MINERVE Facility by Using TLD and OSLD Techniques, IEEE Trans. Nucl Scie. 59, 1360-1368, (2012)

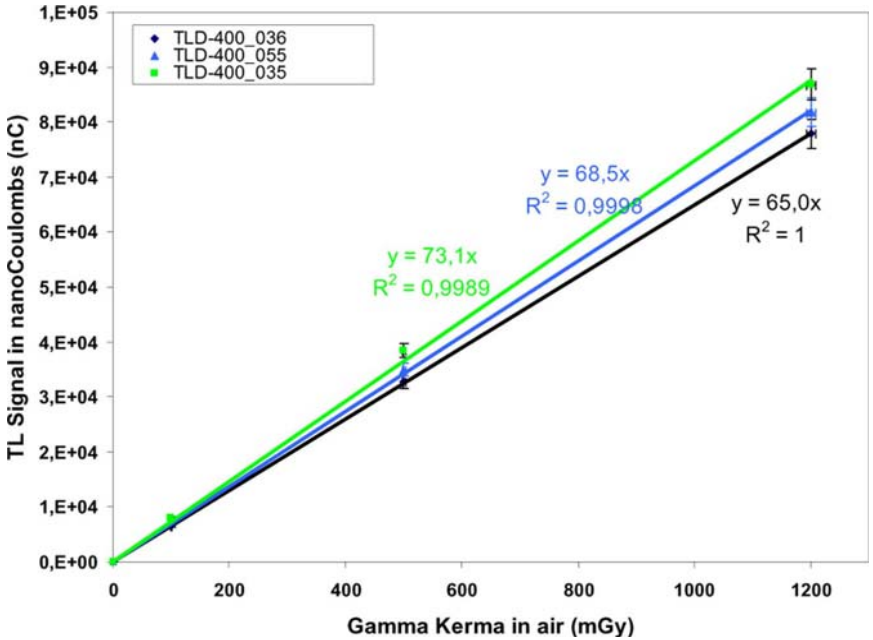
INTEGRAL EXPERIMENTS AND INSTRUMENTATION : ADAPH+ in Minerve

1- Improvement of the calibration :

- Standard ^{60}Co source
- Al pillbox : electronic equilibrium
- Calibration curve
- Calibration uncertainty ~ 2% TLD/OSLD







INTEGRAL EXPERIMENTS AND INSTRUMENTATION : ADAPH+ in Minerve

2- Incore measurement : absorbed dose

- experimental uncertainty (calib., repeatability)
- neutron dose correction :

TLD : 8.6%

OSLD : 5.9%

3- 3D Monte Carlo simulation :

- cavity corection 2 steps calculation

TLD : 1.07

OSLD : 1.05

- Delayed γ contribution : 32%

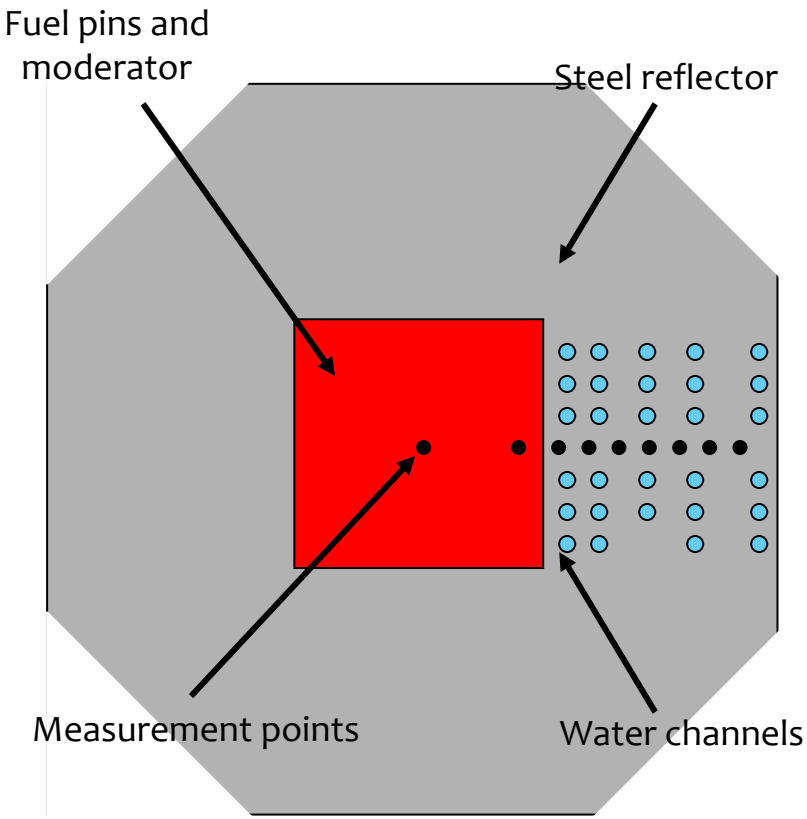
C/E (k=2)

TLD : 1.05±5.3%

OSLD : 0.96±7.0%

discrepancy TLD/OSLD ?
n dose, delayed γ
simulation methods

INTEGRAL EXPERIMENTS AND INSTRUMENTATION : PERLE in EOLE



PERLE in EOLE facility

- A 22 cm stainless steel neutron reflector
- TLD gamma heating measurement in & out-core
- 27 X 27 3.7% ^{235}U enriched fuel pins

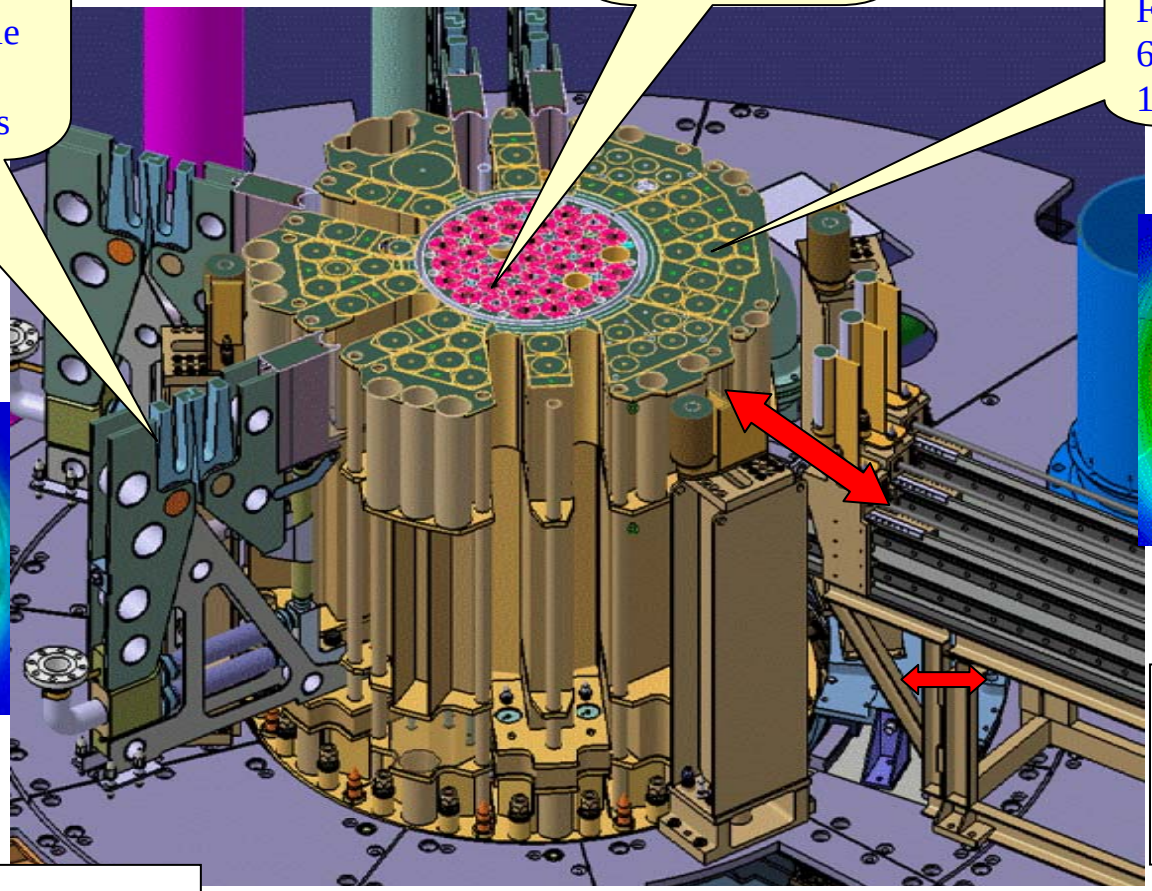
Fe, ^{62}Ni new evaluations qualification

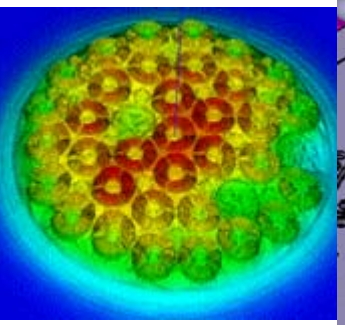
INTEGRAL EXPERIMENTS AND INSTRUMENTATION : JHR general characteristics

Displacement systems:
- To adjust the fissile power
- To study transients

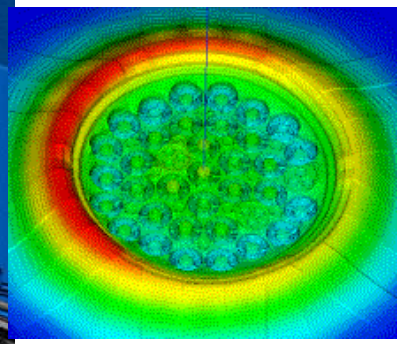
Material ageing (up to 16 dpa/y)

Fuel studies: up to 600 W/cm with a 1% ^{235}U PWR rod





Fast neutron flux

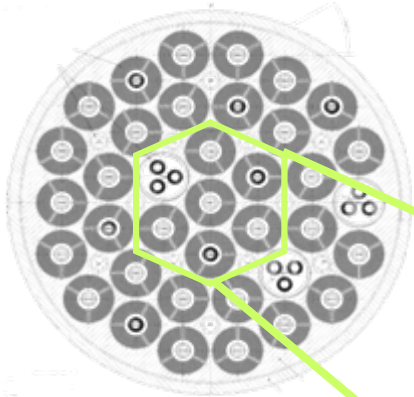


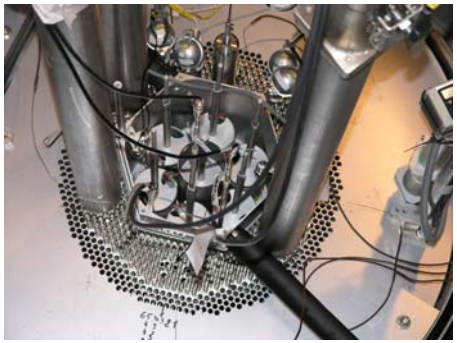
Thermal neutron flux

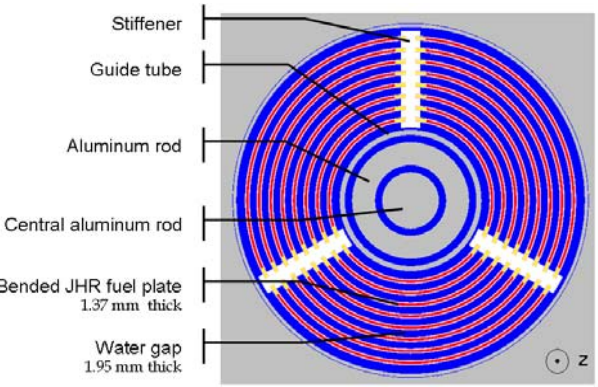
In core
Up to 5.5 10^{14} n/cm².s > 1MeV
Up to 10^{15} n/cm².s > 0.1MeV

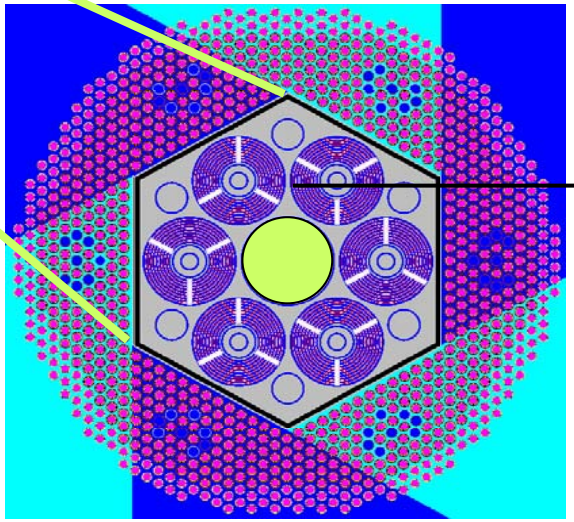
In reflector
Up to 5.5 10^{14} n.cm^{-2}.s^{-1}
Fixed positions and displacement systems

INTEGRAL EXPERIMENTS AND INSTRUMENTATION : AMMON in EOLE



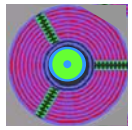




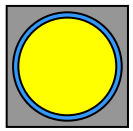


- *Main Configurations:*
- Reference core : 7 JHR assemblies

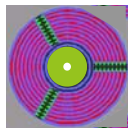
- Hf rod: completely inserted, ½ inserted



- Beryllium



- Voided assembly



- *Experiment characteristics:*
  - Central experimental zone : aluminum rack
  - U_3Si_2-Al fuel (e=27%)
  - Driver zone : 623 UOx fuel pins (e=3.7 %)

Experimental data: critical state, reactivity worth, power distributions, spectrum indices, conversion factor, T° coefficient, **gamma-heating**

AMMON EXPERIMENTAL PROGRAM IN EOLE FACILITY

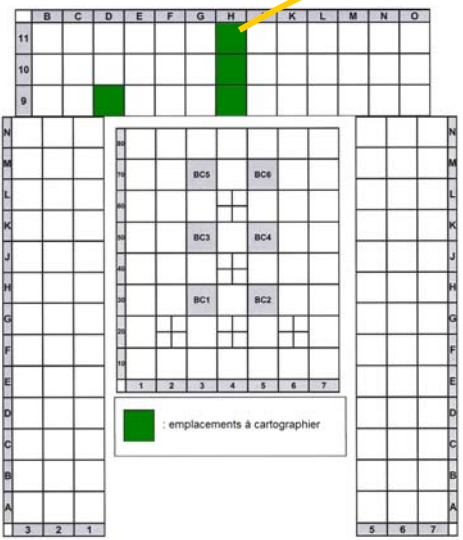
- Experiment in progress

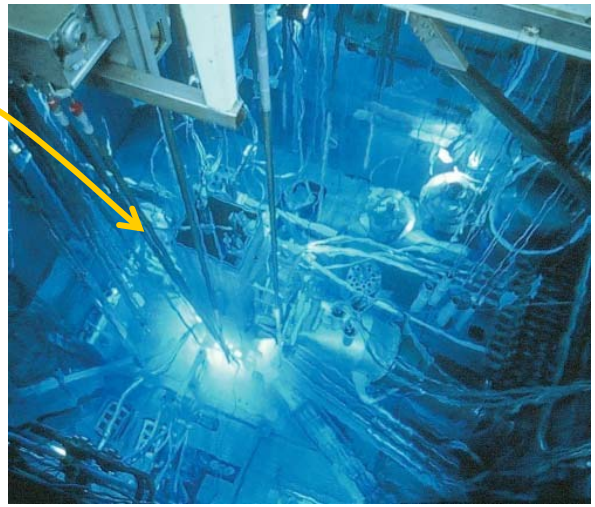
- gamma-heating measurements :
  . TLDs (7LiF, CaF2:Mn) , OSLDs (Al2O3:C), ionization chamber
  . Where ?
  assembly center,
  aluminum filler,
  hafnium rod,
  beryllium block

- Validation :
  deposited energy in **aluminum**, **hafnium** and **beryllium**
  for JHR safety and performance study

- Interpretation : (TRIPOLI4/JEFF3):
  . Collaboration work in progress
  . PhD work starting at the end of 2012

INTEGRAL EXPERIMENTS AND INSTRUMENTATION : CARMEN-1 in OSIRIS





CARMEN-1 in OSIRIS facility

- Neutron & photon measurements
- 2 experimental devices dedicated
- 4 out-core measuring locations scanned in 70 MW OSIRIS reflector (CEA-Saclay)

n,γ combined analysis => JHR core mapping

D. Fourmentel and al.,Combined analysis of neutron and photon flux measurements for Jules Horowitz reactor core mapping, Conf. PHYTRA2, (2011)

INTEGRAL EXPERIMENTS AND INSTRUMENTATION : CARMEN-1 in OSIRIS

CARMEN1-P

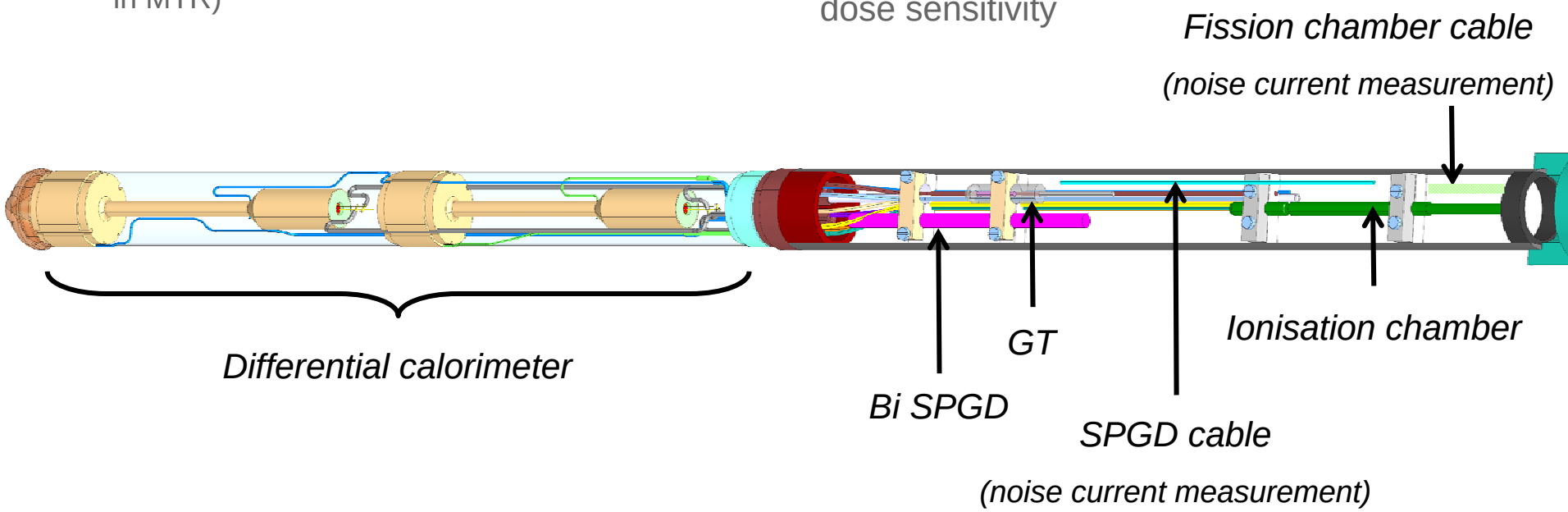
- Gamma flux :
  Ionization chamber,
  Self Powered Gamma Detector (SPGD)

- Nuclear heating :
  Differential calorimeter,
  Gamma Thermometer (commonly used in MTR)

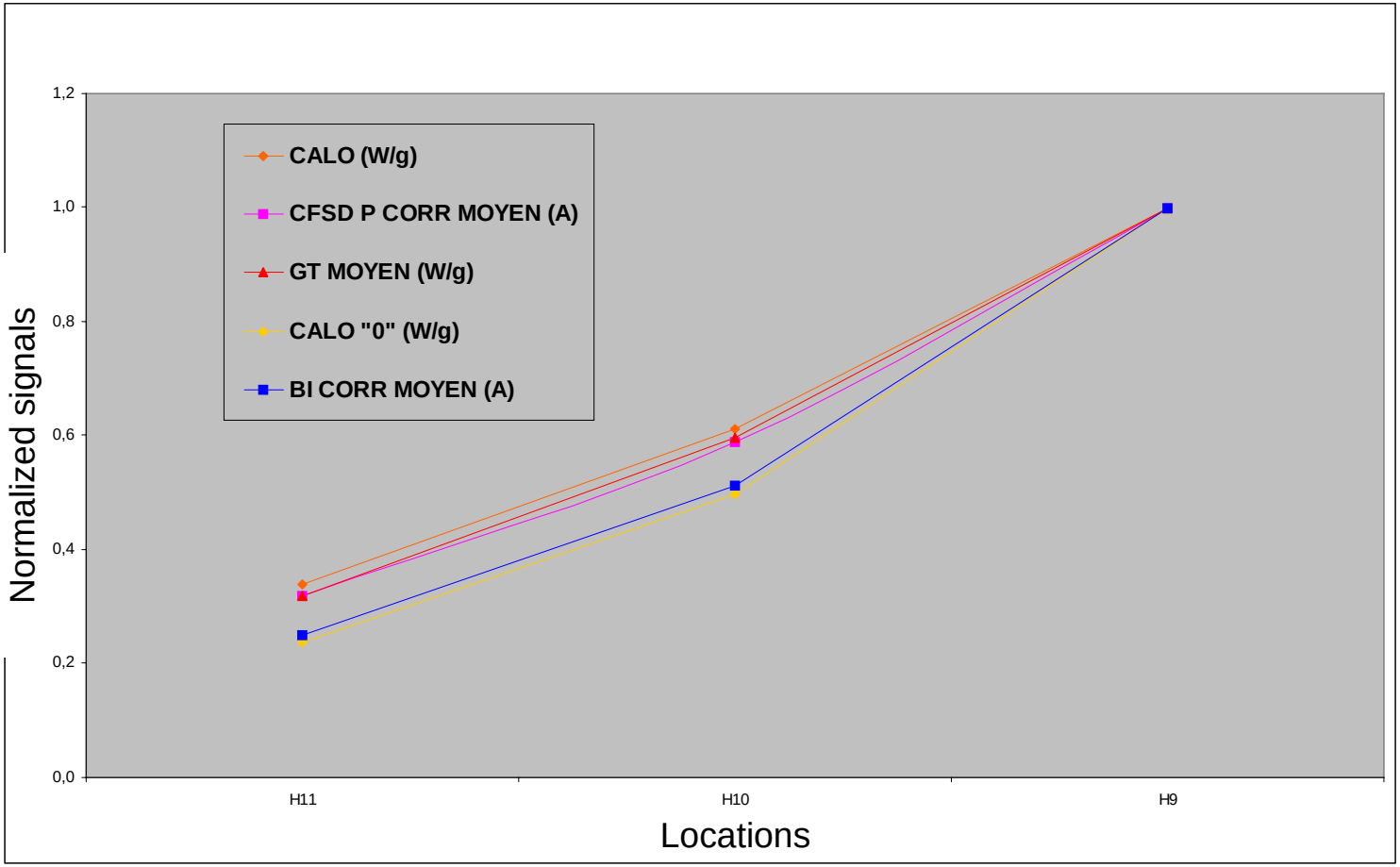
OBJECTIVES

- Reduce measurement uncertainties

- Testing 3 different methods to estimate nuclear heating from temperature measurement
- 2 sensors with different material (grahite vs stainless steel) & neutron dose sensitivity

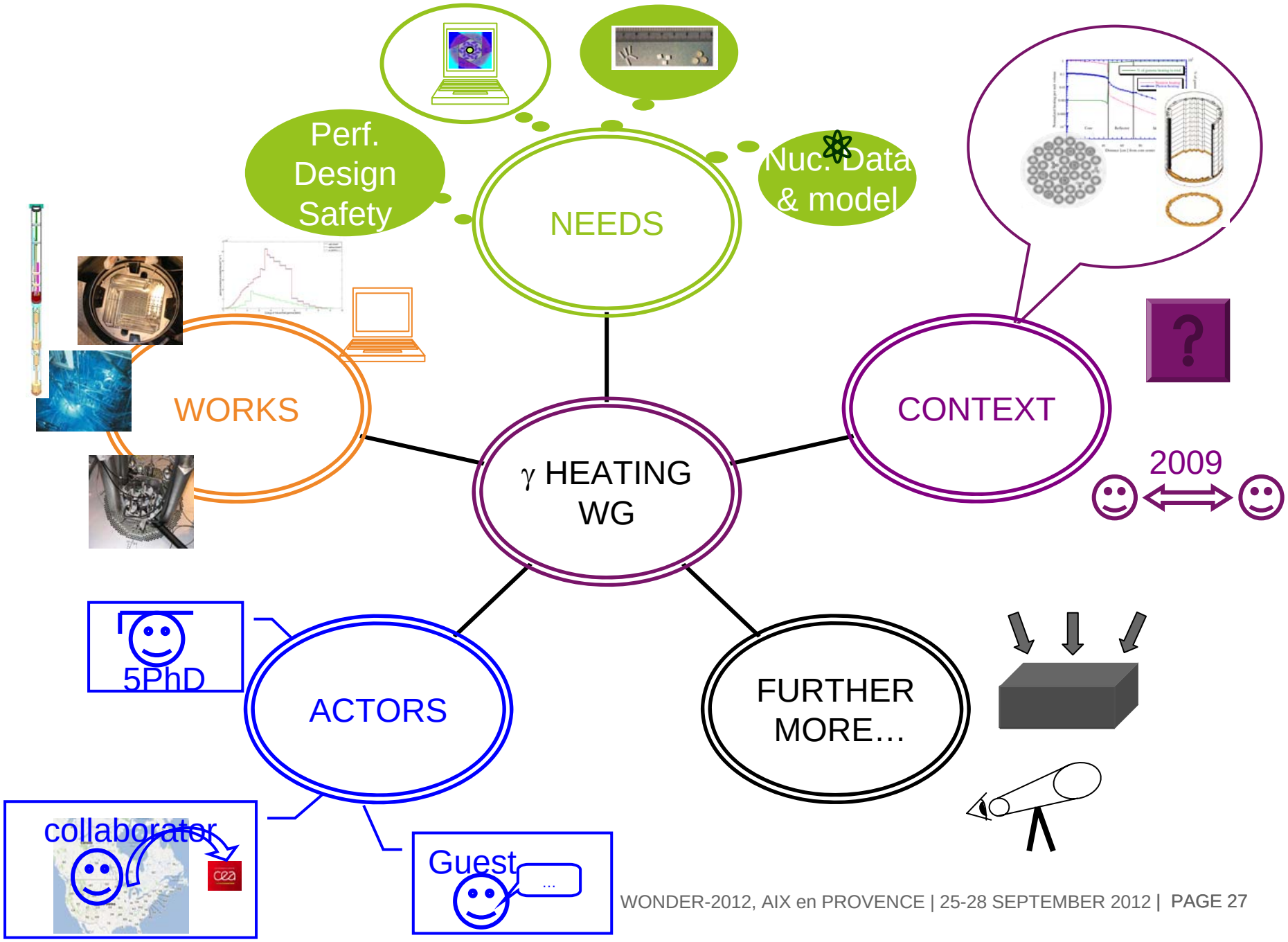


INTEGRAL EXPERIMENTS AND INSTRUMENTATION : CARMEN-1 in OSIRIS



Signals evolution of gamma sensors between different locations

5. CONCLUSION


Perf.
Design
Safety
NEEDS
Nuc. Data
& model
WORKS
CONTEXT
?
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γ HEATING
WG
5PhD
ACTORS
FURTHER
MORE…
collaborator
Guest
...

Thank You

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