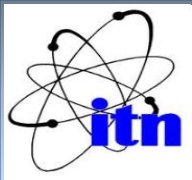


Neutronic Assessment and Criticality Analysis of the In-Vessel Fuel Storage Facilities in the Central Design Team (CDT) Project

S.Di Maria, M.Ottolini, M.Sarotto, F.Martin-Fuertes, M.Vazquez,
E.Malambu Mbala, P.Teles, P.Vaz, D.Castelliti, M.Reale, L.Mansani, P.Baeten

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Content



- Brief introduction on nuclear energy issues
- CDT design project description
- Characterization description (in terms of criticality, **displacement per atom** and power calculations) of the fuel storage vessels
- Conclusions

two general considerations to be taken into account in the nuclear energy related issues are:

I) availability of the nuclear fuel reserves to produce energy

- U235 is present at only 0.7% in natural uranium
- present reactors are thermal-neutron based technology



possible solutions:
FAST REACTORS

II) management of the radioactive waste coming from spent nuclear fuel

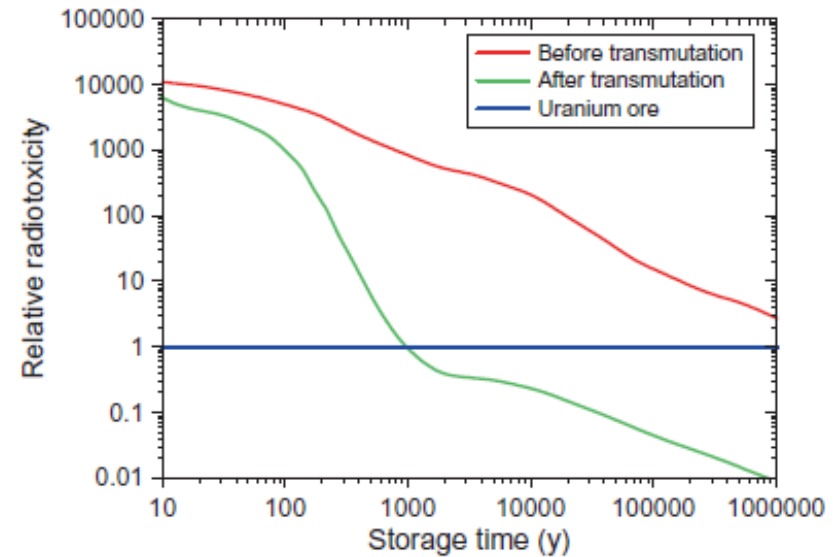
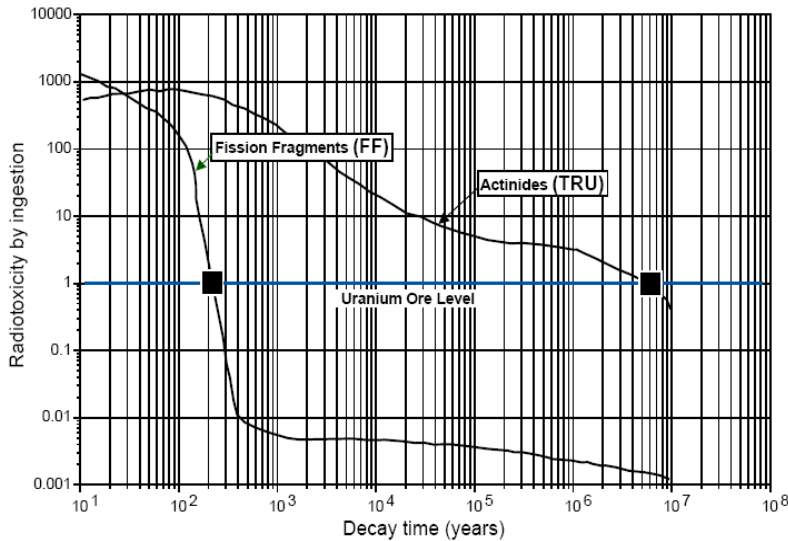
- time scale of radiotoxicity waste is very long (5E5 to 1E6 years)
- too long monitoring periods required



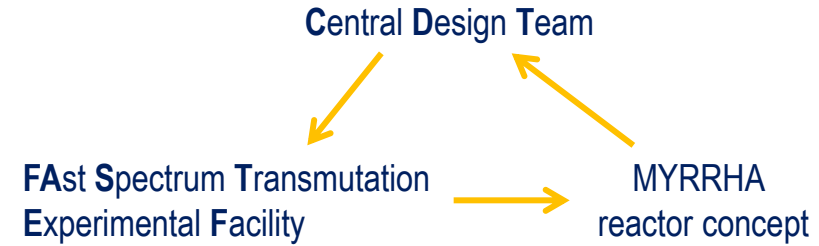
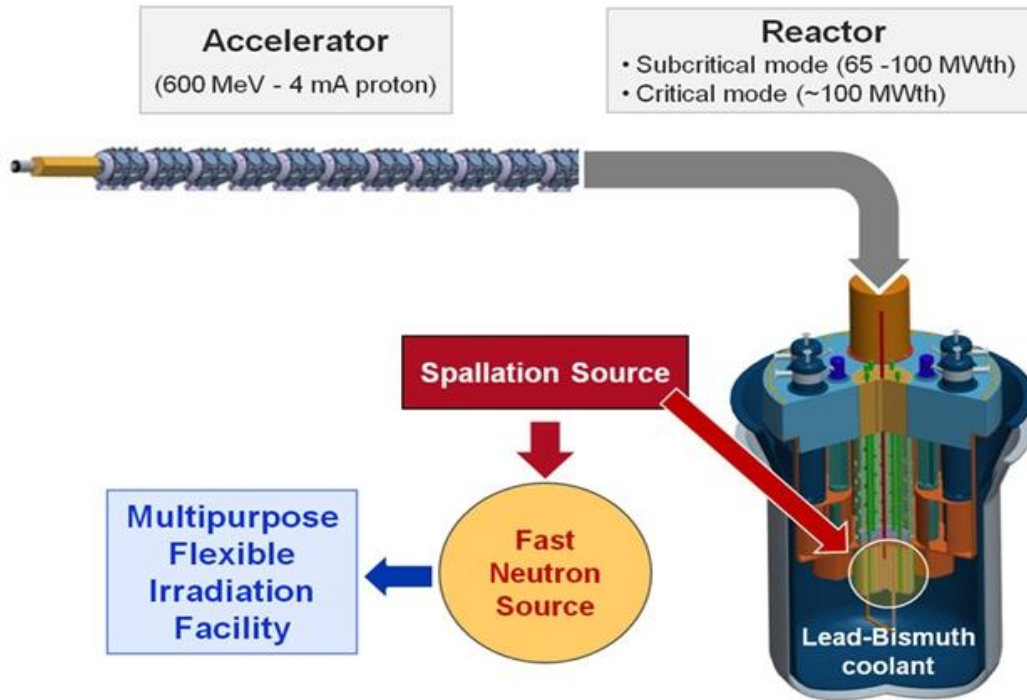
possible solutions:
TRANSMUTATION

TRANSMUTATION

- ADS (nuclear reactor with a subcritical core coupled with an external source)
- fast reactor
(the introduction of Minor Actinides (MA) in the reactor core requires to guarantee the safe operation of the system)

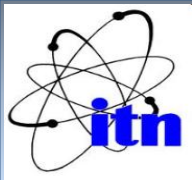


ADS has been designed to destroy MA with the highest efficiency



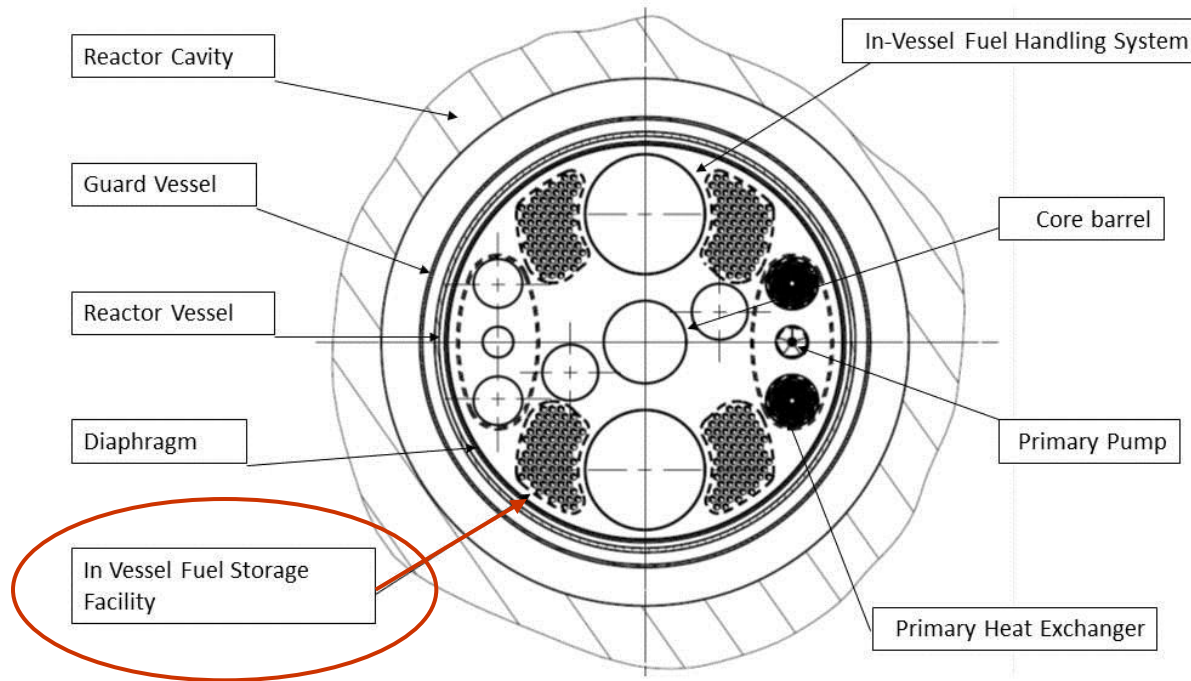
Planned to be built during the next decade under the supervision of the SCK-CEN Belgian Nuclear centre and in collaboration with different national and international partners

- ❑ **Define new R&D activities:**
 - fuel developments for innovative reactor systems;
 - materials developments for GEN IV systems;
 - radioisotope production;
 - industrial applications, such as Si-doping;
 - the study of the efficient transmutation of high - level nuclear waste (MA) requesting high flux intensity ($\Phi_{>0.75 \text{ MeV}} = 10^{15} \text{ n/cm}^2 \text{ sec}^{-1}$)

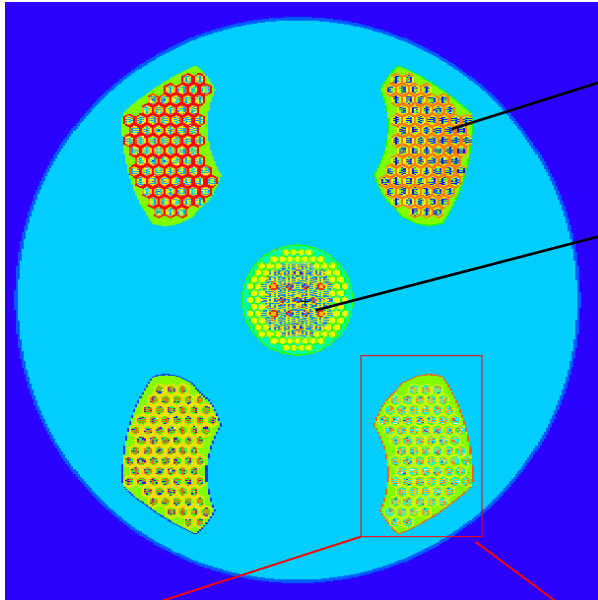


An important issue regarding the MYRRHA/FASTEF reactor design is the In-Vessel Fuel Storage Facility (IVFSF) both for:

- ❑ fresh fuel (the criticality of the overall system must be analyzed and quantified in order to avoid neutron interaction between the core and the fuel in the storage vessels) → critical core operational mode is considered for the following calculations
- ❑ spent fuel (decay heat estimation due to the power release of β and γ decay of actinides and fission products)

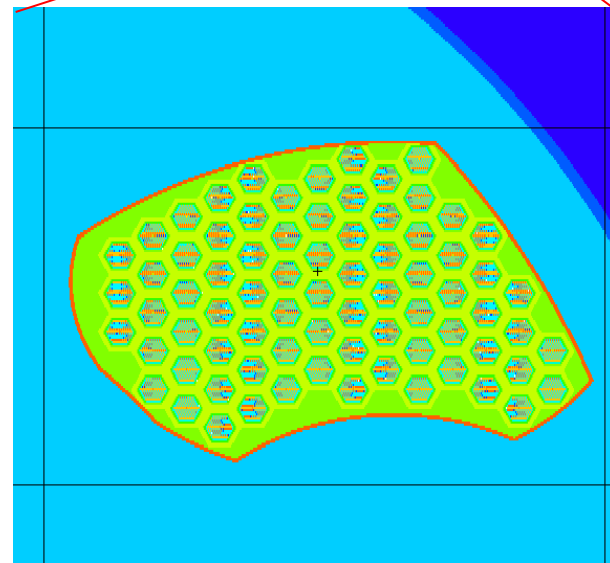
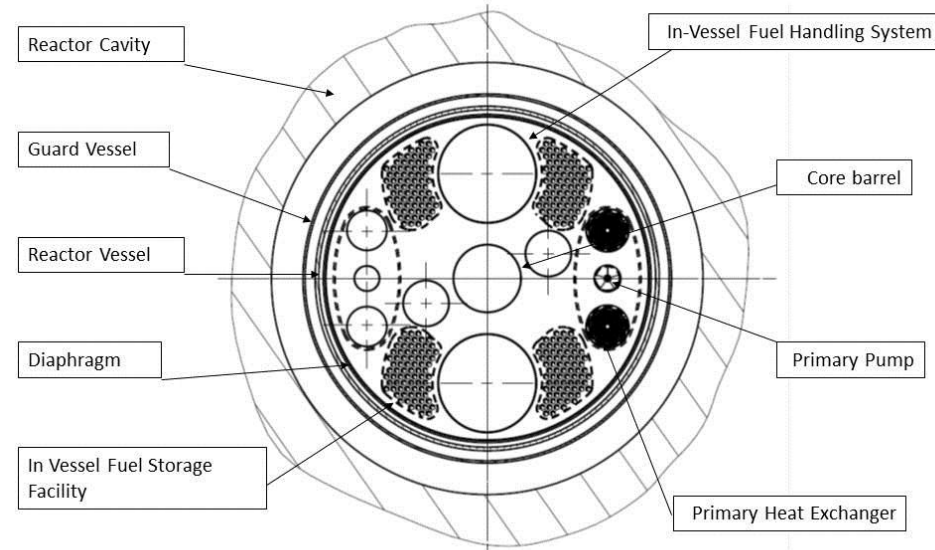


- four IVFSF are foreseen in the actual MYRRHA/FASTEF design in order to contain two core assemblies (76 assemblie positions in each tank)
- strange shape: position of IVFSF in the fuel handling system working area in order to avoid excessive delay between two operation cycles and at the same time to keep the storage vessels far away from the core

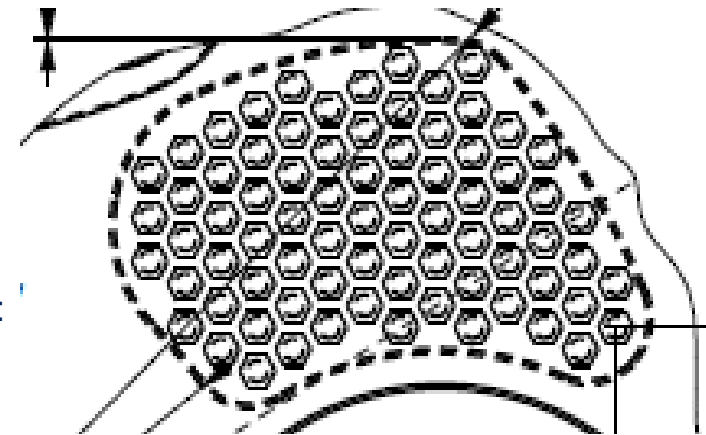


IVFSF

core



- ✓ storage vessel thickness: 1.5 cm AISI 316L
- ✓ diaphragm vessel thickness: 4.5 cm AISI 316L



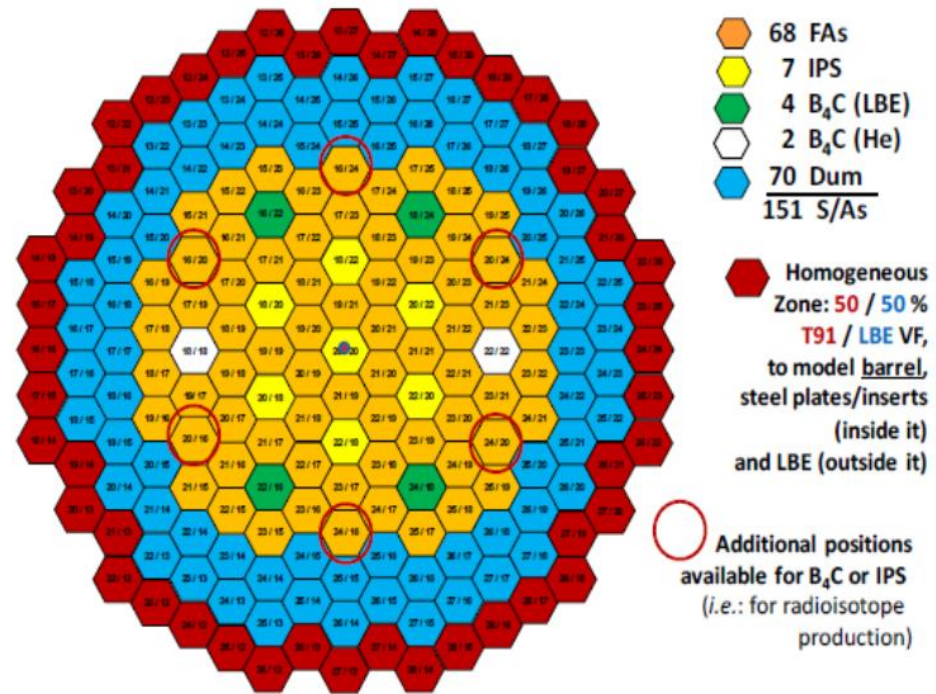
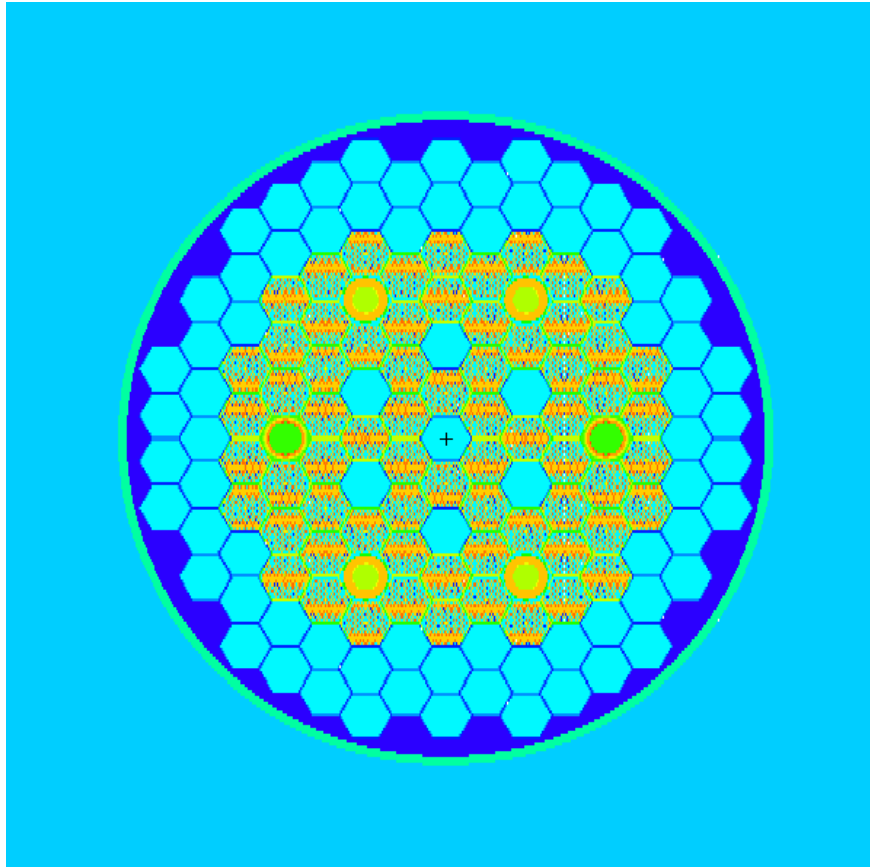
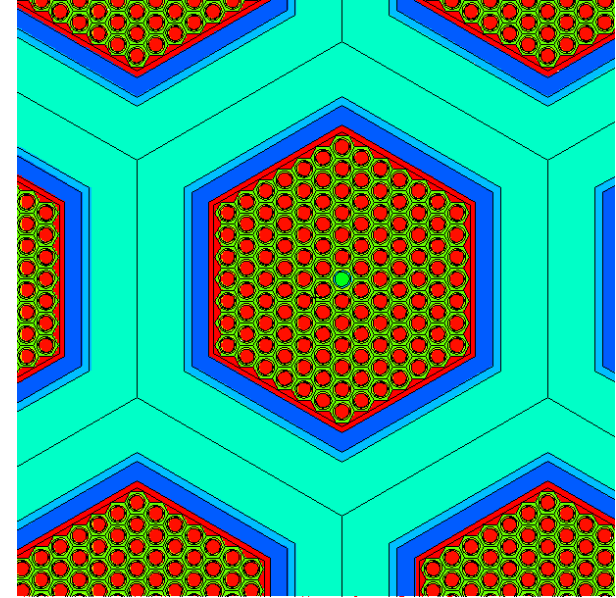
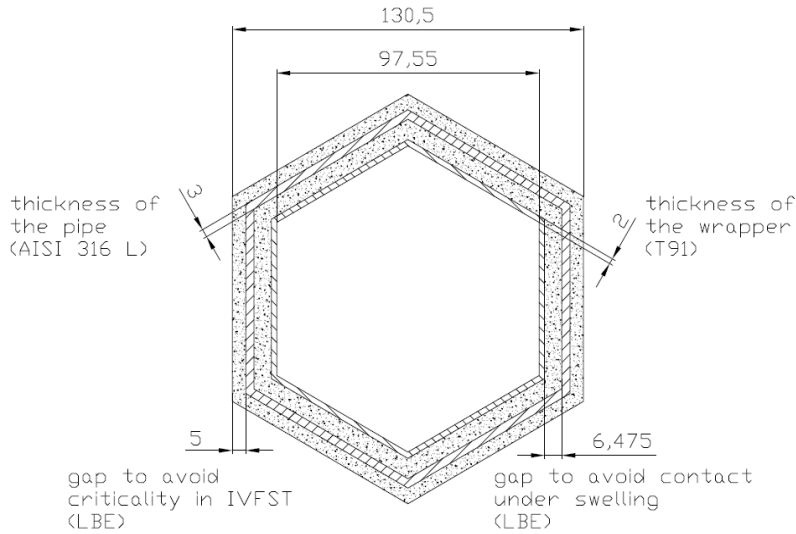


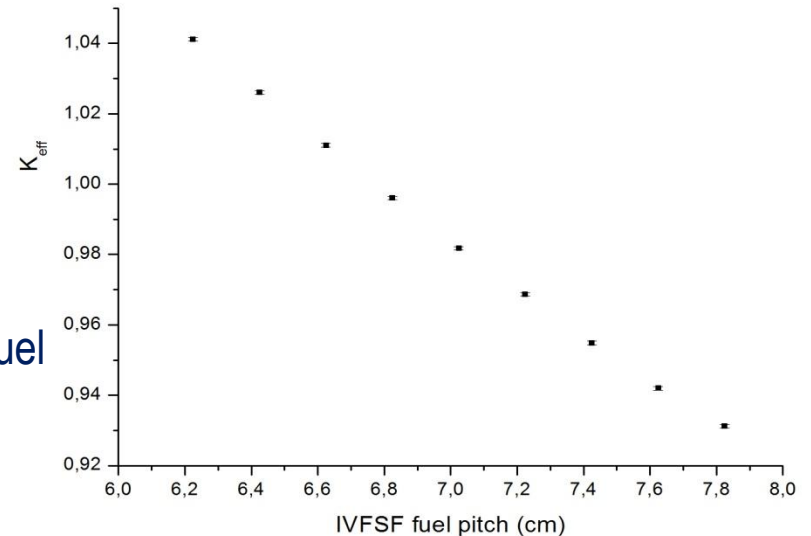
Figure 3 Preliminary design of the 100 MW (68 FA) critical core.

- ✓ MCNPX 2.6.0 version used for calculations
- ✓ 68 FA
- ✓ 33% Pu content MOX fuel
- ✓ Working temperature (tmp card): LBE (300 K), SS (300 K), Fuel (300K)
- ✓ JEFF 3.1 libraries: 300 K for LBE and SS, 300 K for Fuel
- ✓ core barrel thickness: 2 cm AISI316 L

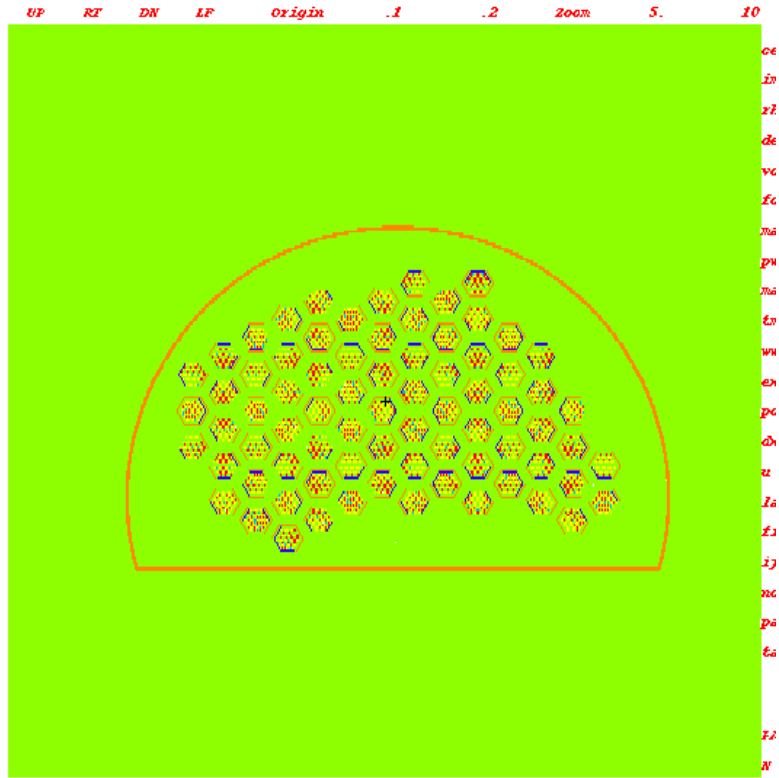


- ✓ the LBE gap in the IVFSF pipe was chosen to avoid criticality in the most conservative case with 76 fresh fuel assemblies in order to get a $K_{\text{eff}} < 0.95$
- ✓ working temperature (tmp card):
LBE (300 K), SS (300 K), Fuel (300 K)
JEFF 3.1 libraries: 300 K for LBE and SS, 300 K for Fuel

$$K_{\text{eff}} (\text{shape}) = 0.93421 \pm 0.00031$$

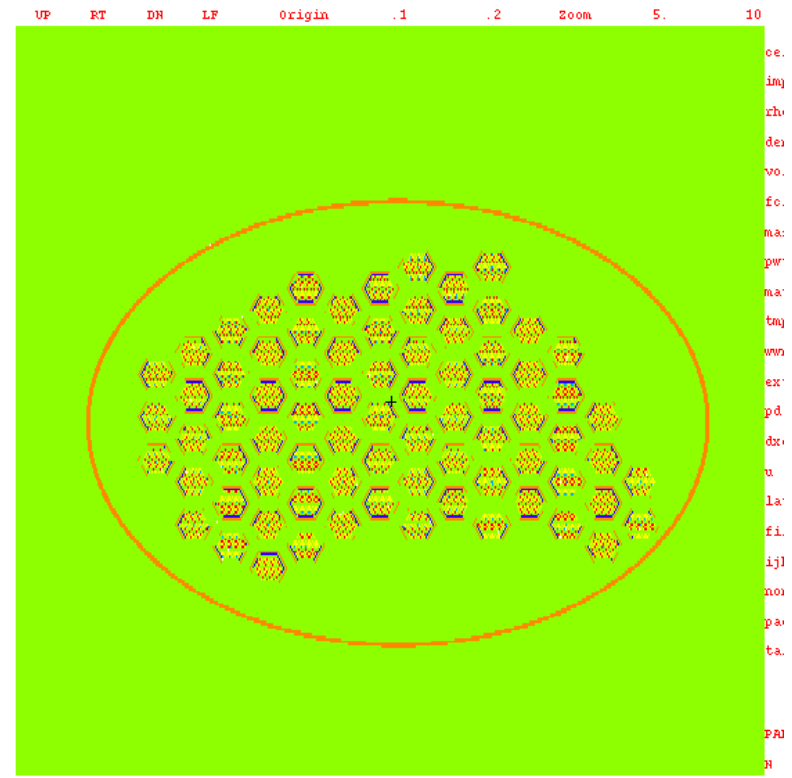


to see how the criticality of the IVFSF is influenced by the shape of the vessel



$$K_{\text{eff}}(\text{scyl}) = 0.93845 \pm 0.00051$$

$$K_{\text{eff}}(\text{scyl}) - K_{\text{eff}}(\text{shape}) = 424 \text{ pcm}$$

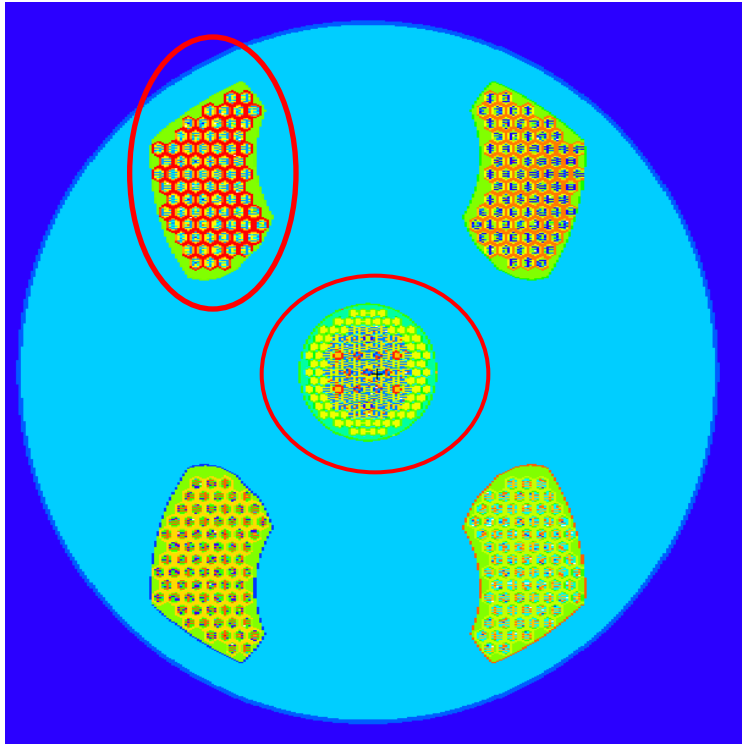


$$K_{\text{eff}}(\text{ell}) = 0.93807 \pm 0.00061$$

$$K_{\text{eff}}(\text{ell}) - K_{\text{eff}}(\text{shape}) = 386 \text{ pcm}$$

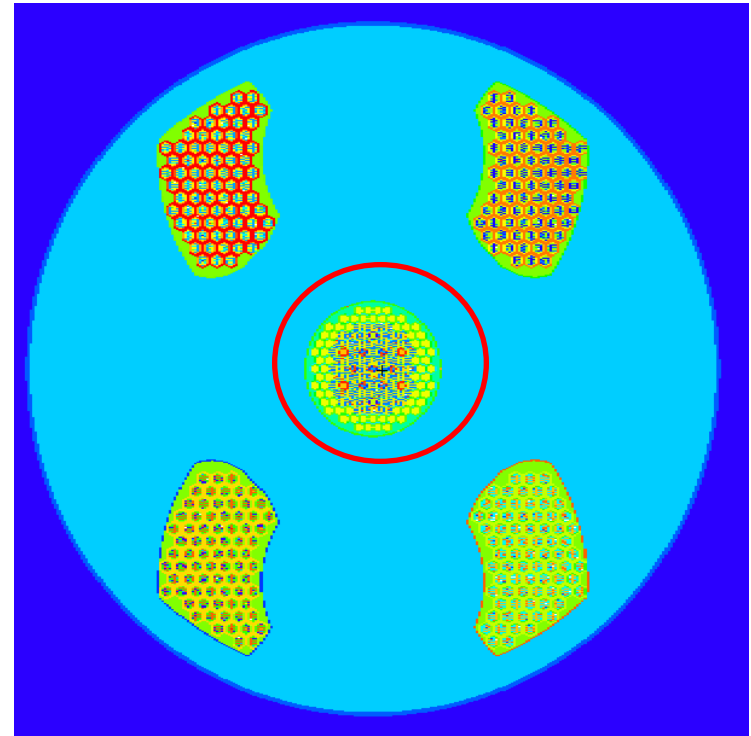
Small influence of the shape on K_{eff}

68 FA in the core+68 FA in one IVFSF



$$K_{\text{eff}} = 1.04353 \pm 0.00049$$

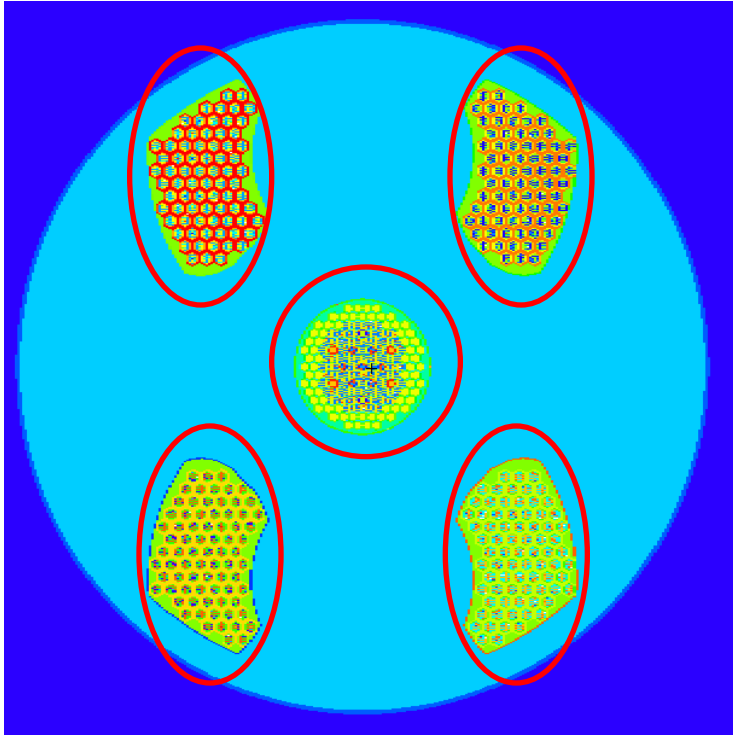
68 FA in the core



$$K_{\text{eff}} = 1.04342 \pm 0.00051$$

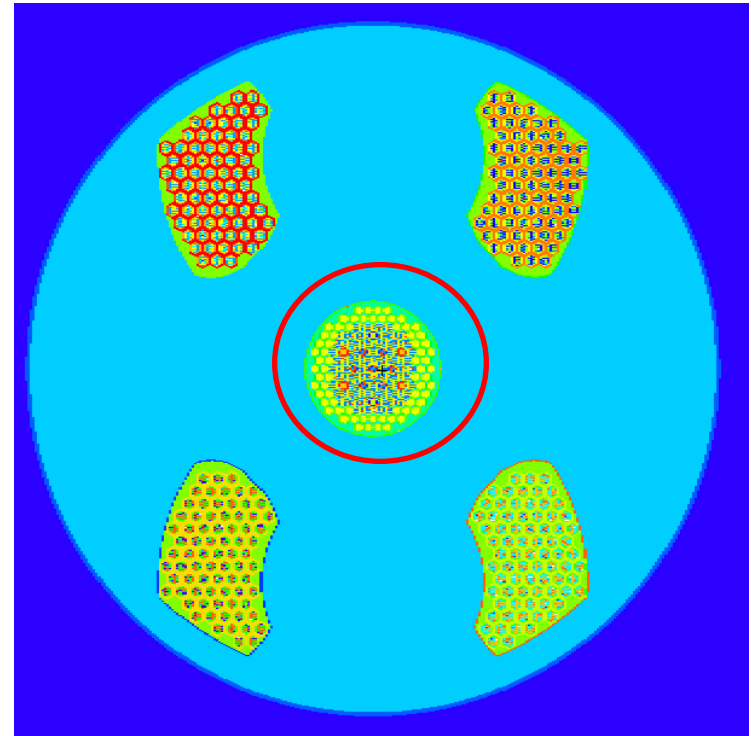
No neutron coupling

68 FA in the core+ 17 FA in each storage vessel



$$K_{eff} = 1.04299 \pm 0.00060$$

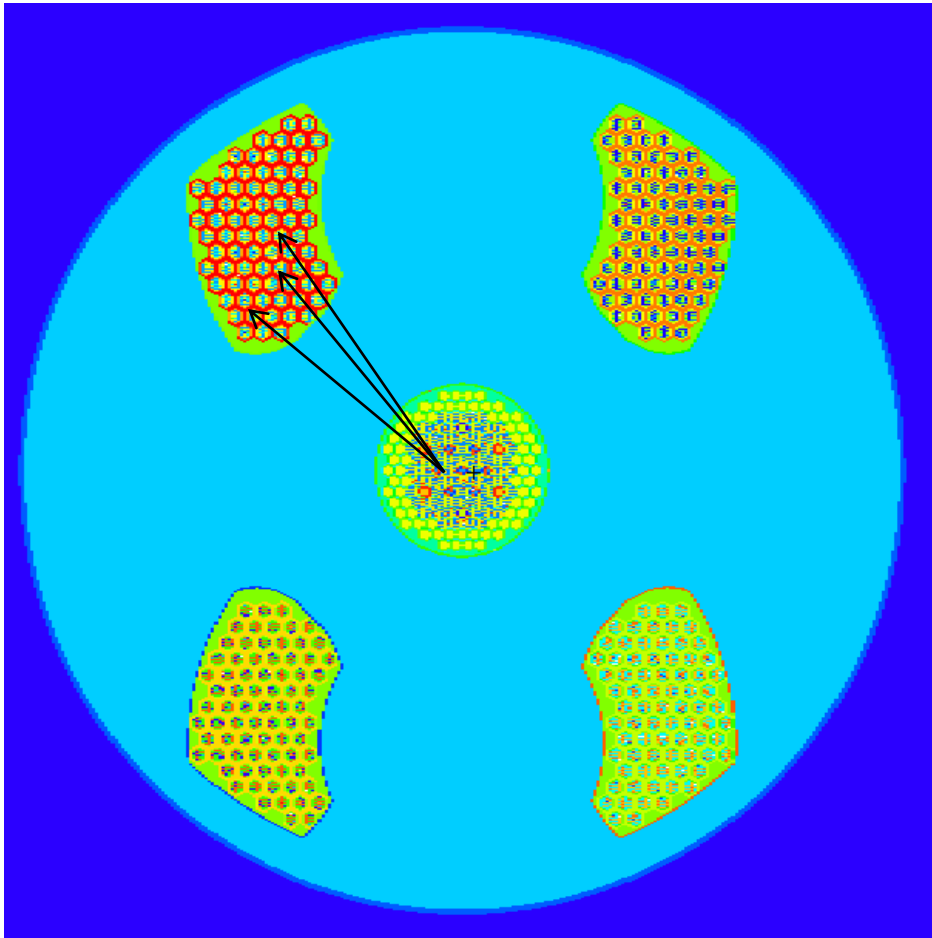
68 FA in the core



$$K_{eff} = 1.04342 \pm 0.00051$$

No neutron coupling

Power generated by neutron flux coming from the critical core in the IVFSF:



MCNPX calculations:

$$\text{Normalization factor} = \frac{P[\text{W}] \bar{\nu} \left[\frac{\text{neutron}}{\text{fission}} \right]}{\left(1.6022 \cdot 10^{-13} \frac{\text{J}}{\text{MeV}} \right) w_f \left[\frac{\text{MeV}}{\text{fission}} \right] k_{eff}} \cdot 1$$

Power \approx 1.5 MW/storage vessel



Power calculation in the IVFSF (2/3)



Power contribution by (α,n) source (for fresh fuel):

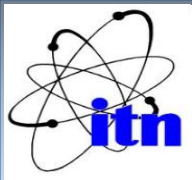
U-235	37.8	} $1.35 \cdot 10^8$ n/s
U238	60.99	
Pu238	1.14E8	
Pu239	7.89E6	
Pu240	1.41E2	
Pu241	1.38E7	
Pu242	5.6E4	

ORIGEN 2.2 calculations

	BoL [kg]
U235	5.33
U238	734.92
Pu238	8.49
Pu239	207.12
Pu240	98.33
Pu241	22.22
Pu242	28.01
MA	0.00
HN	1104.41

MCNPX (energy deposition F6 tally) calculations considering the above neutron yield normalization factor:

Power \approx 0.020 Watt



Power calculation in the IVFSF (3/3)



Power contribution by spontaneous fission (SF) source (for fresh fuel):

U-235	1.59	} $1.7 \cdot 10^8$ n/s
U238	9.99E3	
Pu238	2.19E7	
Pu239	4.51E3	
Pu240	1.00E8	
Pu241	1.09E3	
Pu242	4.81E7	

ORIGEN 2.2 calculations

	BoL [kg]
U235	5.33
U238	734.92
Pu238	8.49
Pu239	207.12
Pu240	98.33
Pu241	22.22
Pu242	28.01
MA	0.00
HN	1104.41

MCNPX (energy deposition F6 tally) calculations considering the above neutron yield normalization factor:

Power \approx 0.025 Watt

$$\frac{dpa}{sec} = \sum_E \frac{\langle \sigma E \rangle}{2E_d} \eta \cdot \phi(E)$$

Norgett-Robinson-Torrens (NRT) theories

σE = dpa energy cross-section

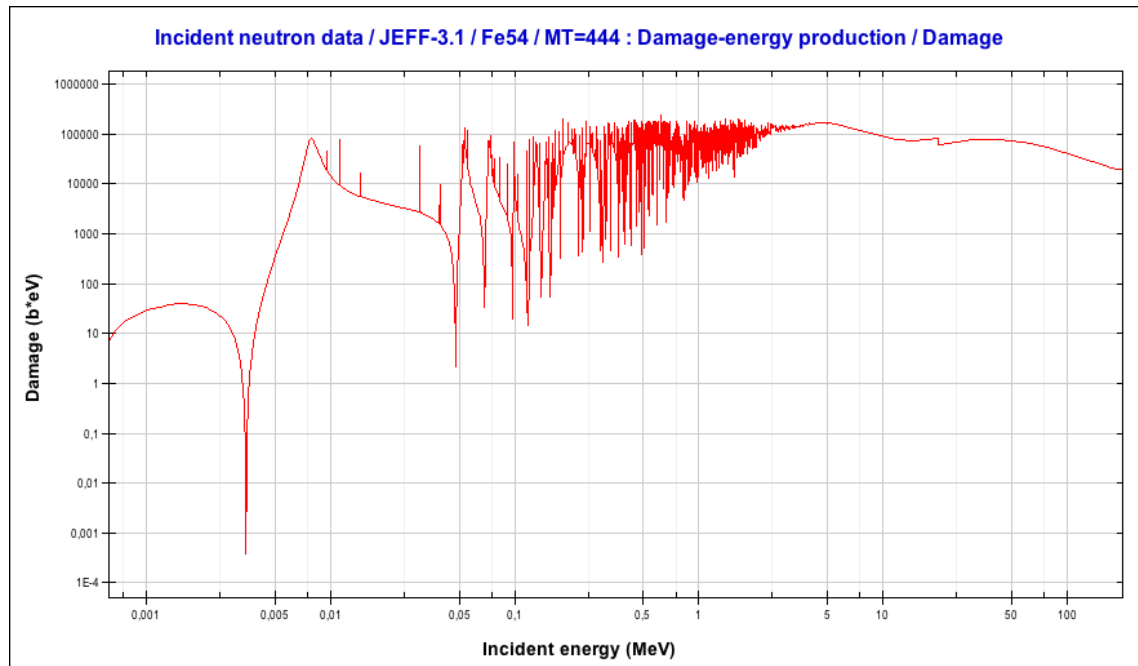
η = displacement efficiency (0.8)

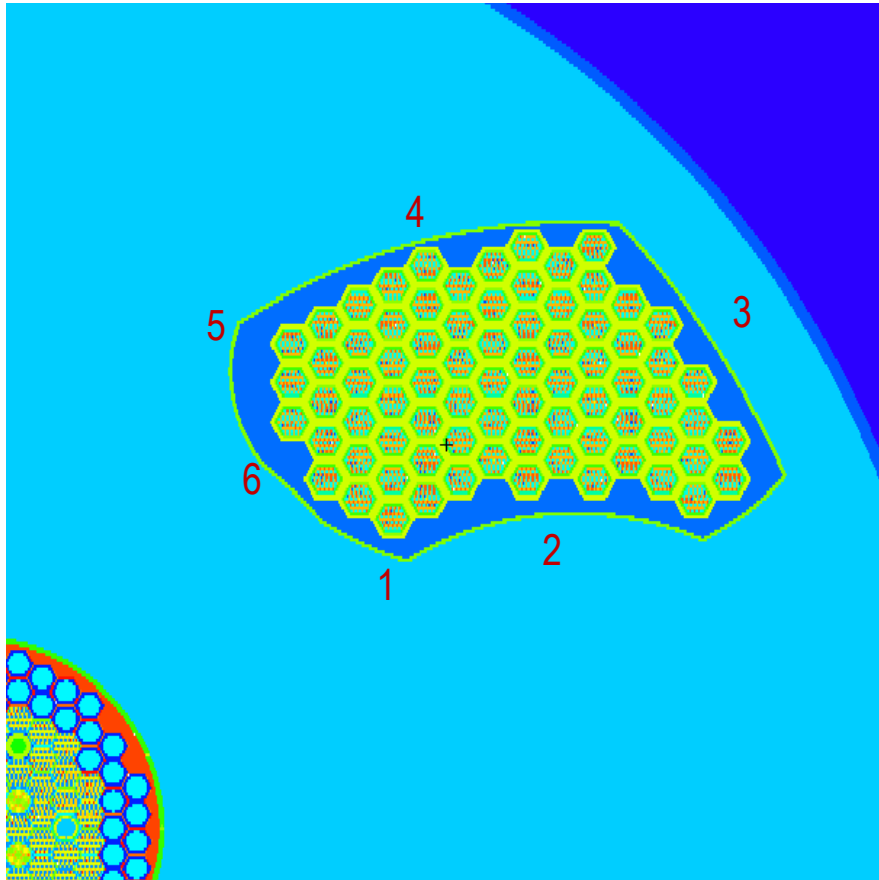
E_d = energy required to displace an atom from lattice position (24-40 eV)

$\Phi(E)$ = neutron flux per energy bin

contribution of the neutron flux coming from the critical core

- ✓ calculation in a sphere of 0.7 cm of radius in AISI 316L material
- ✓ AISI 316L compound composed by Cr52, Fe54, Fe56, Ni58, Ni60
- ✓ NJOY cross-section processing to calculate dpa cross-section





1 \approx 0.014 dpa/year

2 \approx 1.55E-4 dpa/year

3 \approx 0

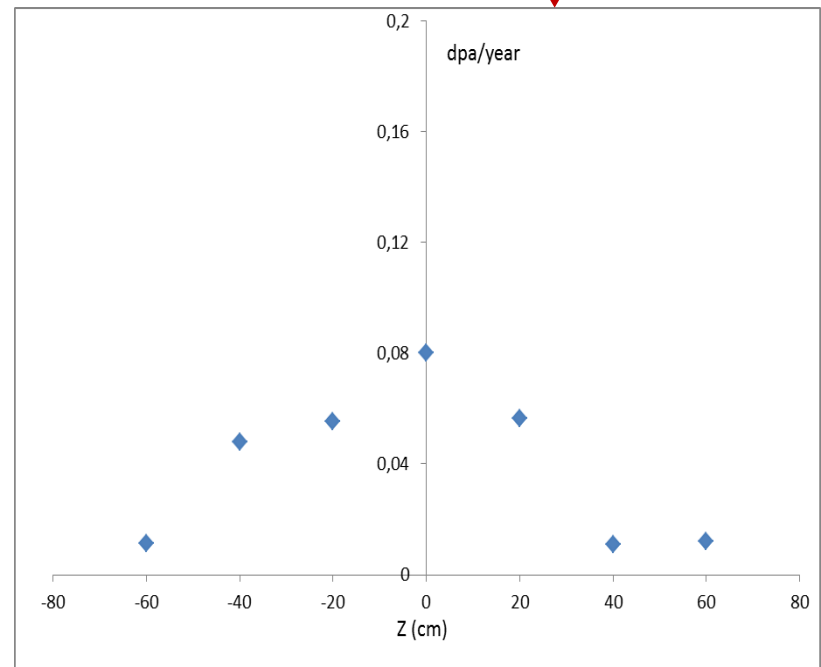
4 \approx 5.57E-5 dpa/year

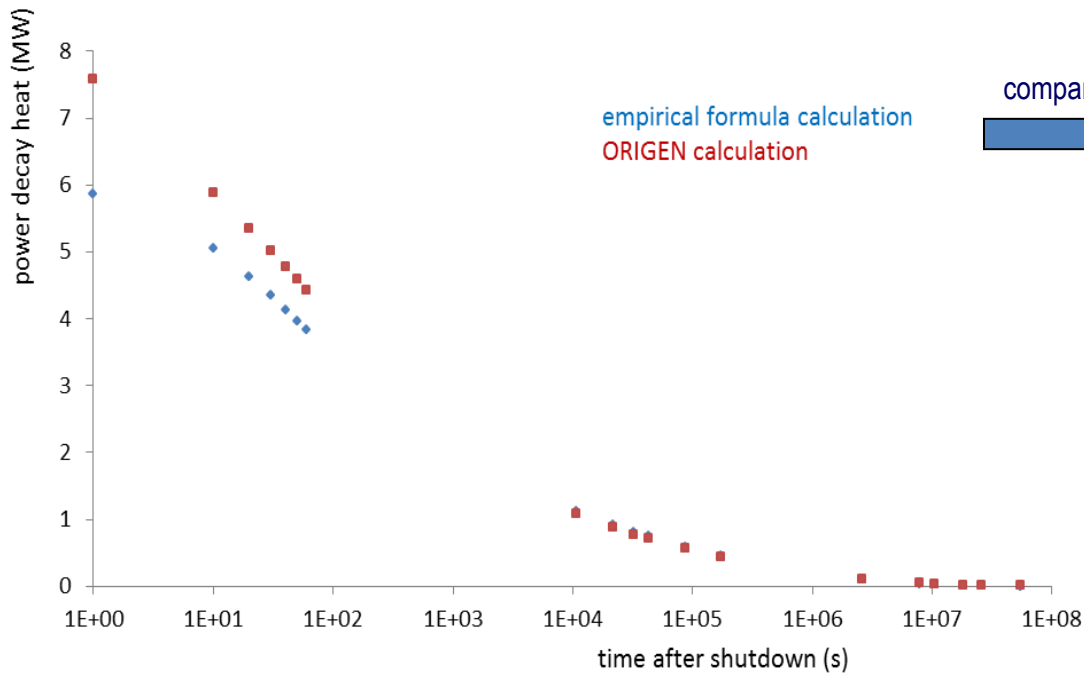
5 \approx 0.04 dpa/year


6 \approx 0.08 dpa/year

Z plane for calculation = 0

axial dpa distribution
in position 6





comparison 

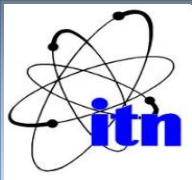
Importance of using decay heat data derived from an appropriate reactor model

ORIGEN 2.2 program to calculate the decay heat of spent fuel:

- ✓ fast reactor model
- ✓ 100 MW nominal power reactor operation
- ✓ 90 days fuel irradiation

some ORIGEN assumptions:

- fission product produced not only by U235, U238, Pu239, Pu241- also other actinides are taken into account for fast fission
- recoverable energy per fission as function of the fissioning nuclide



Conclusions and outlines



Taking into account the current MYRRHA/FASTEF reactor design operating at critical mode, a characterization in terms of criticality, dpa and power calculations was performed for the IVFSF:

- ❖ **In-Vessel Fuel Storage design conceived to store fresh fuel assemblies in a safe way inside the diaphragm (K_{eff} of the IVFSF fuel pitch < 0.95 through MCNPX simulations)**
- ❖ **No neutron coupling between critical core and IVFSF even considering the presence of 68 FA in the storage vessel, as pointed out by MCNPX Monte Carlo simulations**
- ❖ **The power generated in the IVFSF by the neutron flux coming from the critical core, SF source and (α, n) source were quantified and are of the order of 1.5 MW / IVFSF, 0.025 W / IVFSF and 0.020 W / IVFSF respectively;**
- ❖ **Max dpa/year value due to the neutron flux coming from the core and calculated in the storage vessel is of the order of 0.08 dpa/year**