Sensitivity analyses by Generalized Perturbation Theory (GPT) methods applied to GUINEVERE and MYRRHA lead fast reactors.

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Presentation layout

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- ✓ GUINEVERE and MYRRHA facilities
- ✓ Position of the problem
- ✓ GPT methods – Defining a correlation criterion
- ✓ GUINEVERE/MYRRHA RZ models for GPT analysis
- ✓ Results
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Introduction

- From Wikipedia: *"Molten lead or lead-bismuth eutectic can be used as the primary coolant in a nuclear reactor, as lead and bismuth have low neutron absorption and relatively low melting points. Neutrons are less slowed by interaction with heavy nuclei, so lead and bismuth are not neutron moderators, making this type of reactor a fast-neutron reactor. The coolant does serve as a neutron reflector returning some escaping neutrons to the core."*

- Lead coolant technologies for nuclear reactors date back to 70's (Soviet nuclear submarines). The first step in the development of a Lead Cooled Critical Fast Reactor in Europe started in 2006 with the EU - FP6 ELSY project, on the basis of previous projects already carried out in the frame of projects dedicated to Lead-Bismuth/Lead cooled Accelerator Driven Systems (XT-ADS, EUROTRANS etc.).

- In this context SCK•CEN, the Belgian Nuclear Research Centre, is developing MYRRHA, a flexible fast spectrum research reactor (50-100 MW_{th}), able to operate in sub-critical (ADS) and critical modes. It contains a proton accelerator of 600 MeV, a spallation target and a multiplying core with MOX fuel, cooled by liquid lead-bismuth (Pb-Bi).

Introduction

- To support the MYRRHA project the GUINEVERE experimental program was conceived, with the aim to evaluate the confidence interval to associate to calculation methods, analysis tools and nuclear data libraries relevant to lead (lead-bismuth) cooled fast critical and subcritical systems.

- The GUINEVERE (Generation of Uninterrupted Intense NEutrons at the lead VEnus REactor) experimental program was launched in 2007 as European project included in the Integrated Project EUROTRANS of the Sixth EU Framework Programme, and is presently part of the FREYA (Fast Reactor Experiments for hYbrid Applications) project, started on March 2011, of the Seventh EU Framework Programme.

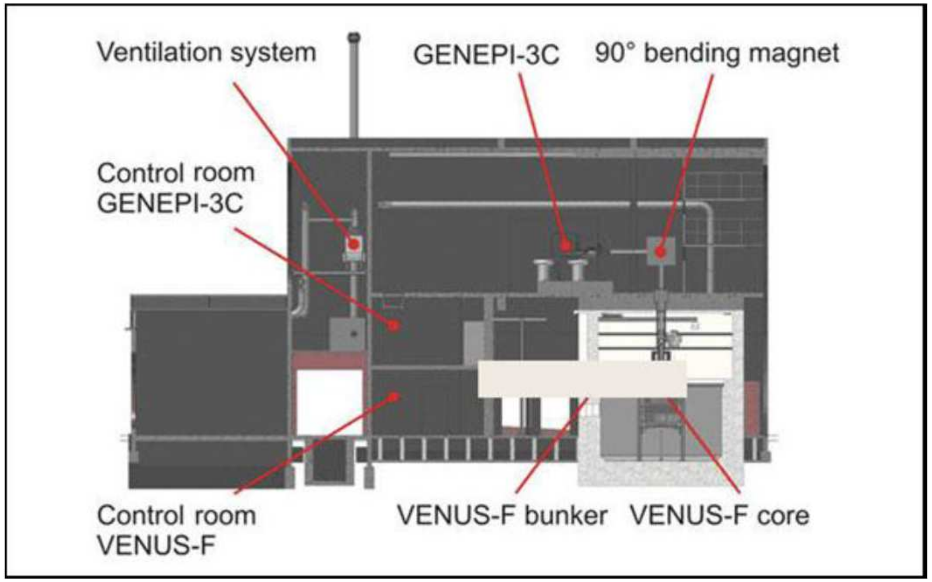
- The experience is performed by using a modified lay-out of the Venus critical facility located at the Belgium SCK•CEN Mol site. The subcritical experiments are performed by coupling the subcritical core, having different degrees of subcriticality, to an accelerator, GENEPI-C (GEnérateur de NEutrons Pulsé Intense-Continue), built by the CNRS in Grenoble, delivering 14 MeV neutrons by bombardment of deuterons on a tritium-target.

Introduction

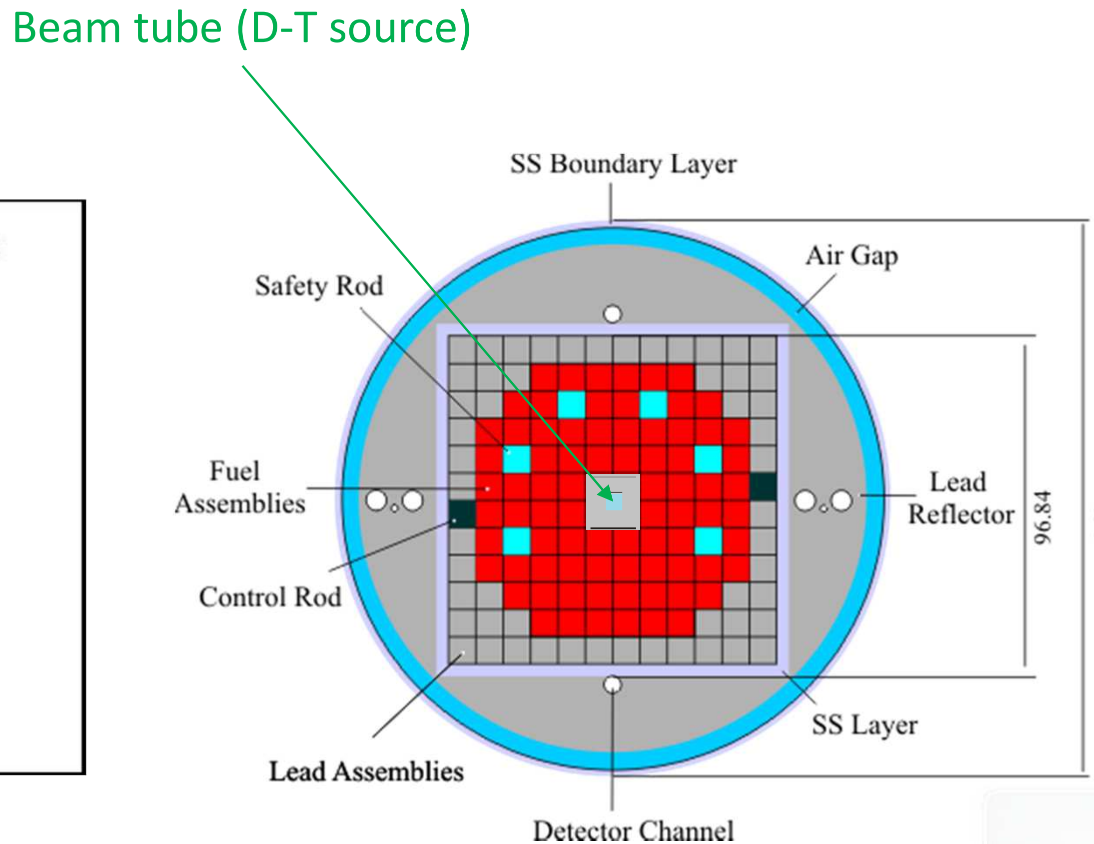
- An important issue concerning the measurements already performed and to be performed in GUINEVERE is the representativeness of such measurements with respect to the reference system MYRRHA, representativeness which has to embrace (as much as possible) the most important neutron properties characterizing this last system, under the point of view of both the normal operation and the safety aspects.

- In this frame it is of fundamental importance a reliable characterization of the energy spectrum of the neutron field relevant to the two facilities GUINEVERE and MYRRHA.

- The present work is focused on the analysis, by numerical simulations, of the representativeness, with respect to analogous quantities relevant to the MYRRHA reference system, of the behaviour of some integral quantities to be measured in the GUINEVERE facility following a localized or global perturbation in the core. The analysis has been carried out by means of different GPT (Generalized Perturbation Theory) calculation routes implemented into the ERANOS French neutronic code.



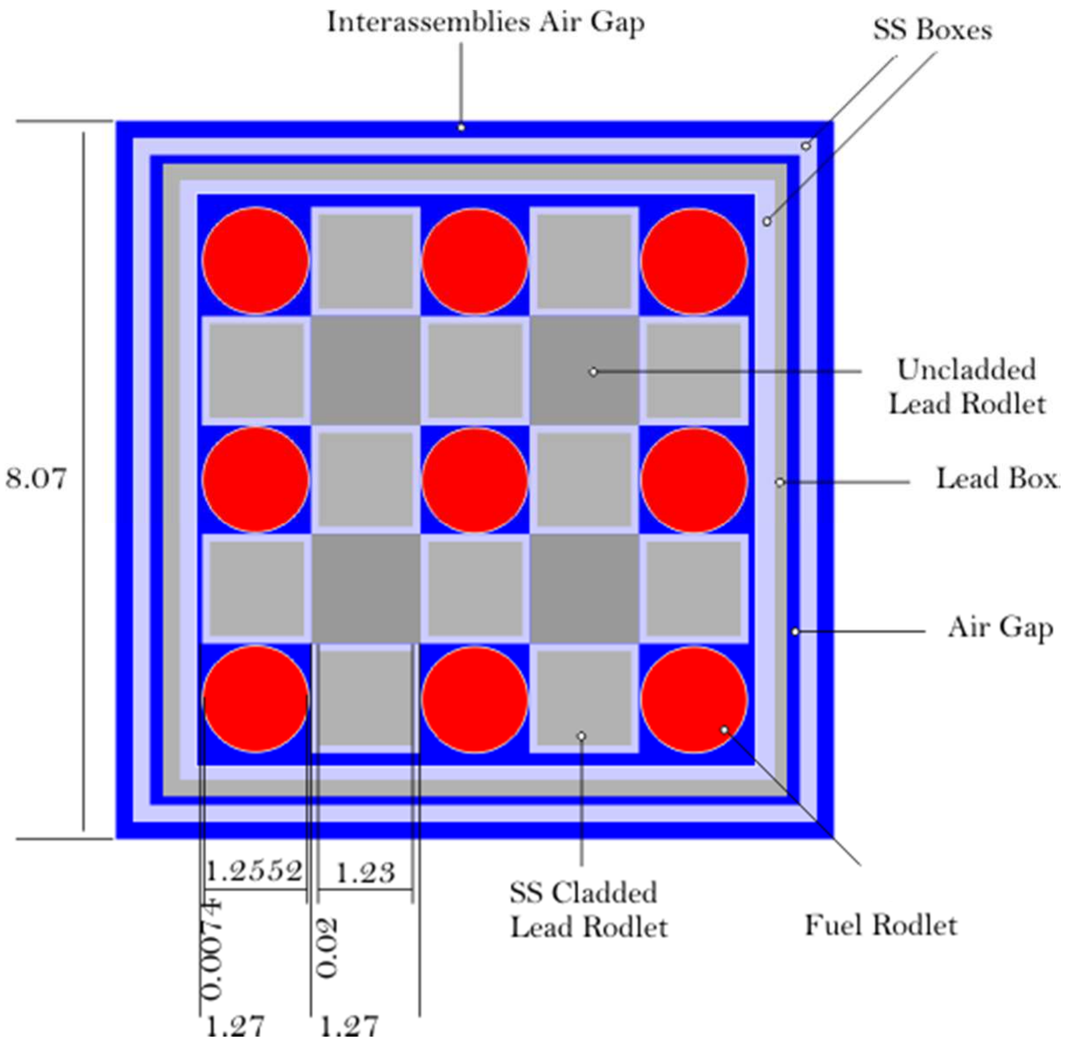
Side view of the modified VENUS Facility



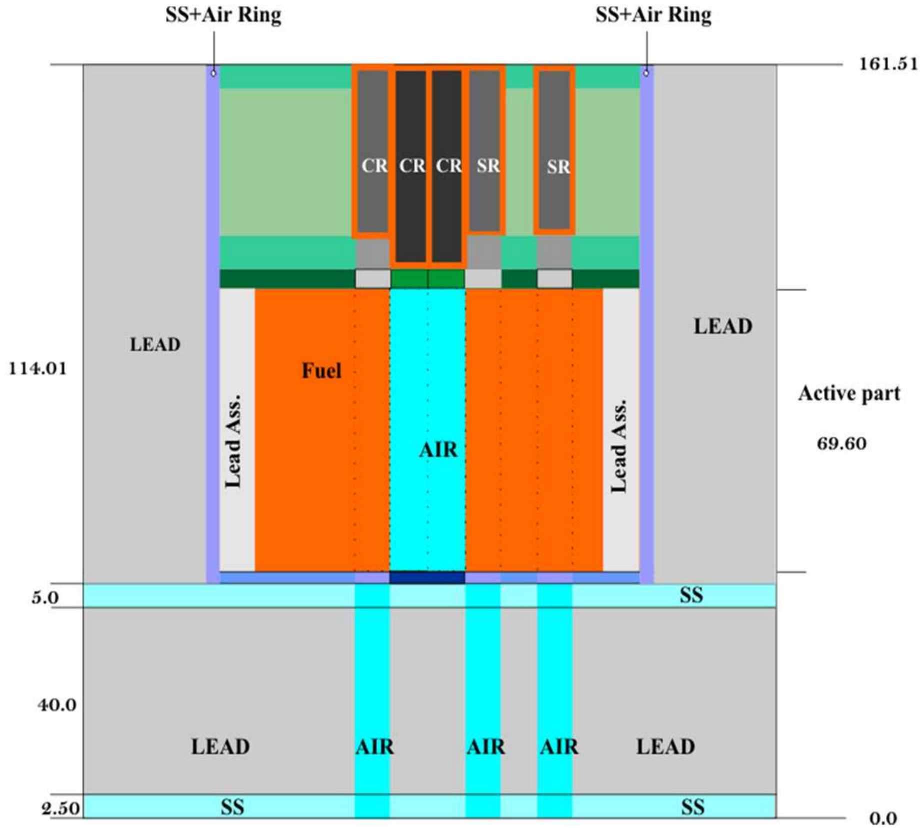
X-Y Reactor Section (sizes in cm)

GUINEVERE

GUINEVERE and MYRRHA facilities



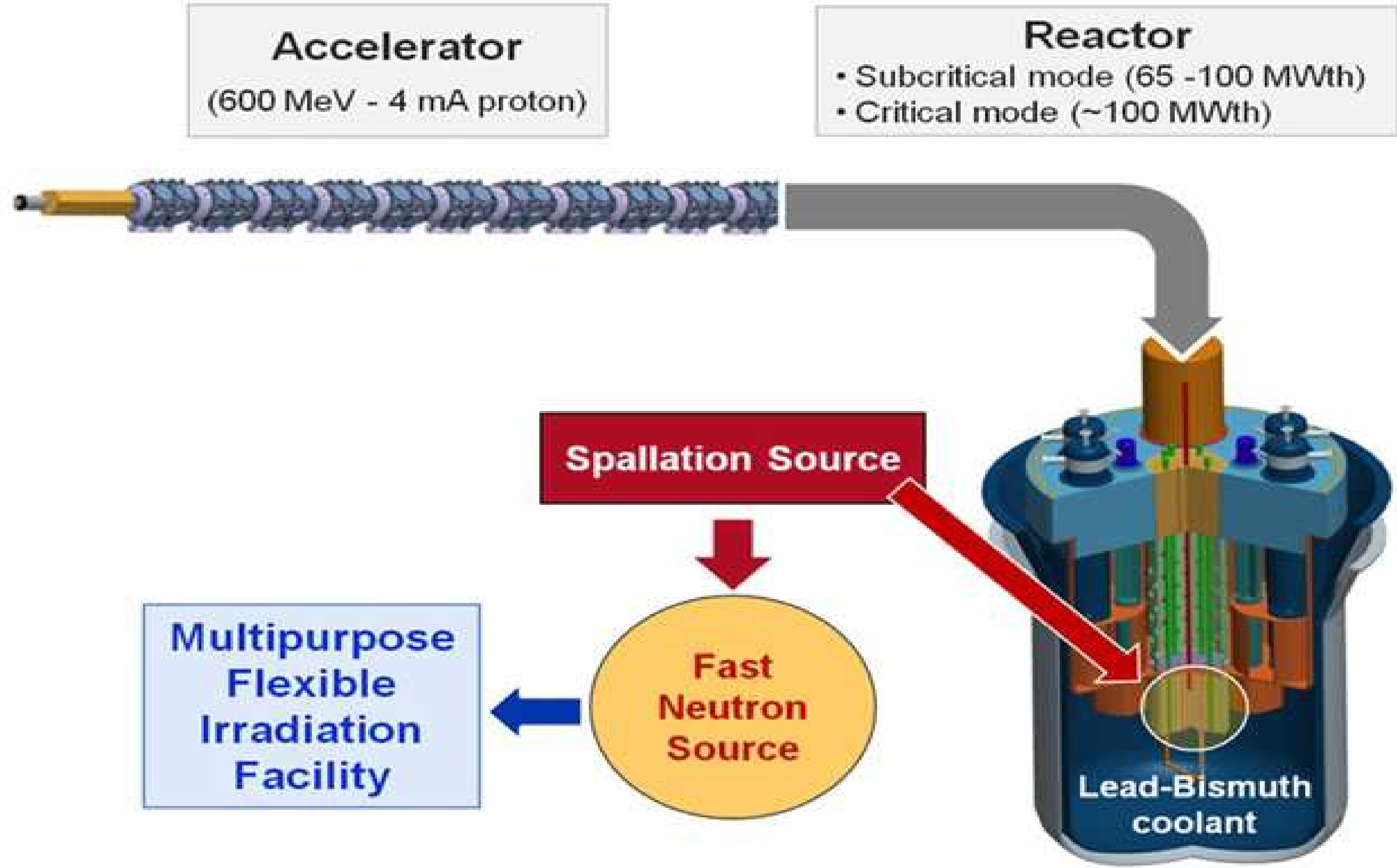
Fuel assembly section (sizes in cm)
Fuel Uranium 30% (weight) enriched in U^{235}



Simplified Reactor vertical view
(sizes in cm)

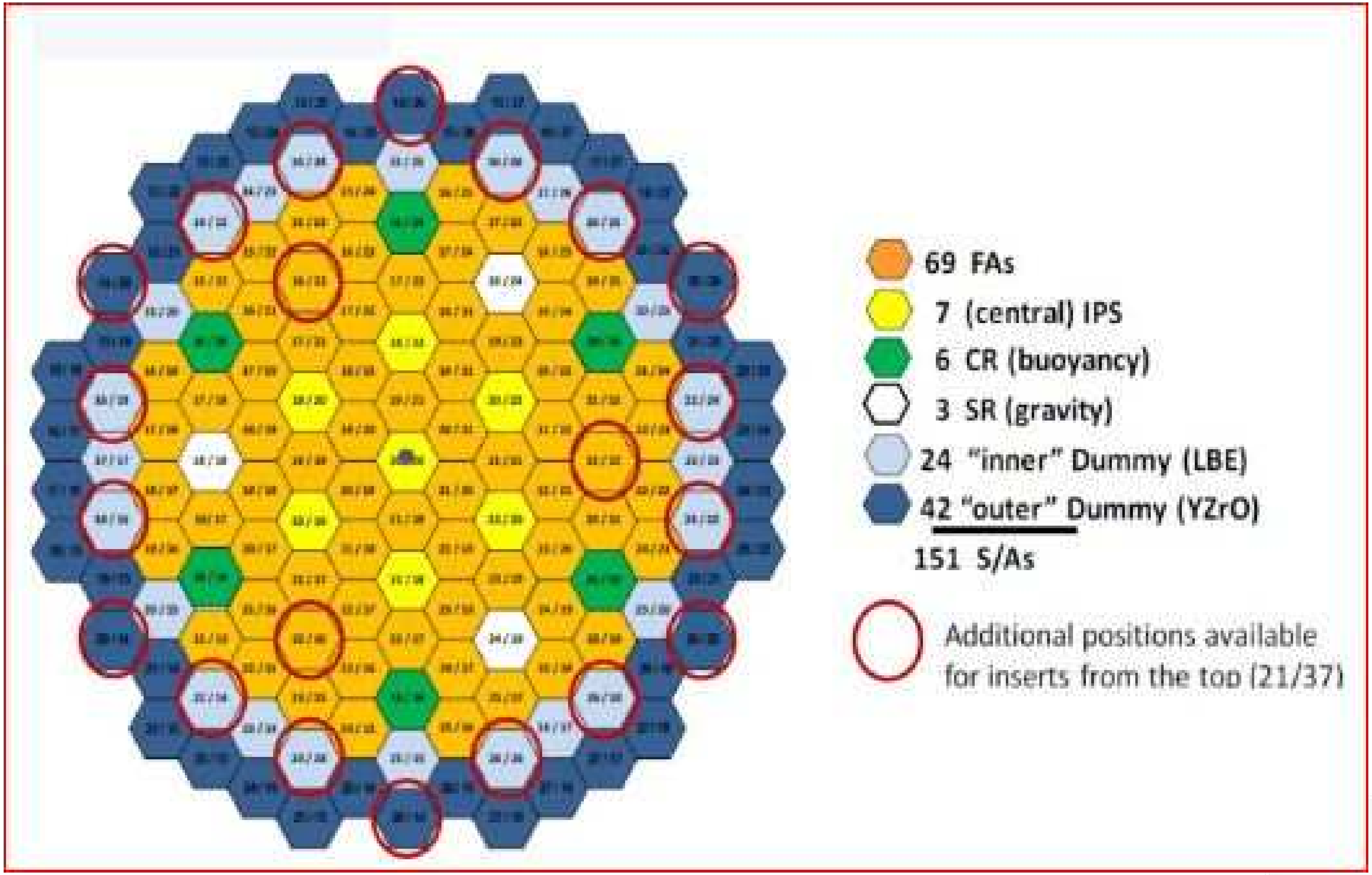
GUINEVERE

GUINEVERE and MYRRHA facilities



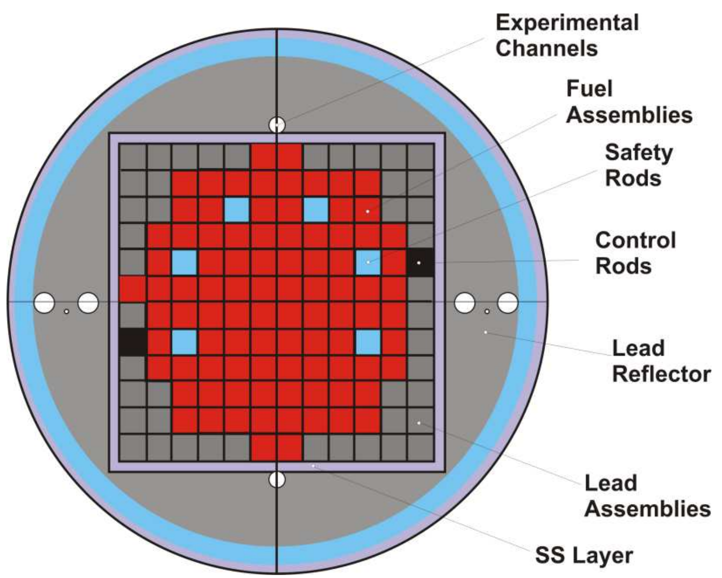
MYRRHA

GUINEVERE and MYRRHA facilities

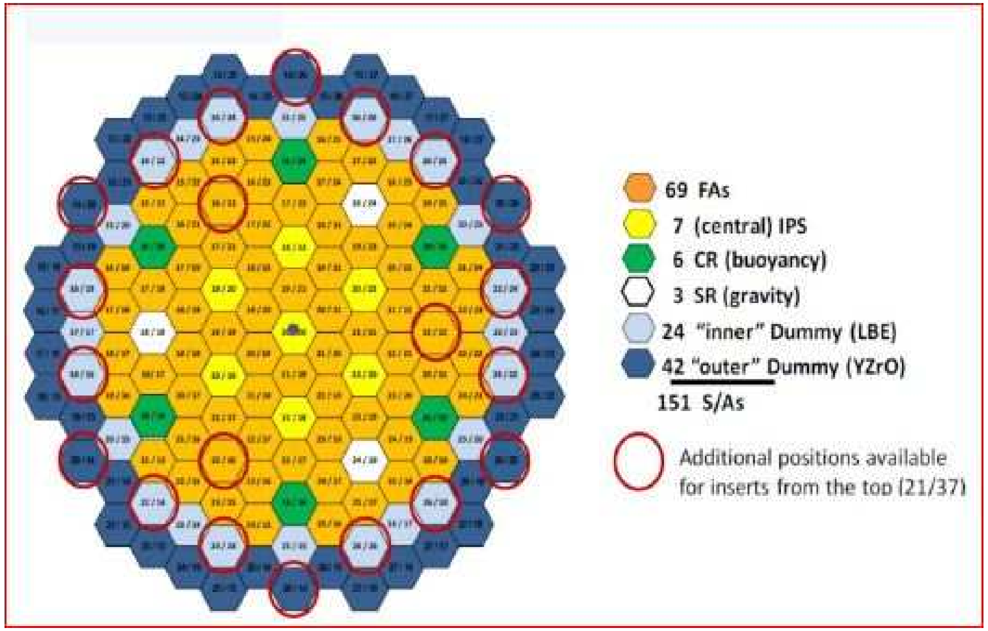


MYRRHA

Position of the problem



?



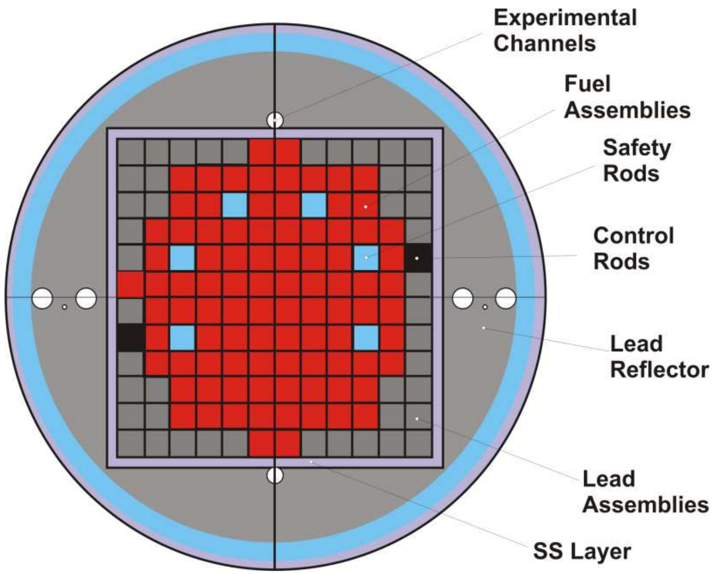
GUINEVERE (A)

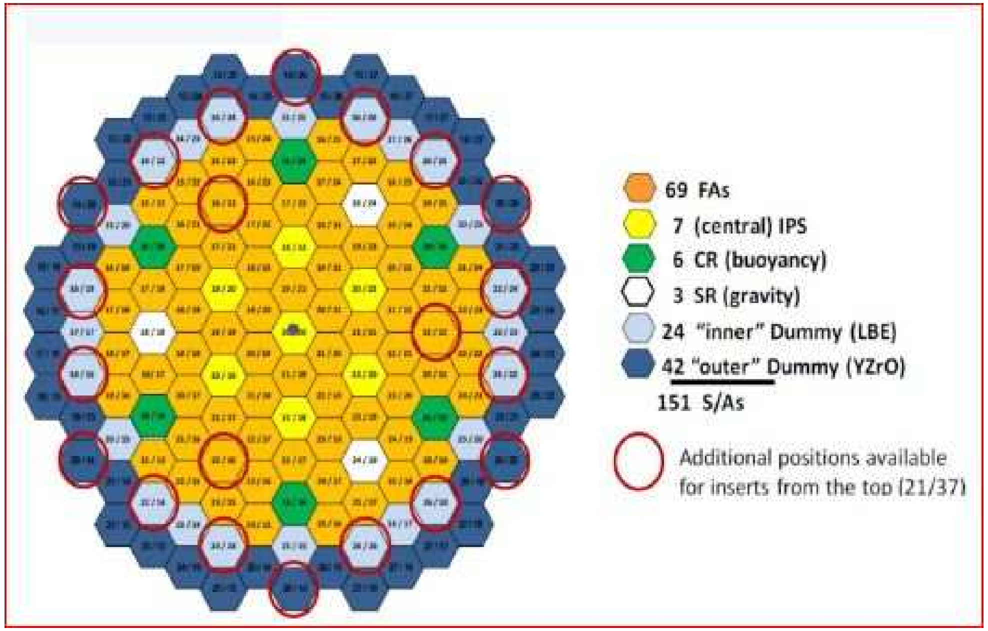
MYRRHA (B)

- **Let us suppose to have a localized (core shell) or global (whole active core) lead (GUINEVERE) or lead-bismuth (MYRRHA) 20% density reduction.**

- **Which is the behaviour of some selected spectral indexes in the two cores, like for example Pu-239 fissions/ U-235 fissions, U-238 fissions/ U-235 fissions and Np-237 fissions/ U-235, following the perturbations?**

Position of the problem





GUINEVERE (A)

MYRRHA (B)

$$R_A = \frac{<\Sigma_1 \phi>_A}{<\Sigma_2 \phi>_A}$$

$$\frac{\Delta R_A}{R_A} \cong < S_\alpha \frac{\Delta\alpha}{\alpha} >_A$$

$$R_B = \frac{<\Sigma_1 \phi>_B}{<\Sigma_2 \phi>_B}$$

$$\frac{\Delta R_B}{R_B} \cong < S_\alpha \frac{\Delta\alpha}{\alpha} >_B$$

Sensitivity coefficients

GPT methods – Defining a correlation criterion

$$R = \frac{<\Sigma_1 \phi>}{<\Sigma_2 \phi>}$$

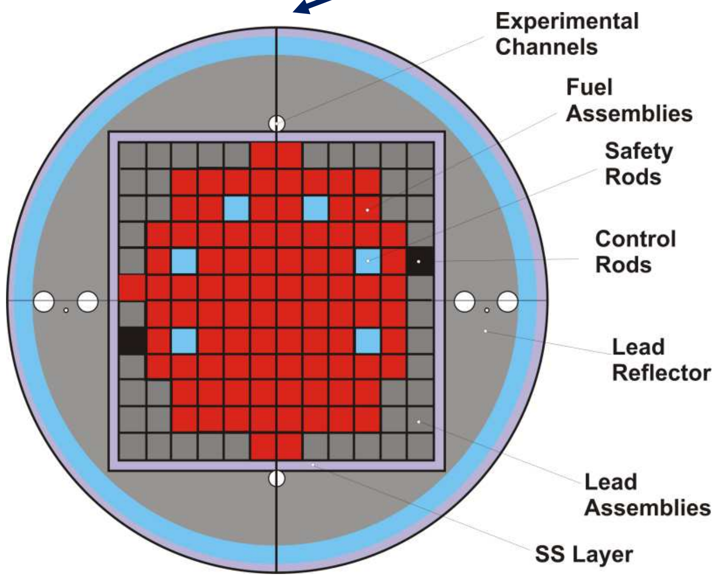
$$\frac{\Delta R}{R} = <\left(\frac{\alpha}{R}\frac{\Delta R}{\Delta \alpha}\right)\frac{\Delta \alpha}{\alpha}> \equiv < S_\alpha \frac{\Delta \alpha}{\alpha} >$$

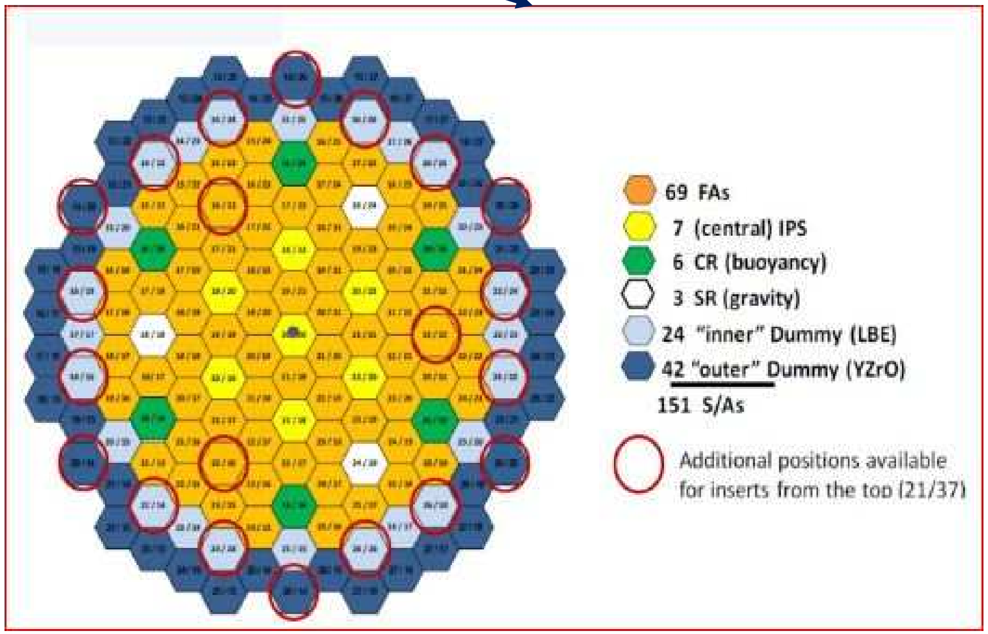
$$S_\alpha \approx -\Gamma^* \left(\frac{\partial \mathbf{L}}{\partial \alpha} - \lambda \frac{\partial \mathbf{P}}{\partial \alpha}\right)\phi$$

$$\left(\mathbf{L}^* - \lambda \mathbf{P}^*\right)\Gamma^* = \frac{1}{R}\frac{\partial R}{\partial \phi} = \frac{\Sigma_1}{<\Sigma_1 \phi>} - \frac{\Sigma_2}{<\Sigma_2 \phi>}$$

GPT methods – Defining a correlation criterion

$$R_i = \frac{< \Sigma_{x,i}\ \phi >}{< \Sigma_{y,i}\ \phi >}$$





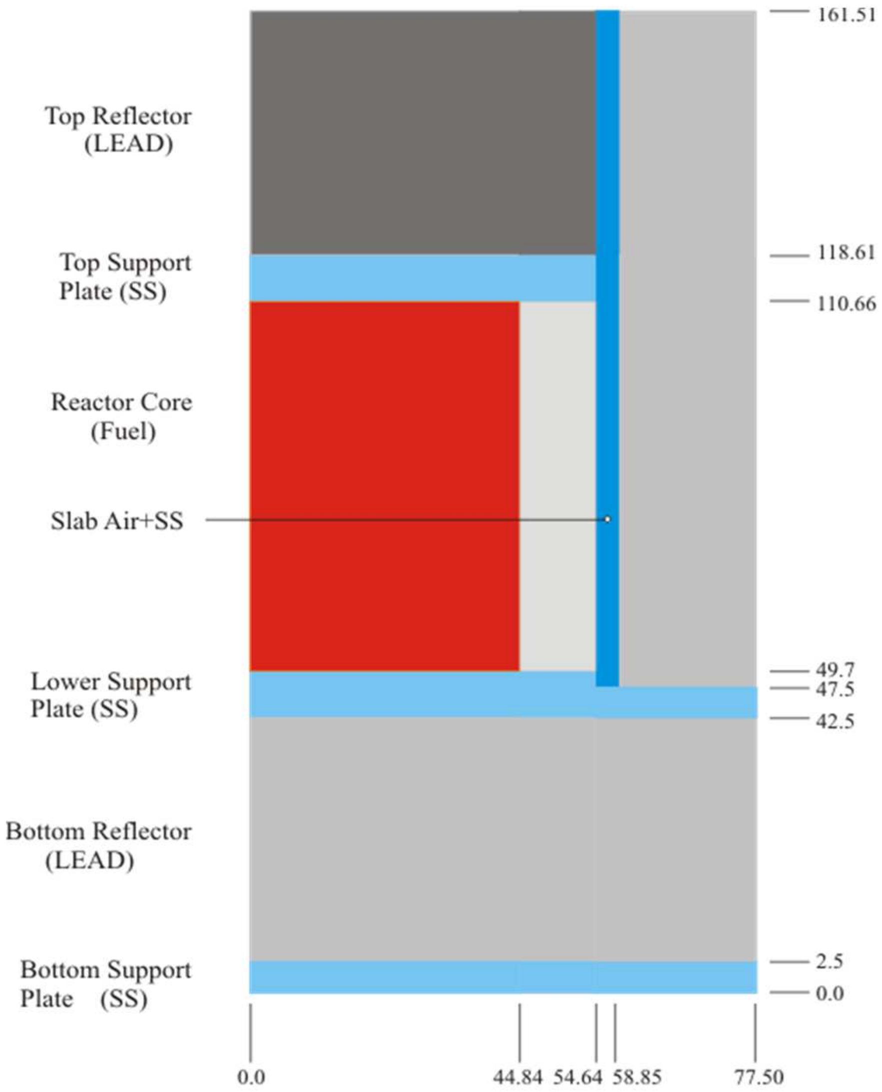
GUINEVERE (A)

MYRRHA (B)

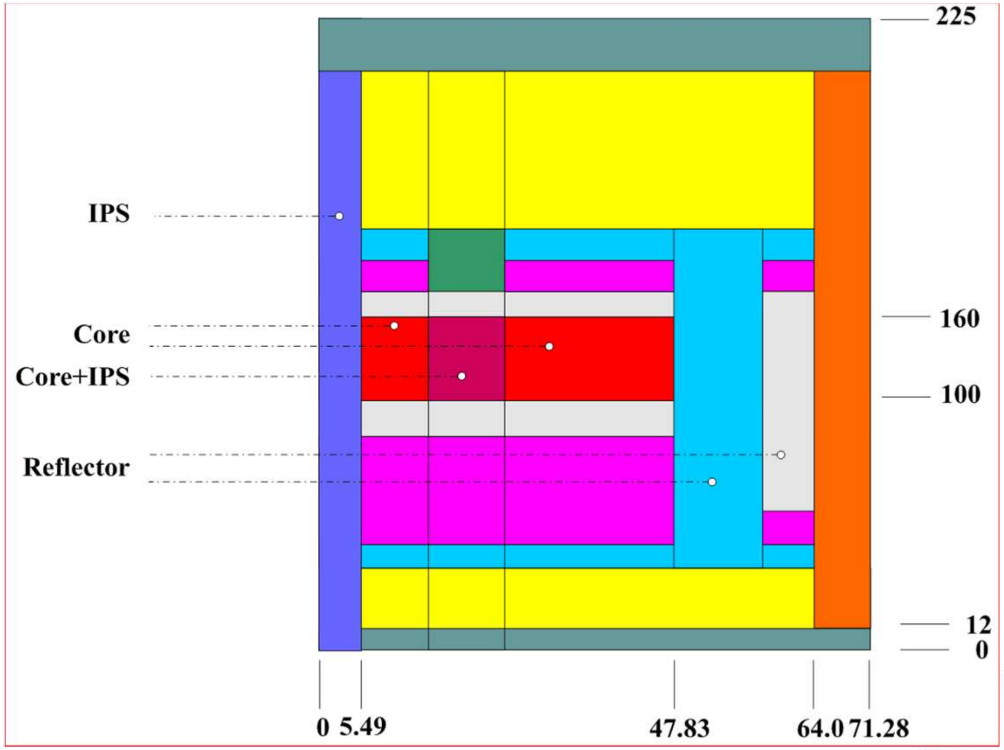
$$r_{BA}^{i} = \frac{\mathbf{S}_{B,i}^{T}\mathbf{D}\mathbf{S}_{A,i}}{\sqrt{\mathbf{S}_{B,i}^{T}\mathbf{D}\mathbf{S}_{B,i}}\sqrt{\mathbf{S}_{A,i}^{T}\mathbf{D}\mathbf{S}_{A,i}}}$$

Nuclear data dispersion matrix (US BOLNA at 15 energy groups)

GUINEVERE/MYRRHA RZ models for GPT analysis

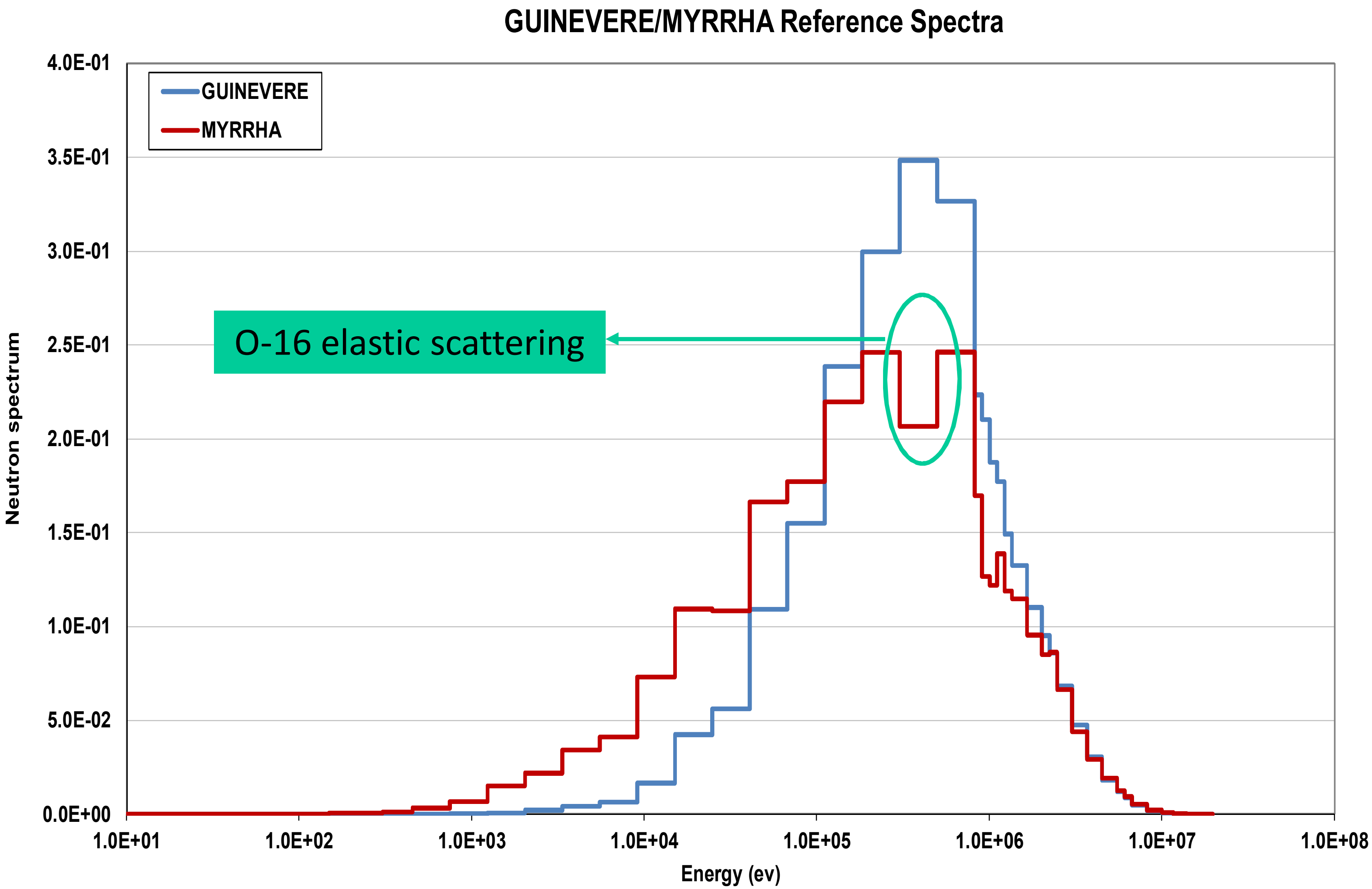


GUINEVERE (A)



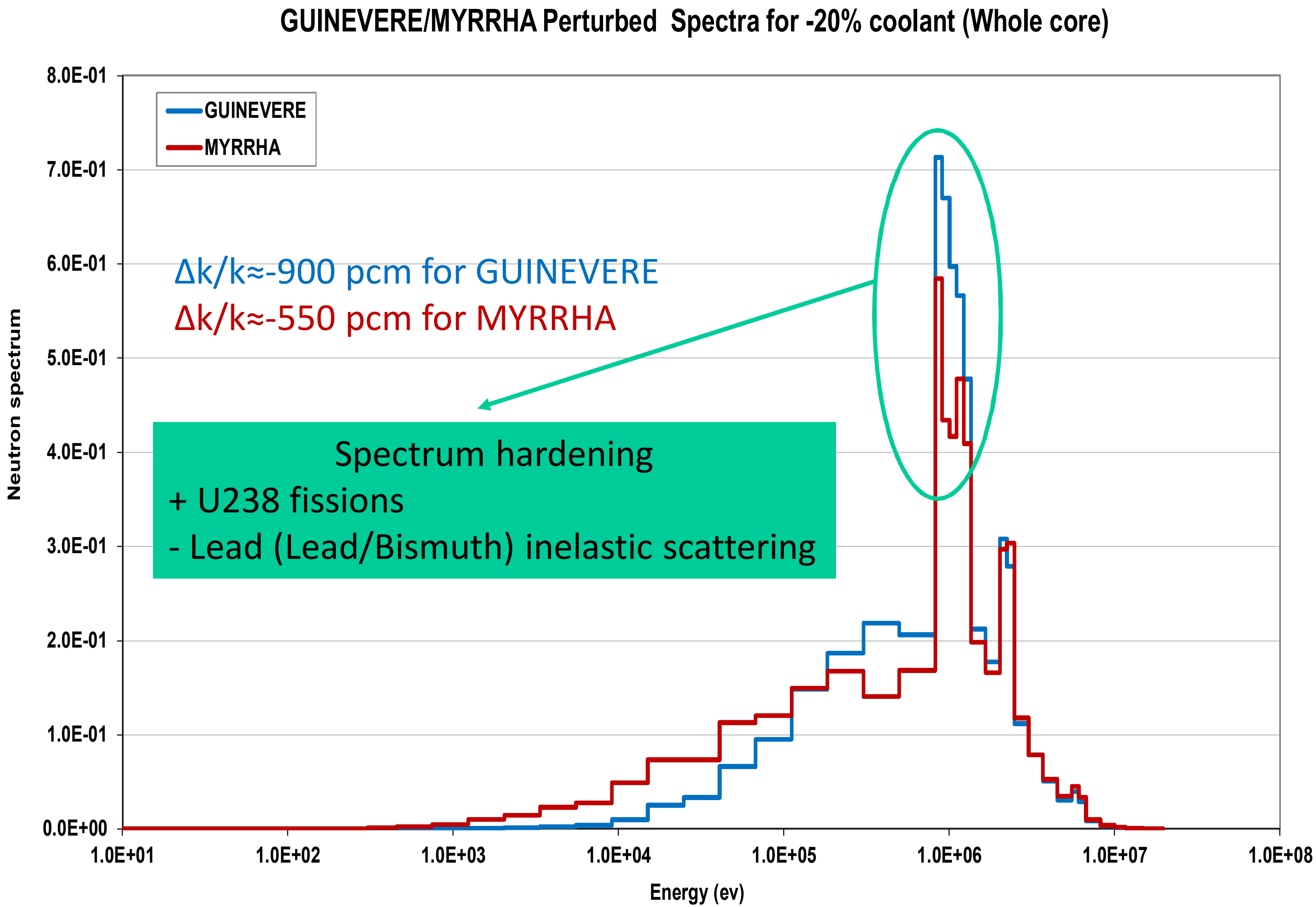
MYRRHA (B)

Results



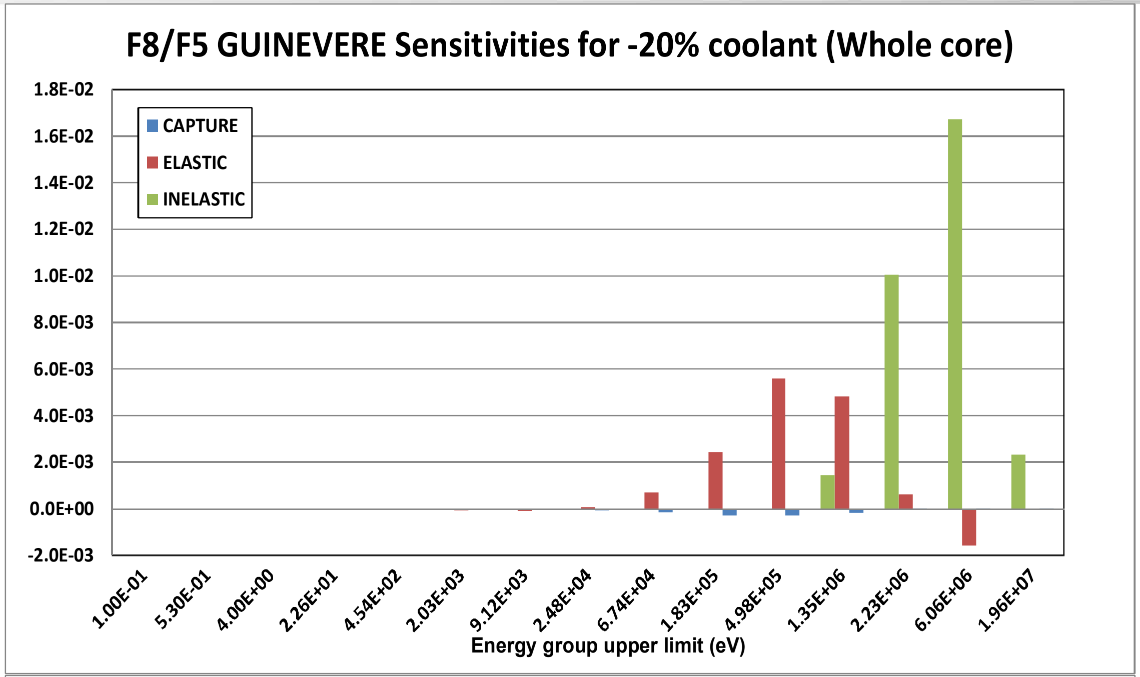
GUINEVERE/MYRRHA Reference Spectra
GUINEVERE
MYRRHA
O-16 elastic scattering
Neutron spectrum
4.0E-01
3.5E-01
3.0E-01
2.5E-01
2.0E-01
1.5E-01
1.0E-01
5.0E-02
0.0E+00
1.0E+01
1.0E+02
1.0E+03
1.0E+04
1.0E+05
1.0E+06
1.0E+07
1.0E+08
Energy (ev)

Results

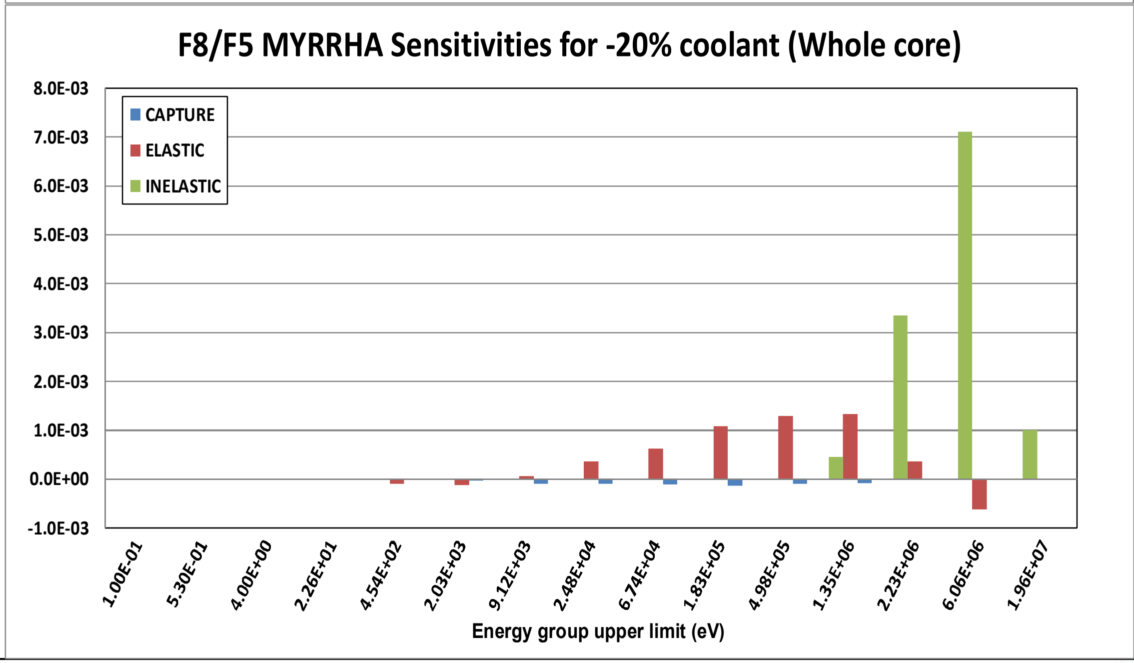


GUINEVERE/MYRRHA Perturbed Spectra for -20% coolant (Whole core)
GUINEVERE
MYRRHA
Δk/k≈-900 pcm for GUINEVERE
Δk/k≈-550 pcm for MYRRHA
Spectrum hardening
+ U238 fissions
- Lead (Lead/Bismuth) inelastic scattering
Neutron spectrum
8.0E-01
7.0E-01
6.0E-01
5.0E-01
4.0E-01
3.0E-01
2.0E-01
1.0E-01
0.0E+00
1.0E+01
1.0E+02
1.0E+03
1.0E+04
1.0E+05
1.0E+06
1.0E+07
1.0E+08
Energy (ev)

Results

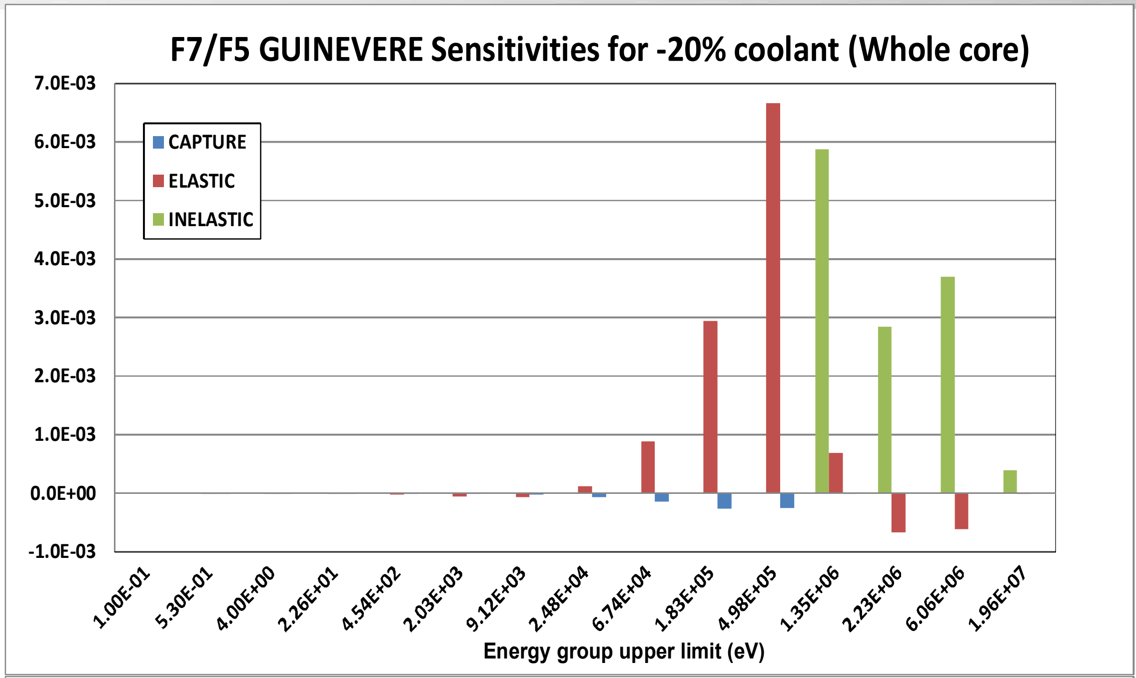


F8/F5 GUINEVERE Sensitivities for -20% coolant (Whole core)
CAPTURE
ELASTIC
INELASTIC
1.8E-02
1.6E-02
1.4E-02
1.2E-02
1.0E-02
8.0E-03
6.0E-03
4.0E-03
2.0E-03
0.0E+00
-2.0E-03
1.00E-01
5.30E-01
4.00E+00
2.26E+01
4.54E+02
2.03E+03
9.12E+03
2.48E+04
6.74E+04
1.83E+05
4.98E+05
1.35E+06
2.23E+06
6.06E+06
1.96E+07
Energy group upper limit (eV)

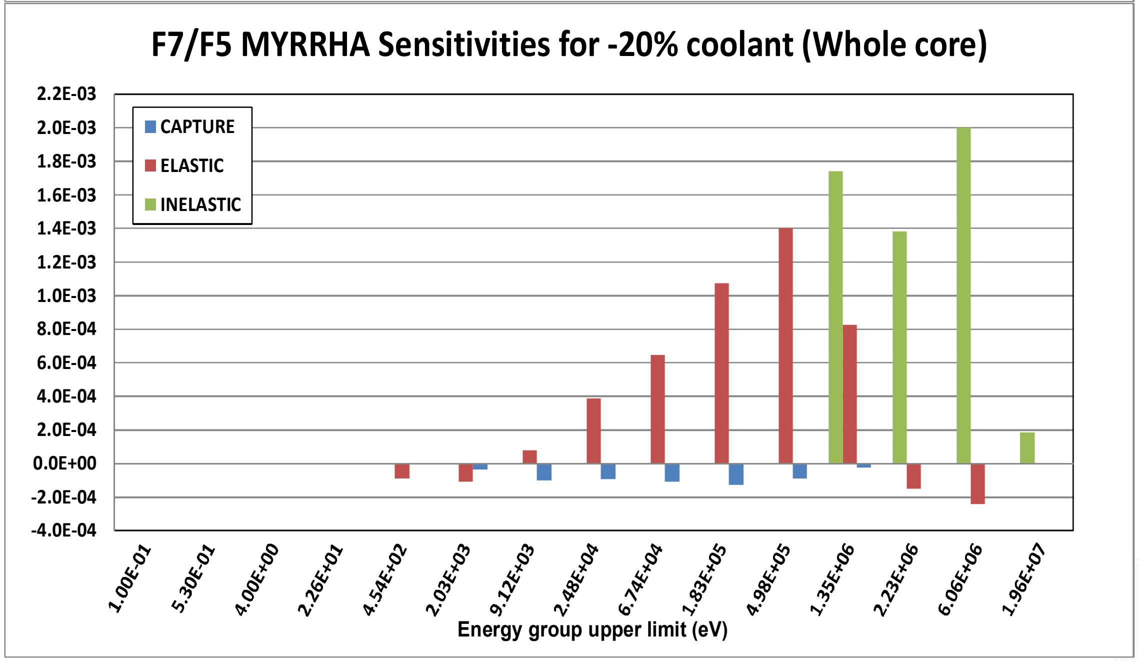


F8/F5 MYRRHA Sensitivities for -20% coolant (Whole core)
CAPTURE
ELASTIC
INELASTIC
8.0E-03
7.0E-03
6.0E-03
5.0E-03
4.0E-03
3.0E-03
2.0E-03
1.0E-03
0.0E+00
-1.0E-03
1.00E-01
5.30E-01
4.00E+00
2.26E+01
4.54E+02
2.03E+03
9.12E+03
2.48E+04
6.74E+04
1.83E+05
4.98E+05
1.35E+06
2.23E+06
6.06E+06
1.96E+07
Energy group upper limit (eV)

Results

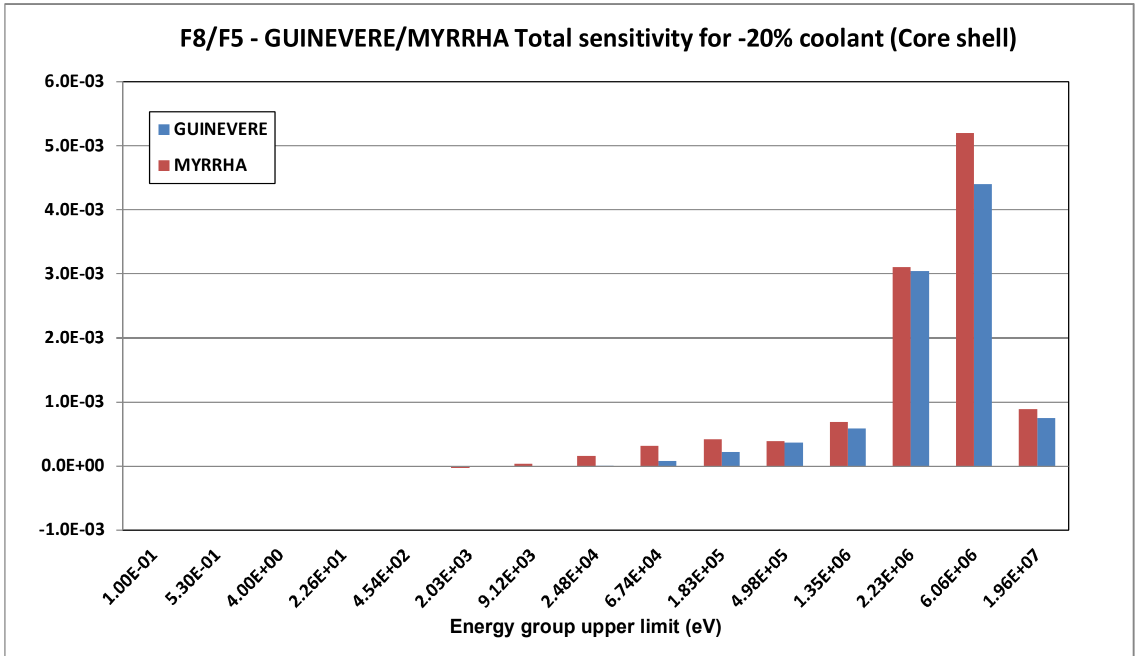


F7/F5 GUINEVERE Sensitivities for -20% coolant (Whole core)
CAPTURE
ELASTIC
INELASTIC
7.0E-03
6.0E-03
5.0E-03
4.0E-03
3.0E-03
2.0E-03
1.0E-03
0.0E+00
-1.0E-03
1.00E-01
5.30E-01
4.00E+00
2.26E+01
4.54E+02
2.03E+03
9.12E+03
2.48E+04
6.74E+04
1.83E+05
4.98E+05
1.35E+06
2.23E+06
6.06E+06
1.96E+07
Energy group upper limit (eV)

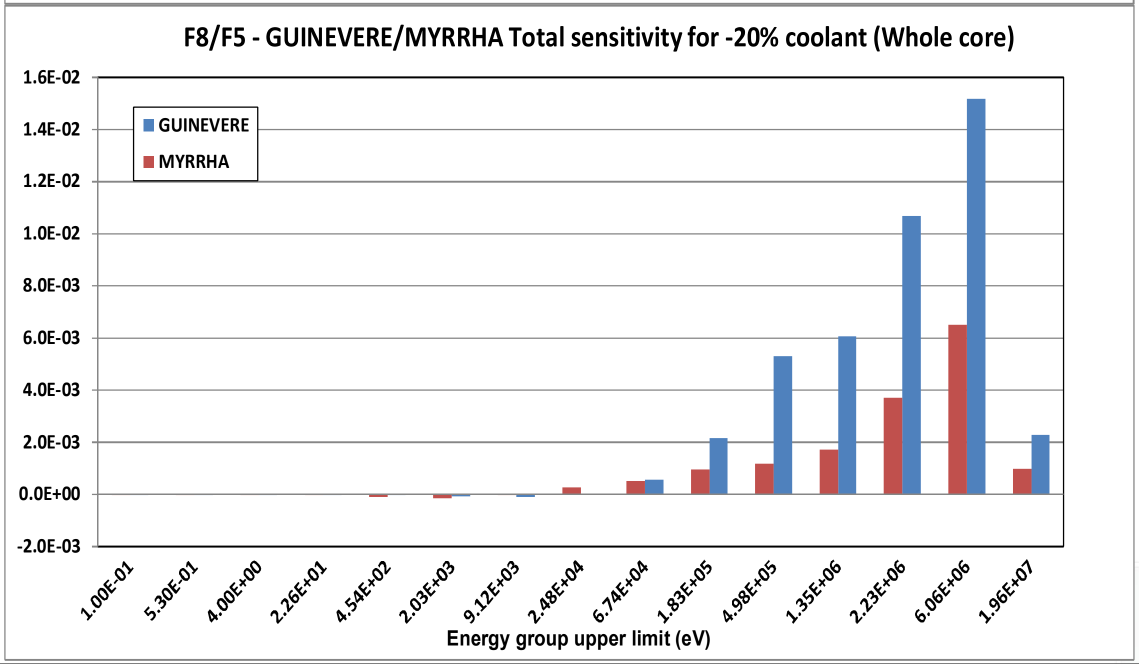


F7/F5 MYRRHA Sensitivities for -20% coolant (Whole core)
CAPTURE
ELASTIC
INELASTIC
2.2E-03
2.0E-03
1.8E-03
1.6E-03
1.4E-03
1.2E-03
1.0E-03
8.0E-04
6.0E-04
4.0E-04
2.0E-04
0.0E+00
-2.0E-04
-4.0E-04
1.00E-01
5.30E-01
4.00E+00
2.26E+01
4.54E+02
2.03E+03
9.12E+03
2.48E+04
6.74E+04
1.83E+05
4.98E+05
1.35E+06
2.23E+06
6.06E+06
1.96E+07
Energy group upper limit (eV)

Results

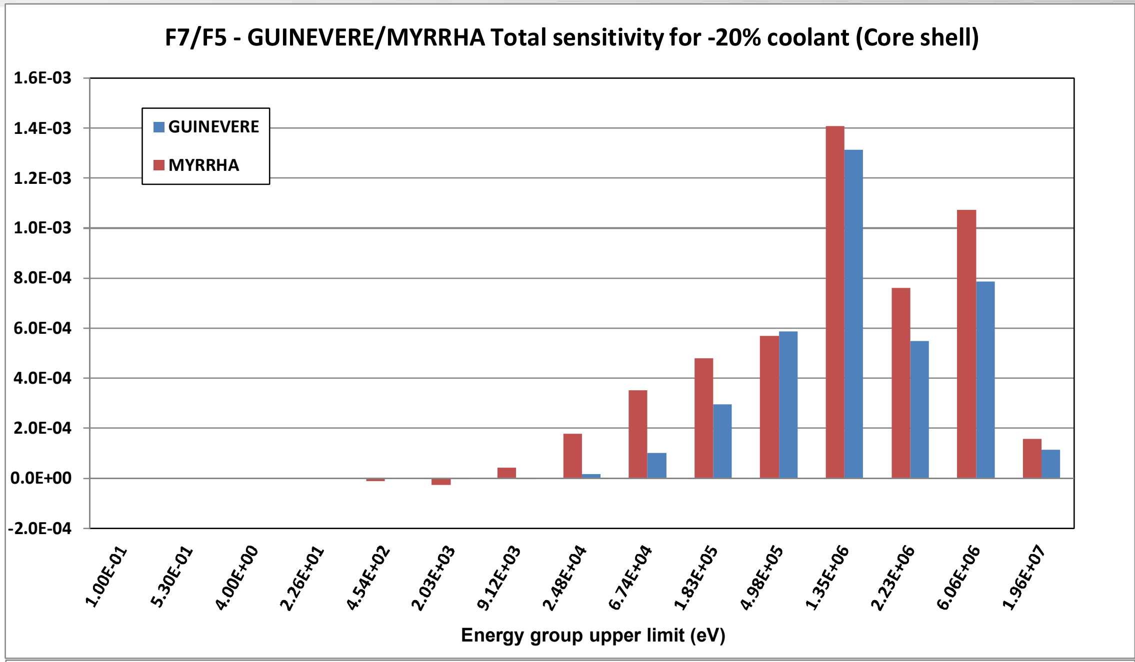


F8/F5 - GUINEVERE/MYRRHA Total sensitivity for -20% coolant (Core shell)
6.0E-03
5.0E-03
4.0E-03
3.0E-03
2.0E-03
1.0E-03
0.0E+00
-1.0E-03
GUINEVERE
MYRRHA
1.00E-01
5.30E-01
4.00E+00
2.26E+01
4.54E+02
2.03E+03
9.12E+03
2.48E+04
6.74E+04
1.83E+05
4.98E+05
1.35E+06
2.23E+06
6.06E+06
1.96E+07
Energy group upper limit (eV)

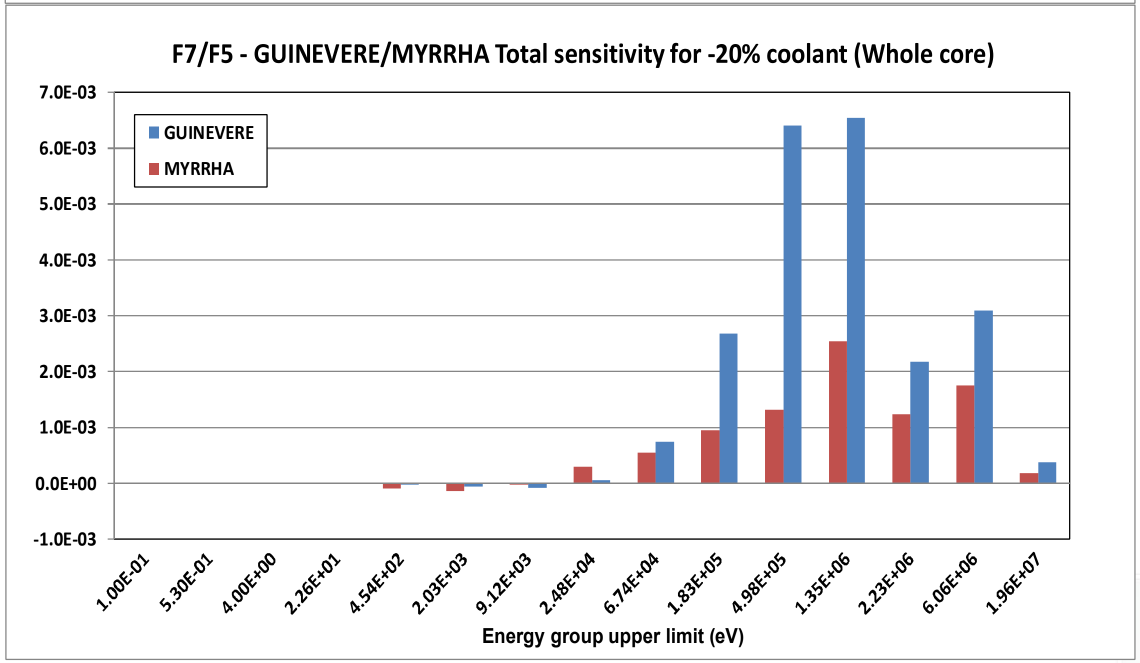


F8/F5 - GUINEVERE/MYRRHA Total sensitivity for -20% coolant (Whole core)
1.6E-02
1.4E-02
1.2E-02
1.0E-02
8.0E-03
6.0E-03
4.0E-03
2.0E-03
0.0E+00
-2.0E-03
GUINEVERE
MYRRHA
1.00E-01
5.30E-01
4.00E+00
2.26E+01
4.54E+02
2.03E+03
9.12E+03
2.48E+04
6.74E+04
1.83E+05
4.98E+05
1.35E+06
2.23E+06
6.06E+06
1.96E+07
Energy group upper limit (eV)

Results



F7/F5 - GUINEVERE/MYRRHA Total sensitivity for -20% coolant (Core shell)
1.6E-03
1.4E-03
1.2E-03
1.0E-03
8.0E-04
6.0E-04
4.0E-04
2.0E-04
0.0E+00
-2.0E-04
GUINEVERE
MYRRHA
1.00E-01
5.30E-01
4.00E+00
2.26E+01
4.54E+02
2.03E+03
9.12E+03
2.48E+04
6.74E+04
1.83E+05
4.98E+05
1.35E+06
2.23E+06
6.06E+06
1.96E+07
Energy group upper limit (eV)



F7/F5 - GUINEVERE/MYRRHA Total sensitivity for -20% coolant (Whole core)
7.0E-03
6.0E-03
5.0E-03
4.0E-03
3.0E-03
2.0E-03
1.0E-03
0.0E+00
-1.0E-03
GUINEVERE
MYRRHA
1.00E-01
5.30E-01
4.00E+00
2.26E+01
4.54E+02
2.03E+03
9.12E+03
2.48E+04
6.74E+04
1.83E+05
4.98E+05
1.35E+06
2.23E+06
6.06E+06
1.96E+07
Energy group upper limit (eV)

Results

	-20% coolant in core shell	-20% coolant over the whole core
F9/F5	8.89E-01	9.16E-01
F8/F5	9.95E-01	9.90E-01
F7/F5	9.81E-01	9.48E-01

Correlation coefficients

Conclusions

- **GPT methodologies can provide a codified "key to reading" to the properties of some GUINEVERE integral characteristics respect to analogous characteristics in MYRRHA.**

- **The present work has been focused on the analysis, by numerical simulations, of the representativeness, with respect to the MYRRHA situation assumed as reference system, of the behaviour in GUINEVERE of the spectral indexes F9/F5, F8/F5 and F7/F5 following a localized (core shell) or global (whole active core) lead (GUINEVERE) or lead-bismuth (MYRRHA) 20% density reduction.**

- **The analysis, carried out by means of GPT methodologies implemented into the ERANOS French neutronic code, and using the US dispersion matrix BOLNA, provided encouraging results concerning the correlation for all the spectral indexes taken into account.**