MYRRHA: a multipurpose research facility for waste management & fast spectrum irradiation. Importance of Nuclear Data for MYRRHA project

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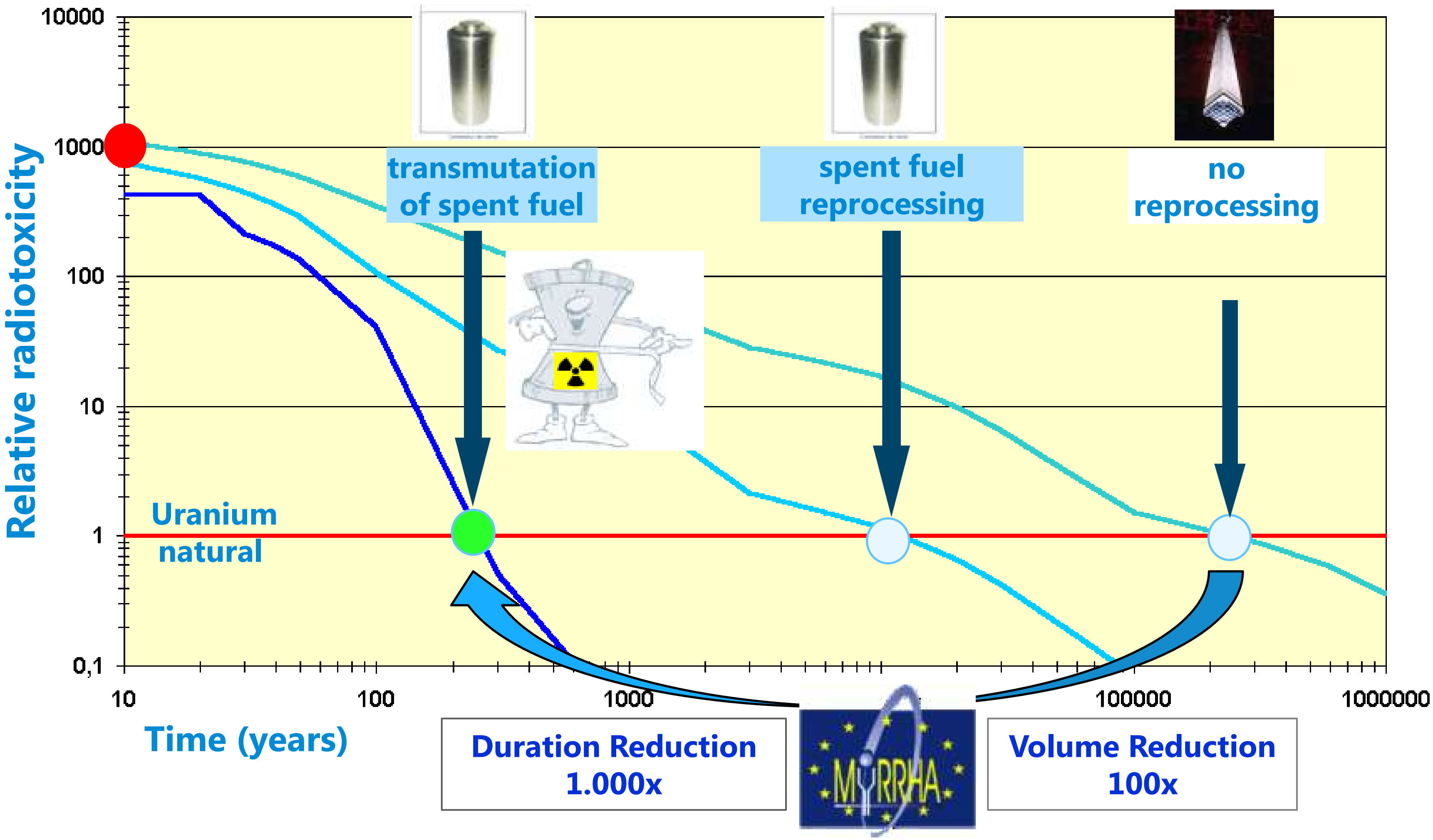
MYRRHA

Outline

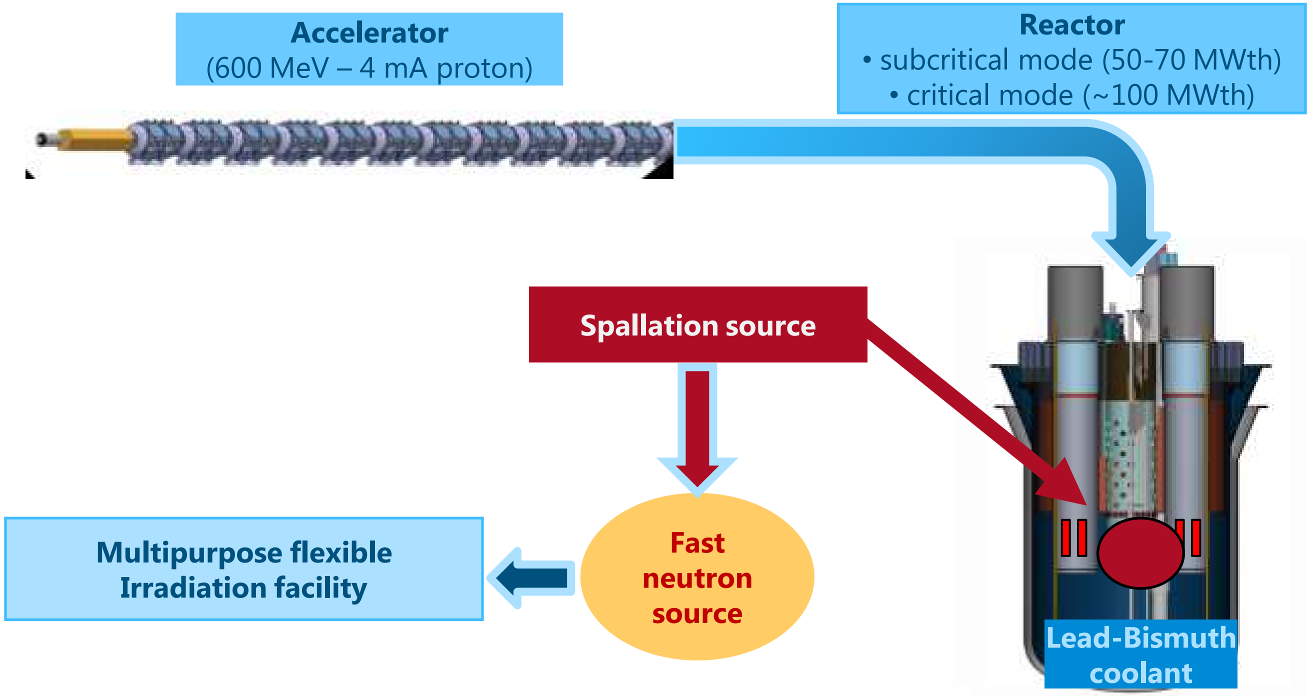
- Overview of MYRRHA project
  - Objective of MYRRHA
  - The main components of MYRRHA
  - Implementation approach
  - Programme structure
- Nuclear data & associated uncertainties in reactor energy domain (< 20 MeV)
  - Uncertainties on main safety parameters (k_{eff}, decay heat…)
  - Data validation through integral experiments at VENUS-F
- ADS-specific nuclear data and associated uncertainties above 20 MeV
  - Neutron multiplicities
  - Spallation products
  - Radiation damage

Transmutation of HLW is an acceptable solution



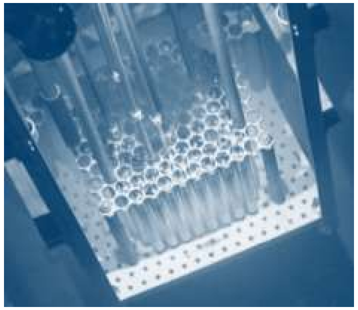
Key objective of the MYRRHA-programme

- Construction of an Accelerator-Driven System (ADS) consisting of
  - A 600 MeV – max. 4 mA proton linear accelerator
  - A spallation target/source
  - A lead-Bismuth Eutectic (LBE) cooled reactor able to operate in subcritical & critical mode



MYRRHA is a multipurpose research facility

Fission GEN IV



Fusion

Waste

Multipurpose
h**Y**brid
Research
Reactor for
High-tech
Applications

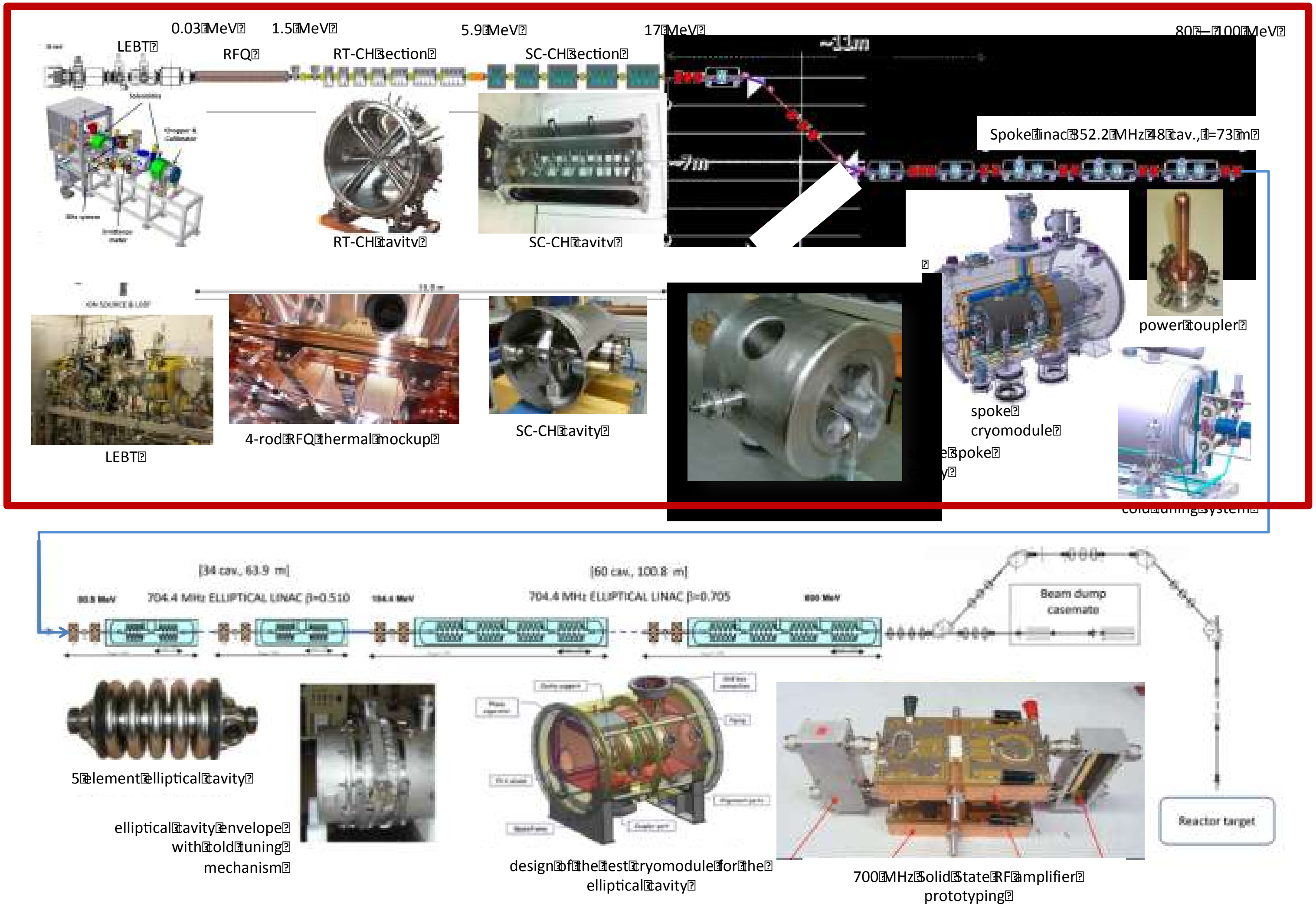
Fundamental research

Radioisotopes

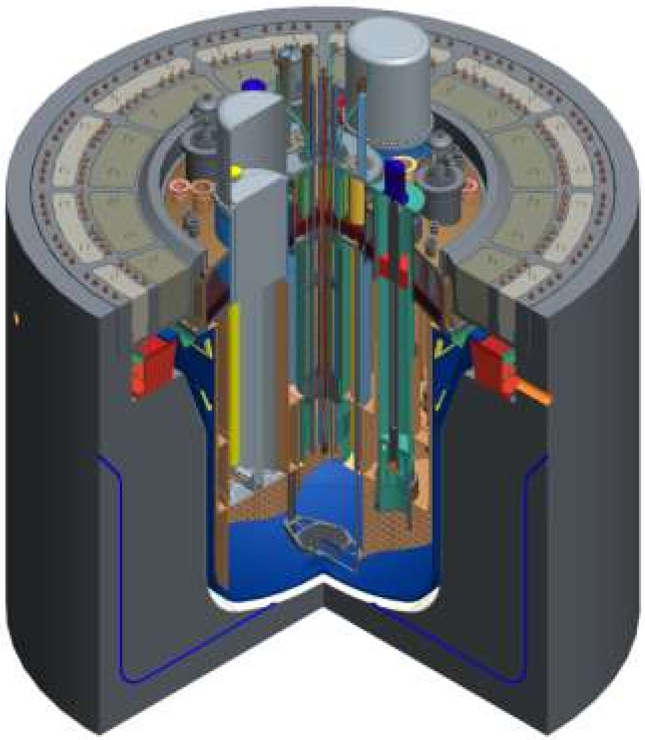
Silicon doping

MYRRHA accelerator design

MYRRHA accelerator 0 – 100 MeV section



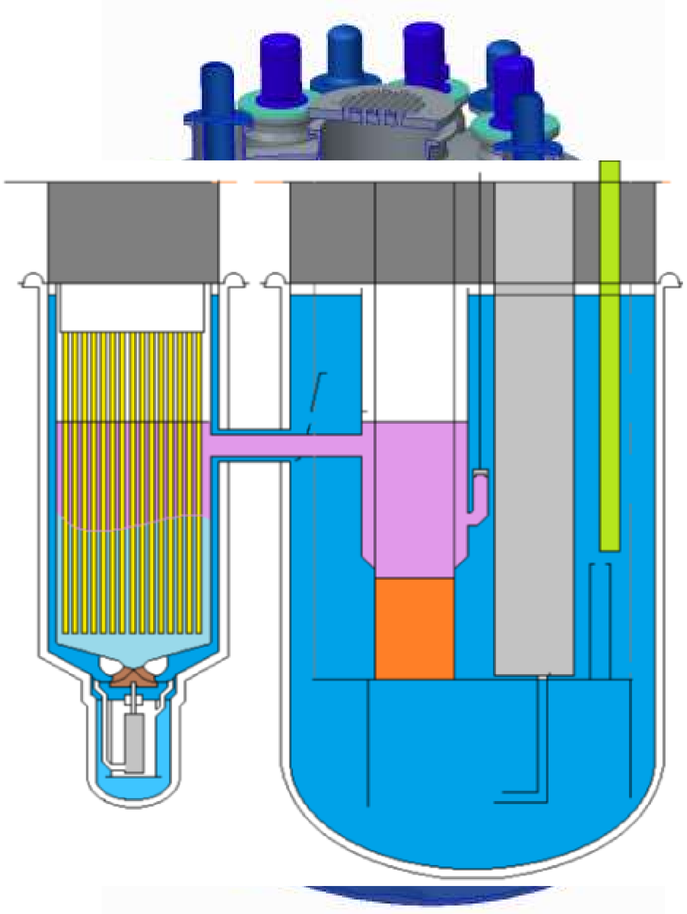
MYRRHA reactor design



MYRRHA design rev. 1.6
Ø reactor vessel : 10,4 m
Ø reactor skirt: 14,6m

- MYRRHA primary system rev. 1.6 consolidated
  - Operation in critical mode limited to 100 MW_{th}
  - Four lines of defence for major safety functions
- End 2014 total cost 1,6 G€
- Po-issue
- O_2-concentration control

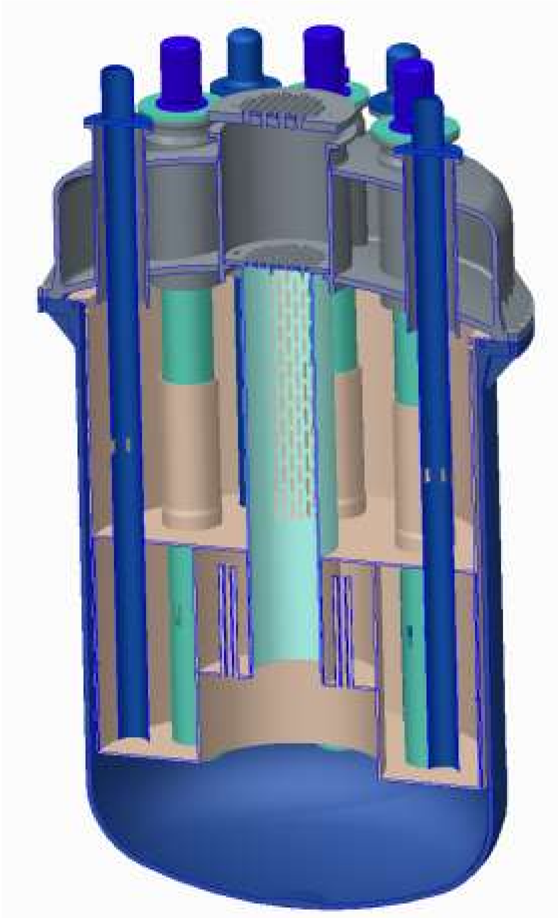
MYRRHA reactor design



- Four MYRRHA primary system design options investigated to reduce the dimensions of the reactor vessel (& associated cost)

Option	Reactor type	Description
1	Pool	Reduced size Innovative IVFHM & double-walled PHX
3	Loop	Top loading

MYRRHA reactor design



- Four MYRRHA primary system design options investigated to reduce the dimension of the reactor vessel (& associated cost)

Option	Reactor type	Description
1	Pool	Reduced size Innovative IVFHM & double-walled PHX
2	Loop	Bottom loading Existing IVFHM concept & external double-walled PHX
3	Loop	Top loading

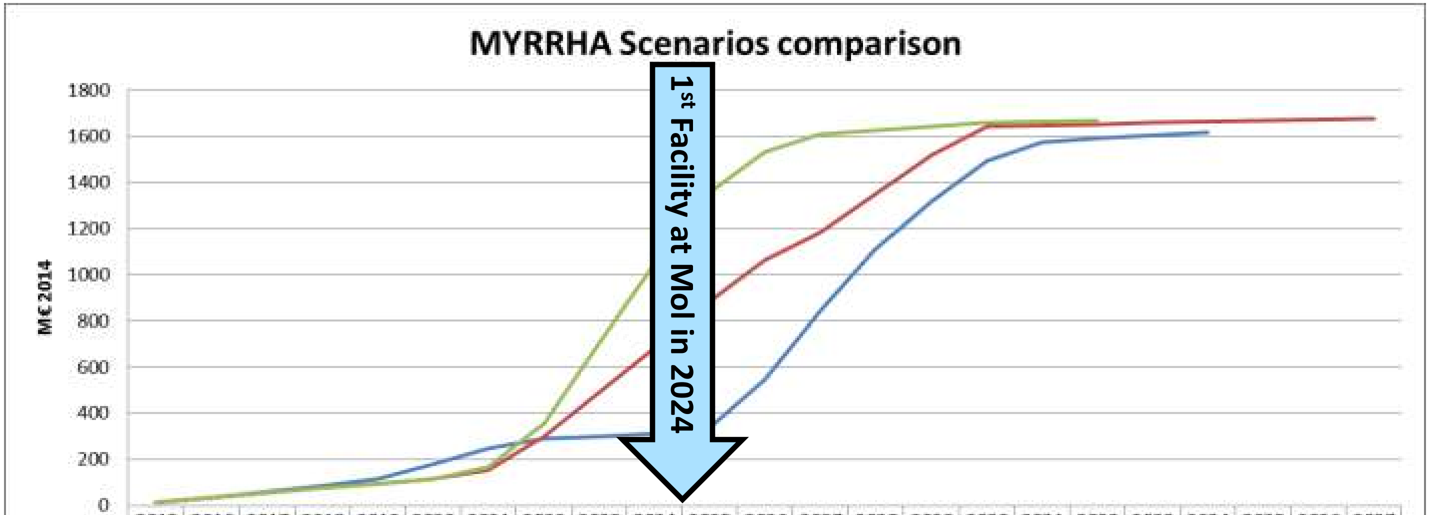
Option 0 is now the reference design under further optimisation

Implementation approach

- SCK•CEN investigated three scenarios for the implementation of MYRRHA:
  - SC1: Accelerator first + Reactor later
  - SC2: Reactor first + Accelerator later
  - SC3: Accelerator and Reactor all together
- Scenario one (SC1) was selected as the most appropriate approach for the realisation of MYRRHA
  - Reducing the technical risks
  - Spreading the investment cost
  - Allowing first R&D facility available by 2024

Financing scheme
> Scenario 1

- Spreads investment cost with smaller upfront investment value
- Mitigates risk related to accelerator reliability and allows more time for risk reduction on the reactor
- Extends timeline
  - For solving innovative reactor design options
  - For building & extending consortium
- **Allows new facility by 2024 at SCK•CEN**



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
SC1	11,3	34,5	59,3	83,8	115,3	177,7	249,3	288,8	298,3	311,8	339,3	547,5	841,3	1113	1320	1497	1577	1592	1607	1619			
SC2	11,3	33,3	56,3	79,3	96,3	116,8	153,9	300,9	493,5	683	882,7	1066	1182	1350	1519	1643	1650	1655	1661	1667	1672	1676	1679
SC3	11,3	33,3	56,3	79,3	96,3	116,8	166,9	355,4	703,5	1049	1359	1533	1611	1628	1645	1661	1666	1669					

Implementation approach
Phase 2 & 3: sequential or in parallel

2024: Stage-gate decision

Phase 1

LINAC injector & accelerator & exp. Stations up to 100 MeV

Preparations

Preparing the construction of SPs 2 & 3

Phase 2

Upgrade to 600 MeV

Phase 3

Reactor & spallation target module

Phase 1

LINAC injector & accelerator & exp. Stations up to 100 MeV

Phase 2

Upgrade to 600 MeV

Preparations

Preparing the construction of SP 2 & 3

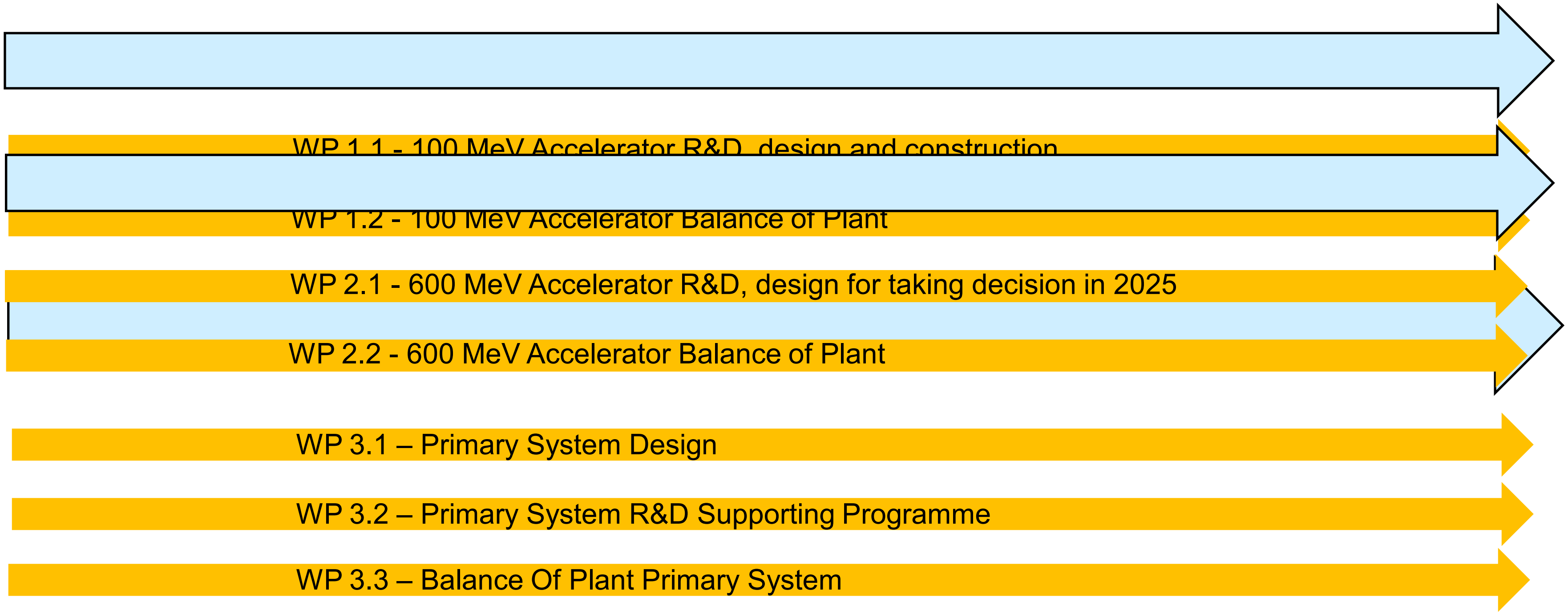
Phase 3

Reactor & spallation target module

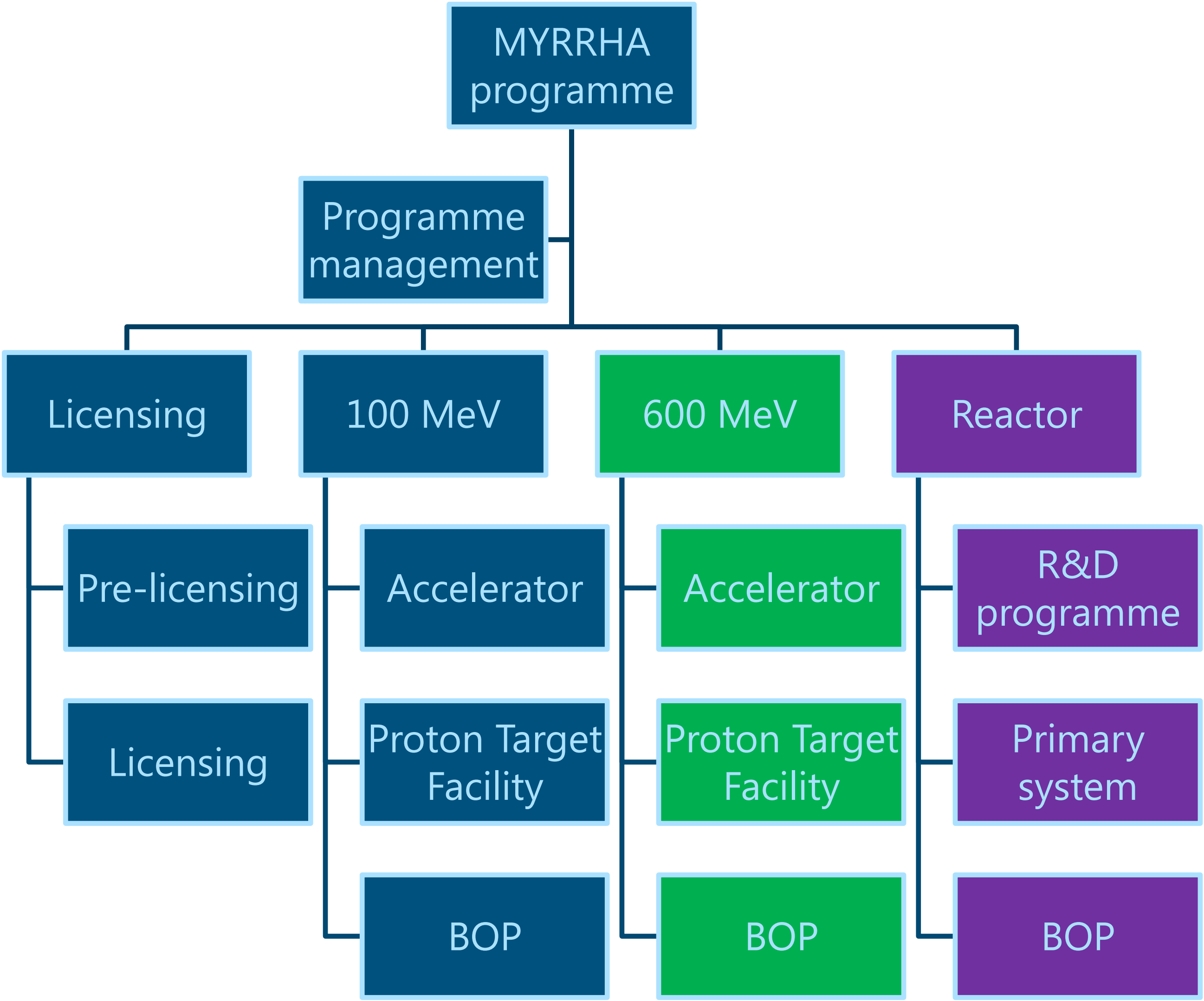
Global planning

Phase 1
LINAC Injector + Accelerator + experimental stations up to 100 MeV

2016	2017	2018	2019	2020	2021	2022	2023	2024

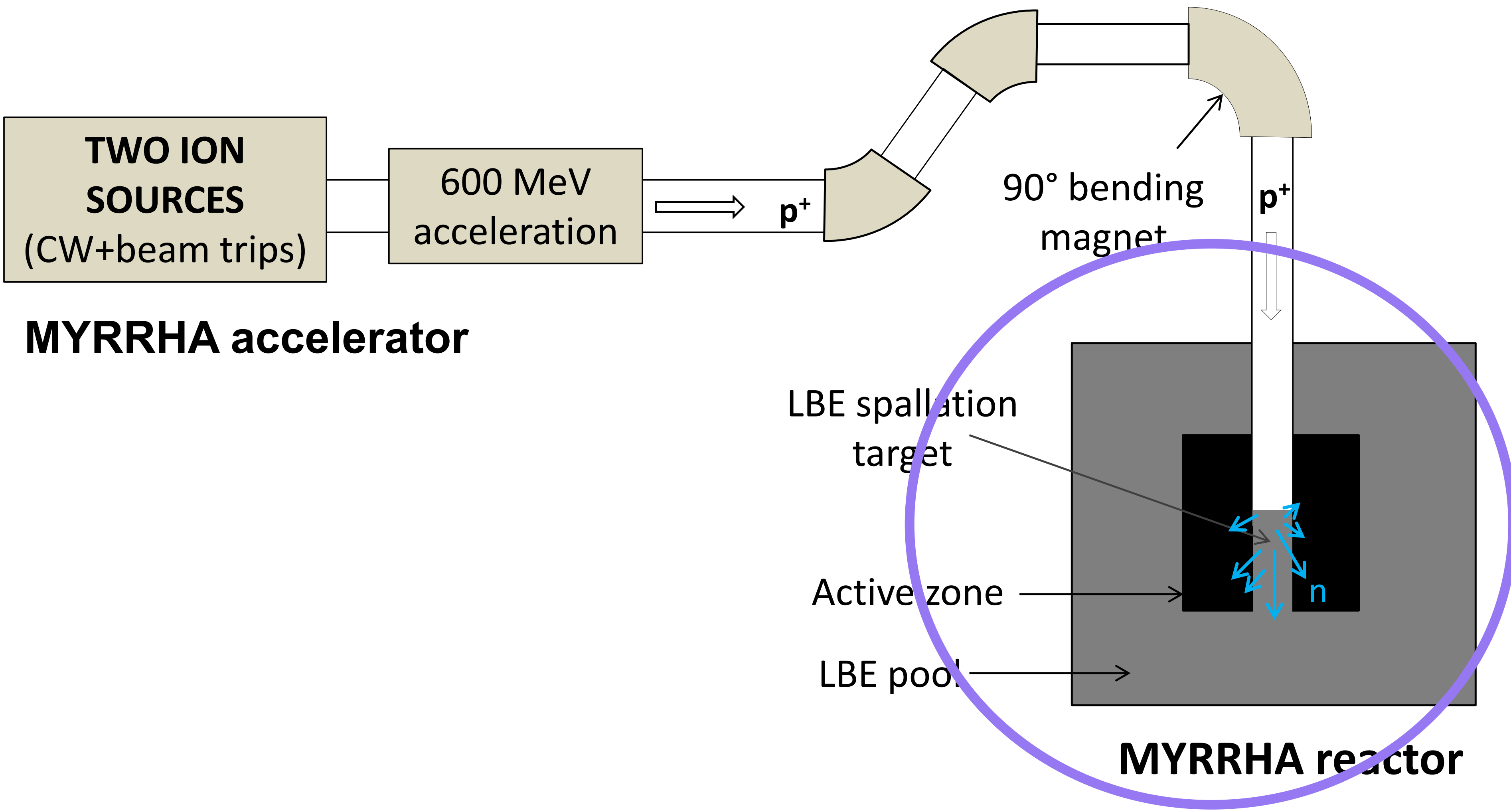


Programme structure



With a positive decision in 2017, we will break ground in 2020

Importance of Nuclear Data for MYRRHA project



EC FP7 CHANDA project

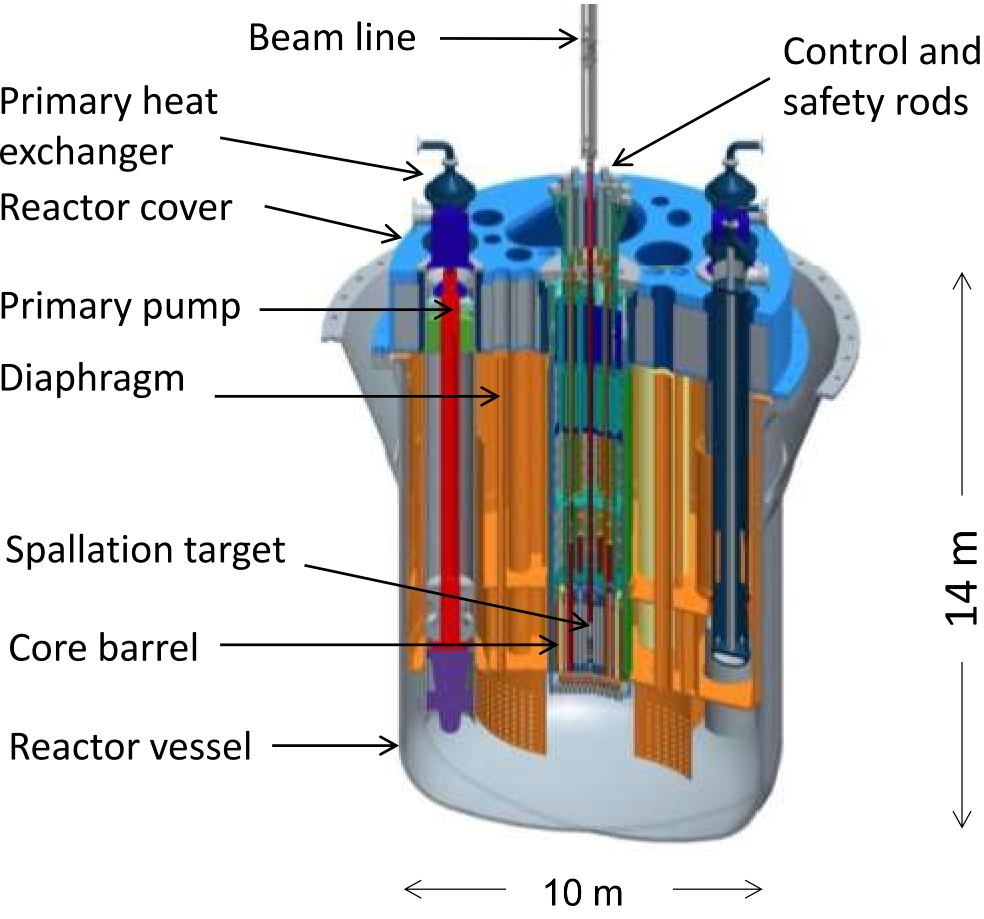
2 Work Packages dedicated to MYRRHA:

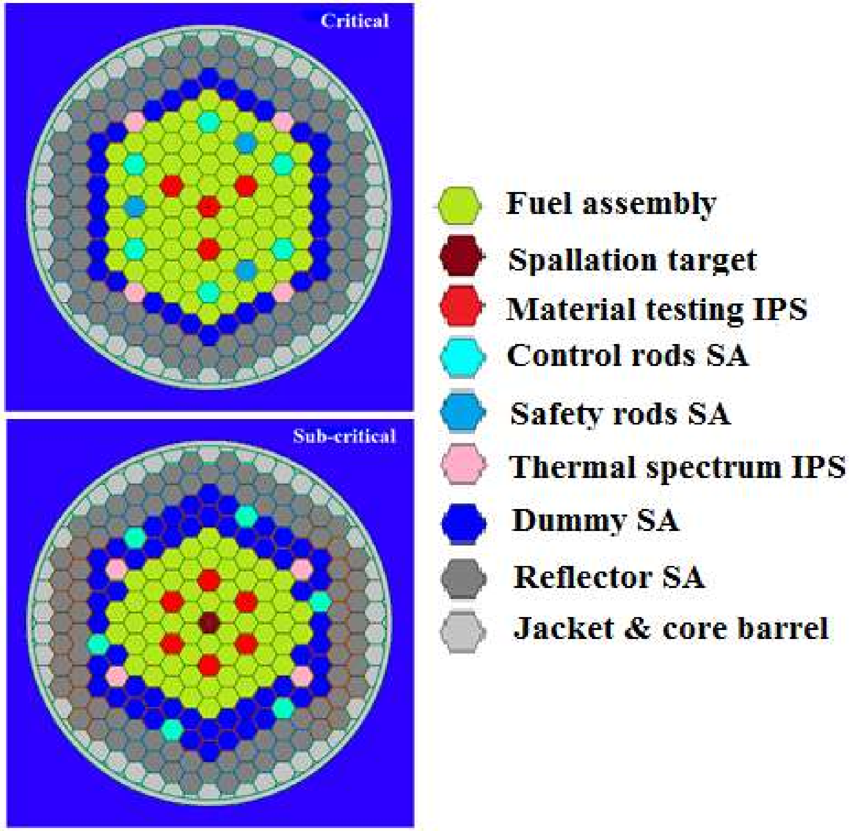
WP10 "Development of nuclear data for Myrrha reactor safety analyses"
Nuclear data required for the development, safety assessment and licensing of MYRRHA are studied and recommendations for improvements must be given. Support JEFF, CIELO by identifying issues in current nuclear data files for MYRRHA-relevant elements and isotopes

WP11 "Development of a methodology for uncertainty assessment and minimization in ADS target and accelerator safety analyses "
Development of new methodology to assess uncertainties of high-energy (above 20 MeV) data. Key critical parameters for the safety analysis of MYRRHA are used for the uncertainty assessment.

Focus on propagation of nuclear data uncertainties to key safety parameters

Neutron induced data < 20 MeV and their impact to the reactor safety parameters uncertainty



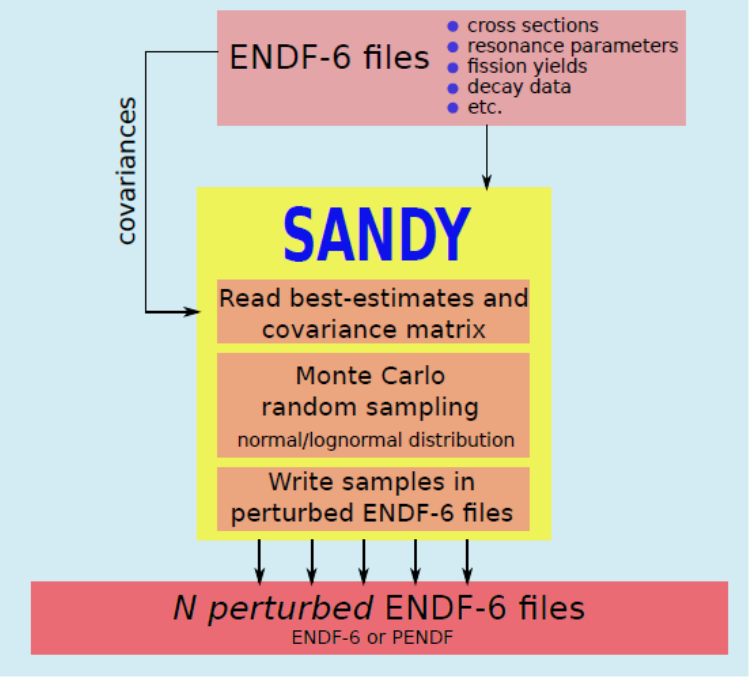


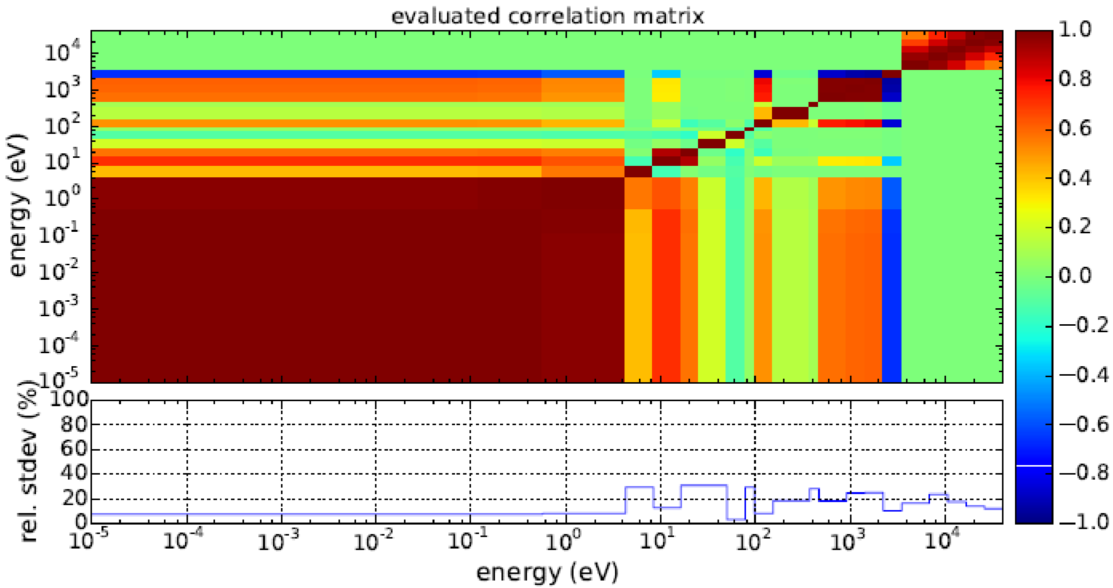
Uncertainty propagation

Main tool: SANDY code

(**SA**mpler of **N**uclear **D**ata uncertaint**Y**)

Monte Carlo sampling, variance-based decomposition, generation of covariance matrices, e.g. for fission yields

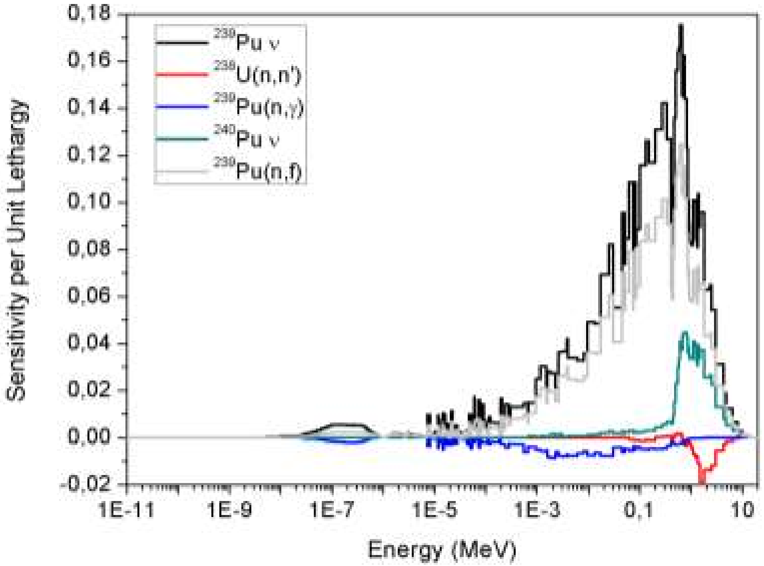




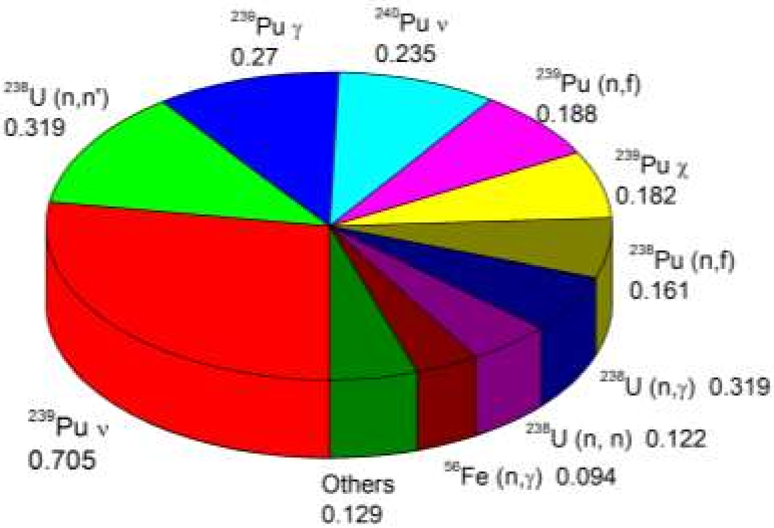
JEFF-3.2 multigroup correlation matrix and uncertainty of the ^{235}U(n,f) cross-section

K_{eff} uncertainties

Sensitivity profiles



Total 0.957 %Δk/k

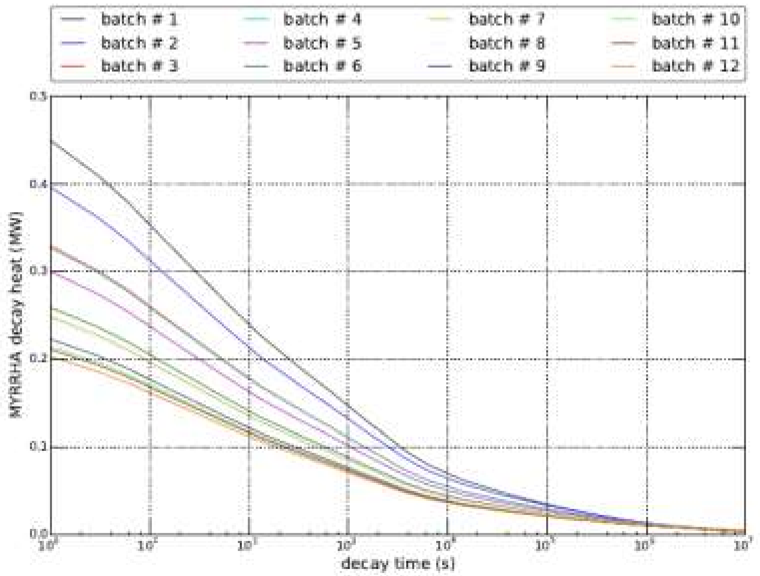


Increase of confidence by improving the uncertainties is needed for

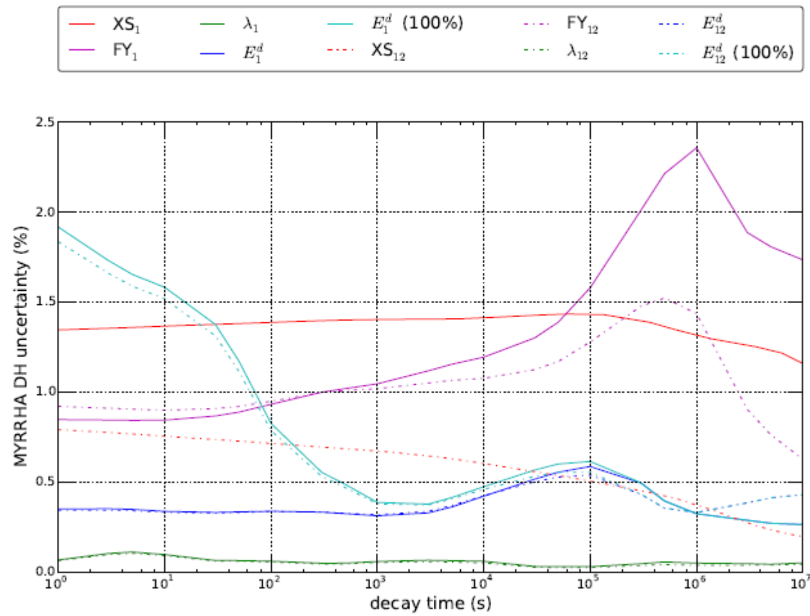
- ^{239}Pu: (n,γ) both in resonance and fast energy region, (n,f) fast, χ and $\bar{\upsilon}$ fast
- ^{238}U: (n,n') fast, (n,γ) resonance and fast, (n,n) resonance and fast
- ^{240}Pu: $\bar{\upsilon}$ fast
- ^{238}Pu: (n,f) both resonance and fast
- ^{56}Fe: (n,γ) both resonance and fast

Special attention to ^{209}Bi (n,γ) and (n,n'), ^{208}Pb (n,n) and (n,n') and ^{235}U , (n,f) and (n,γ) due to flexibility of providing neutron spectrum in various core regions

Uncertainties on decay heat



(fresh and most burned fuels only)



- Propagation of fission product yield and decay data uncertainties: ASAP (Adjoint Sensitivity Analysis Procedure)
- Neutron transport feedback: Monte Carlo sampling

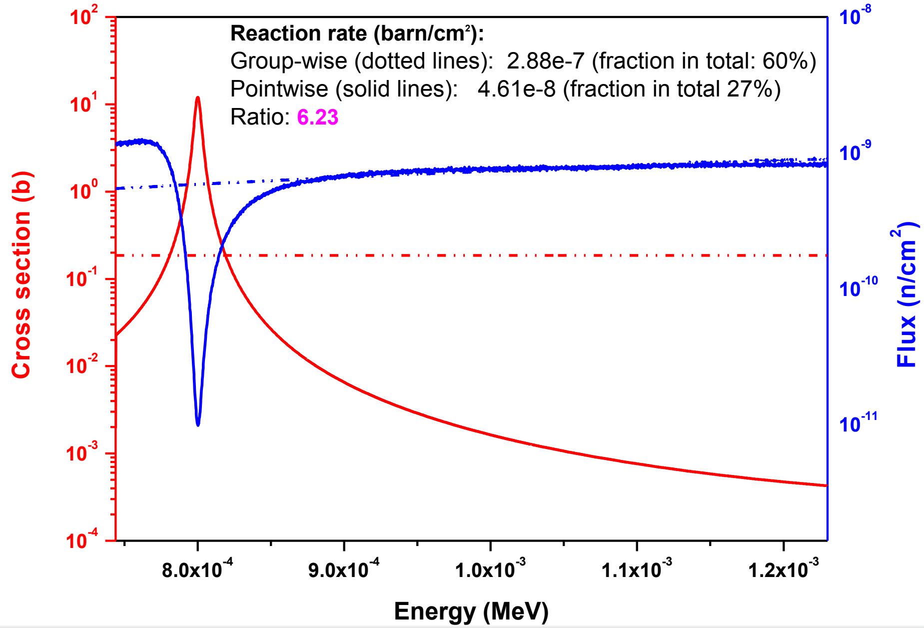
Uncertainties much less than requirements of Belgian safety authorities (20%)

In order to improve…

Differential and integral experiments

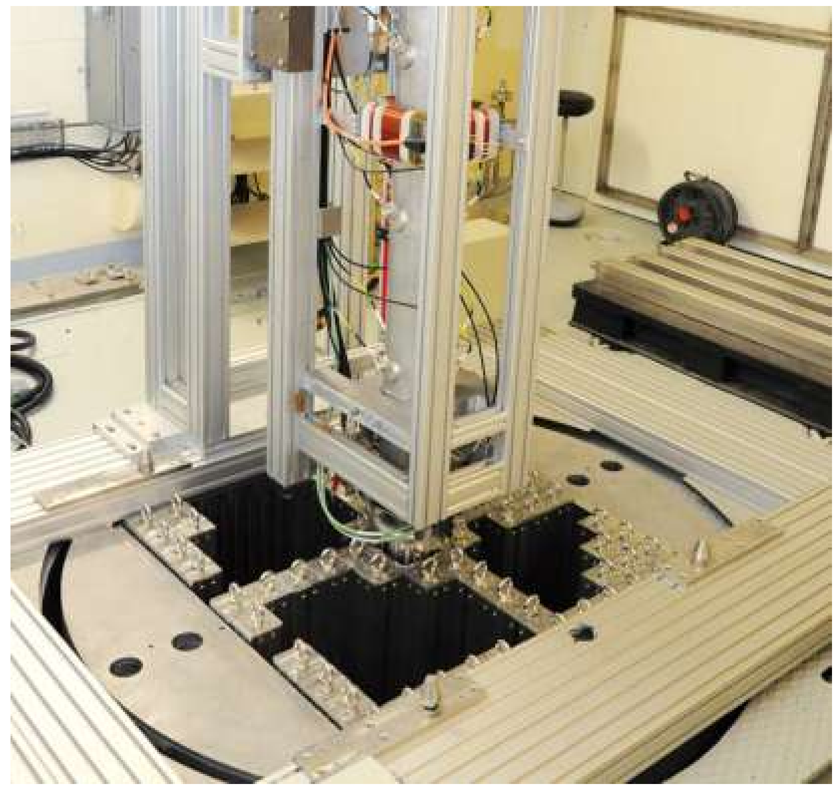
Differential measurements: GELINA

Radiotoxicity and decay heat of LBE: ^{210}Po issue
Accurate knowledge of best-estimates and associated uncertainties for branching ratio $^{209}Bi(n,\gamma)$ is needed, especially around 800 eV resonance



Integral measurements: VENUS-F

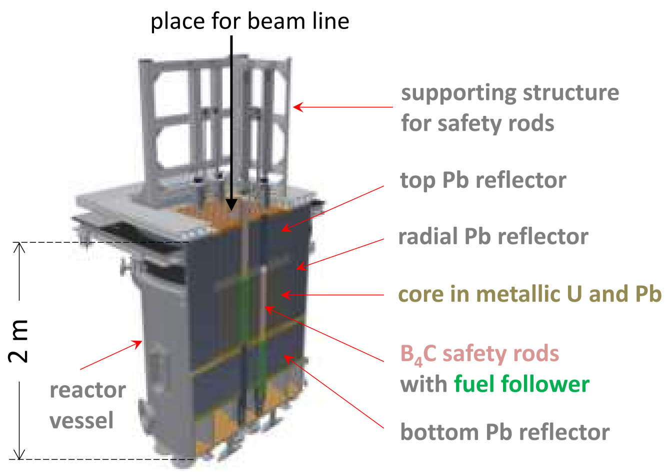
VENUS-F fast zero power reactor coupled to GENEPI -3C deuteron accelerator (14 MeV neutrons from D+T)



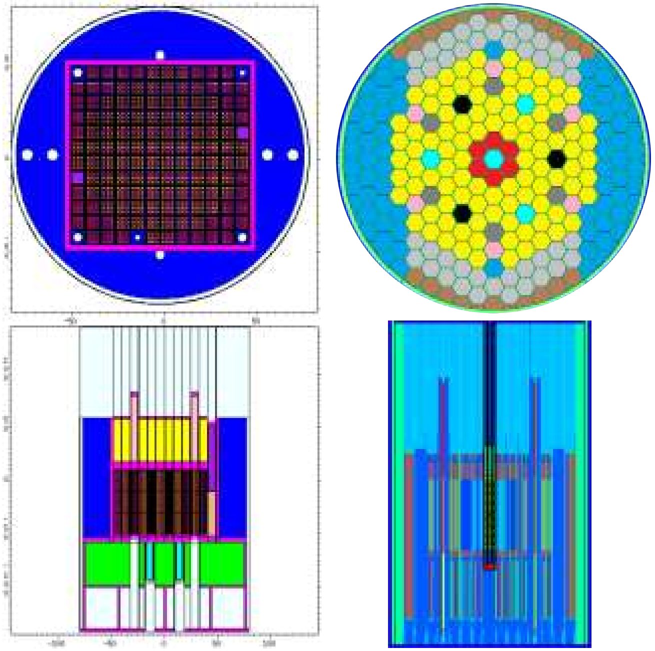
Integral measurements: VENUS-F

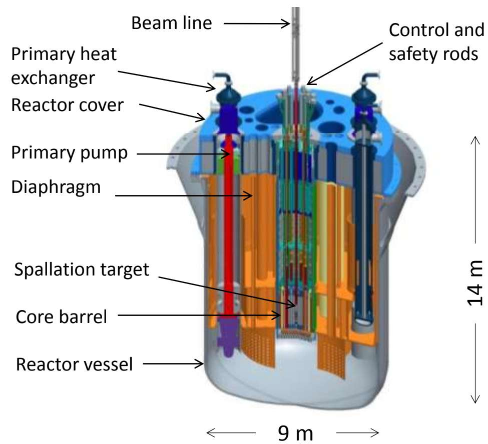
- Serves licensing and design tasks for MYRRHA :
  - validation of online sub-criticality monitoring of an ADS
  - validation of nuclear data and neutronic codes
  - experimental characterization of fast critical and subcritical cores representative for MYRRHA
- Measurements:
  - spectral indices
  - axial and radial traverses
  - control rod worth
  - kinetic parameters
  - reactivity effects (coolant void, fuel Doppler, water ingress, fuel agglomeration)

Difficulties



VENUS-F: metallic U fuel





MYRRHA: MOX fuel

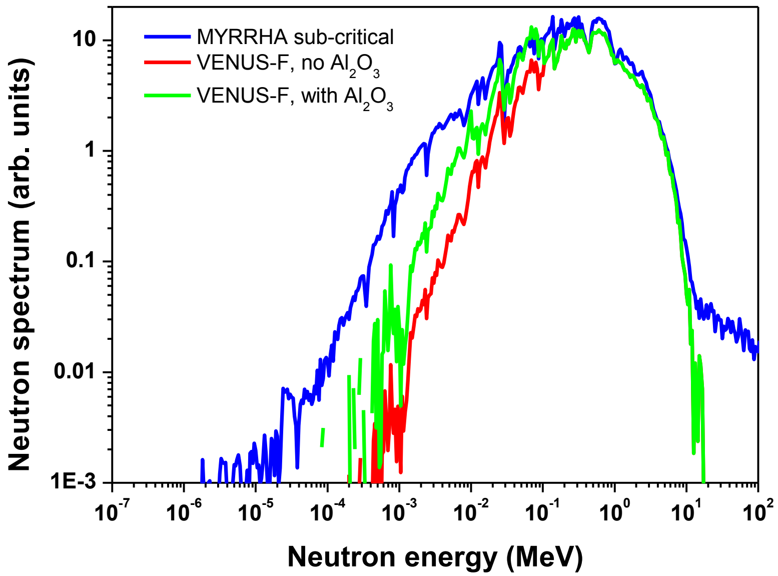
Al_2O_3

Solid Pb or solid Bi

Ratios fuel/clad/moderator (coolant) are close to MYRRHA

Spectra & replacement of Pb by Bi

Spectrum in VENUS-F is harder than in MYRRHA

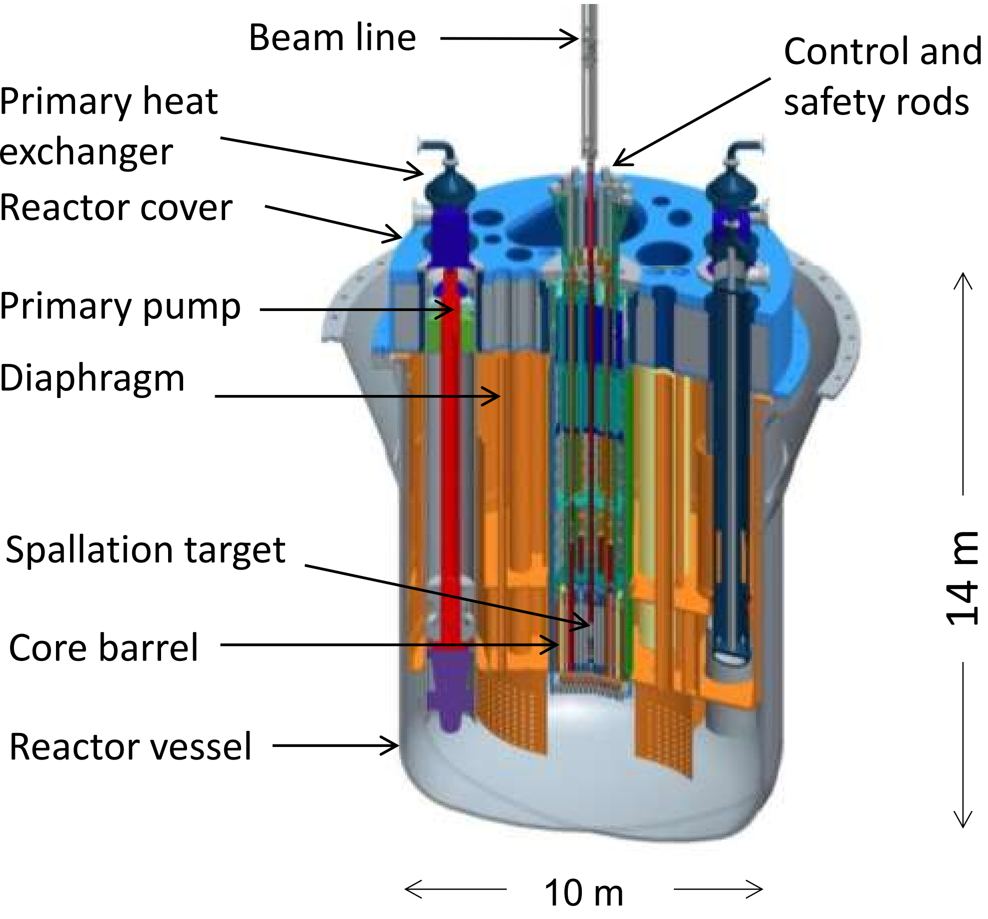


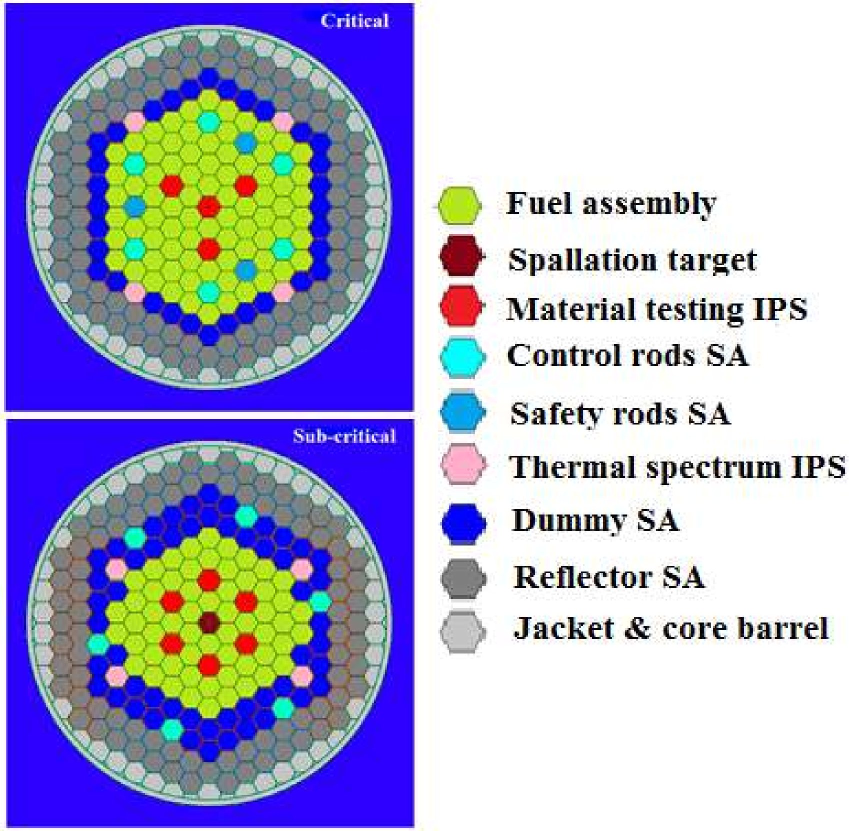
The use of Al_2O_3 gives softening, but not enough:

Ratio O/U = 0.45 while in MOX or UO_2 fuels this ratio is 2

Replacement of original Pb blocks to Bi blocks → negative reactivity
In MYRRHA: replacement of LBE coolant by Pb coolant gives negative reactivity → different directions
Reason: macroscopic cross sections, density effect:
Effective microscopic el. scattering cross section: Bi /Pb = 1.1
Densities of liquid Bi and Pb at 550°C: Bi/Pb = 0.94
Densities of solid Bi and Pb at room temperature: 0.86

Intermediate and high-energy (> 20 MeV) data





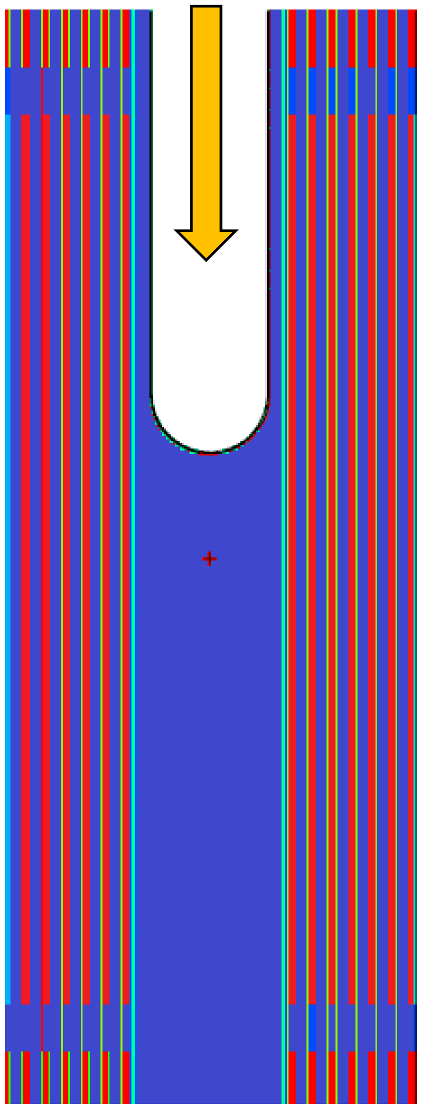
Needs in intermediate and high-energy neutron data (> 20 MeV)

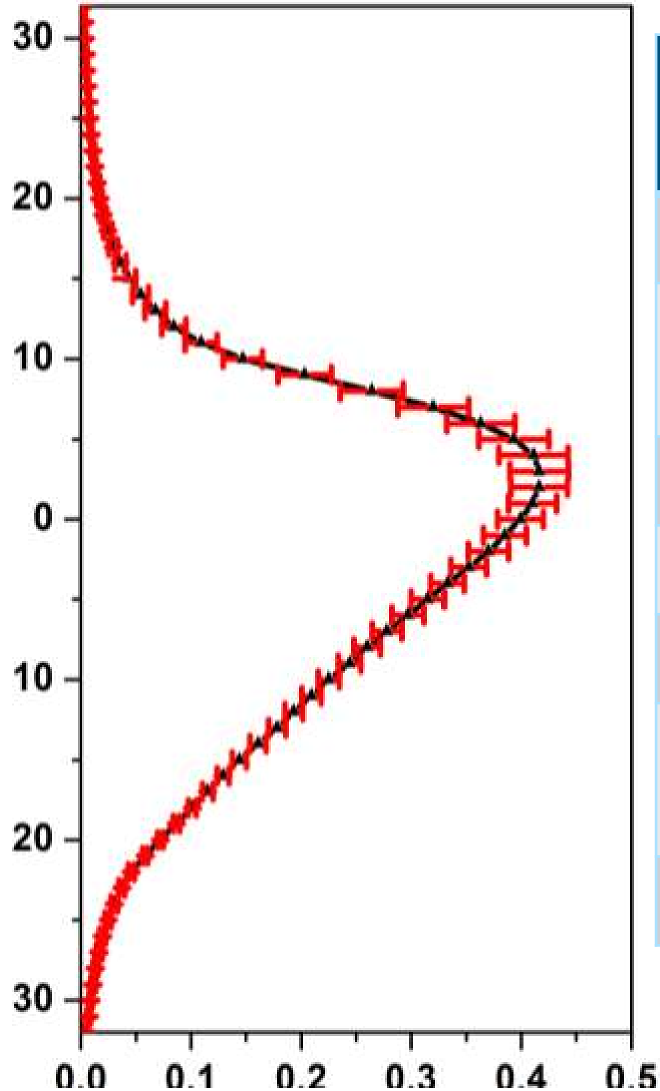
- Most of nuclear data libraries have neutron data up to 150-200 MeV with associated covariance matrices to propagate uncertainties

- Region > 200 MeV is still covered by physics models (intranuclear cascade + preequlibrium + equilibrium models, quantum molecular dynamics models). No information to estimate uncertainty is available.

- How important for the subcritical core safety these data are ?

Neutron production in spallation target





Para-meter	Model average	Std. dev., %
Z = n/p	**9.04**	**5.9**
P_{th}, MW	70	-
PF_{rad}	1.37	<0.1
PF_{ax}	1.27	<0.1
$PF_{fa,rad}$	1.08	<0.1
E_{th}, MeV/p	3.5e+4	6.0
I, mA	**2.0**	**6.0**

Neutron-induced radiation damage

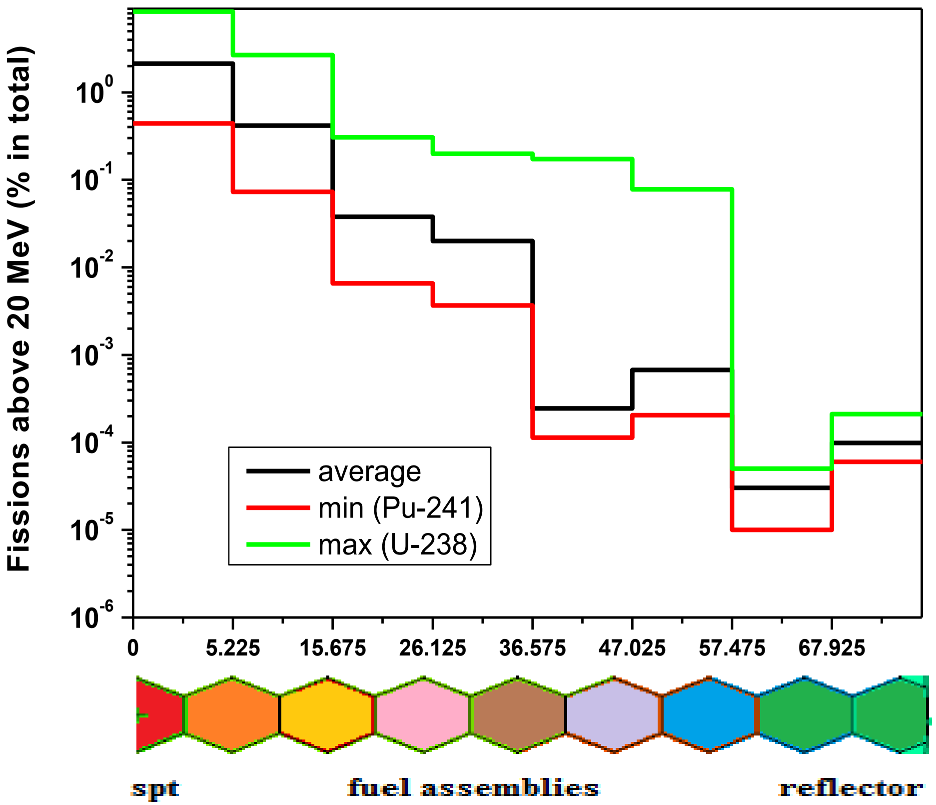
- Irradiation of samples for fusion in the spallation target
- Material testing in IPS (In-Pile Sections)
- Structural materials (beam window, fuel pin clad, core barrel,…): lifetime

	Fraction of n > 20 MeV, %	Fraction of n > 200 MeV, %	Uncertainty due to cross section data, %
Spallation target	9.4	1.4	0.6
Beam window	4.4	0.17	0.4
Fuel pin clad	2.1	0.15	0.7
IPS	0.5	0.03	0.5
Core barrel	0.1	0	0.3

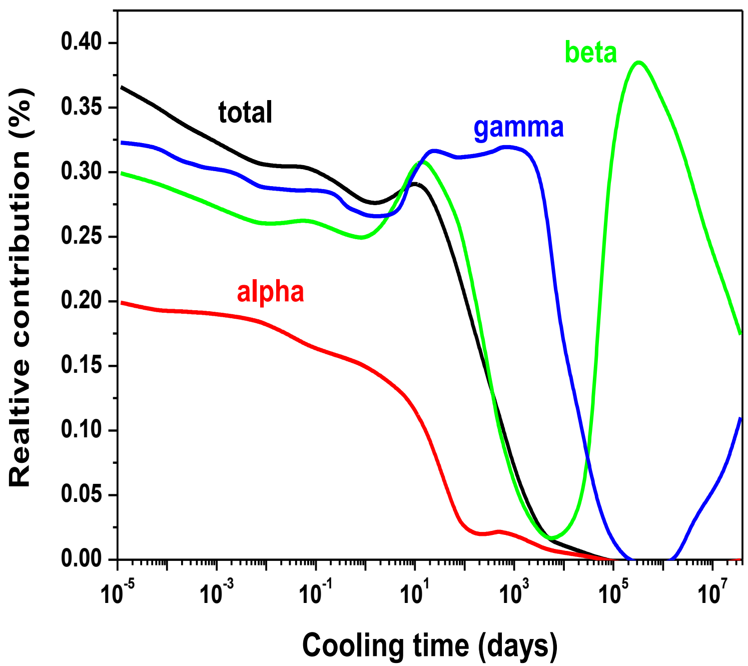
Contribution of neutrons from model range (200-600 MeV) is less than uncertainty in the table range < 200 MeV

High-energy (above 20 MeV) fissions

Radial distribution of HE fissions



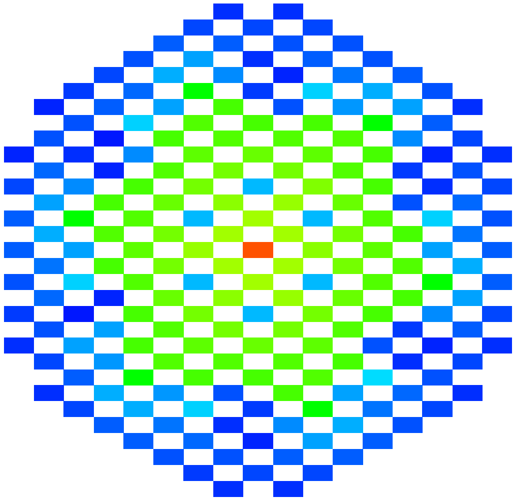
Decay heat of FA close to the target: contribution of HE neutrons



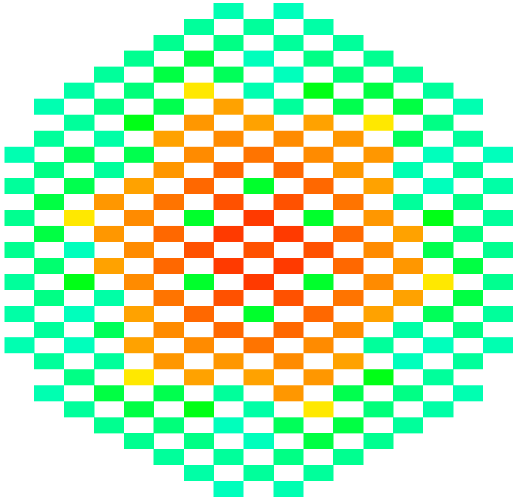
High-energy fissions contribute to 0.4% in 1st ring of FA, 0.07% in 2nd ring of FA…
They do not play serious role in neutron balance of the system

Power map

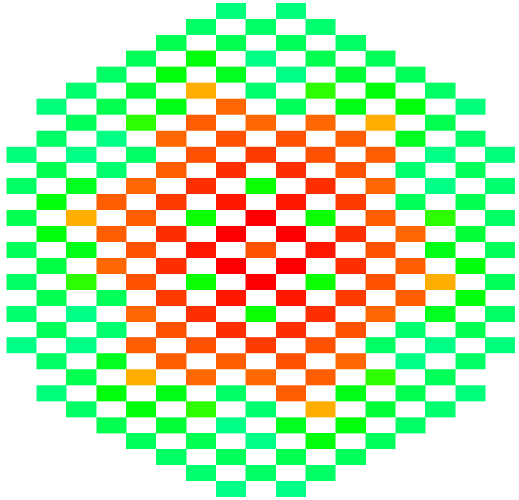
100 MeV
core power 2.5 MW
(design limits on beam current – max 4 mA)



600 MeV
core power 75 MW



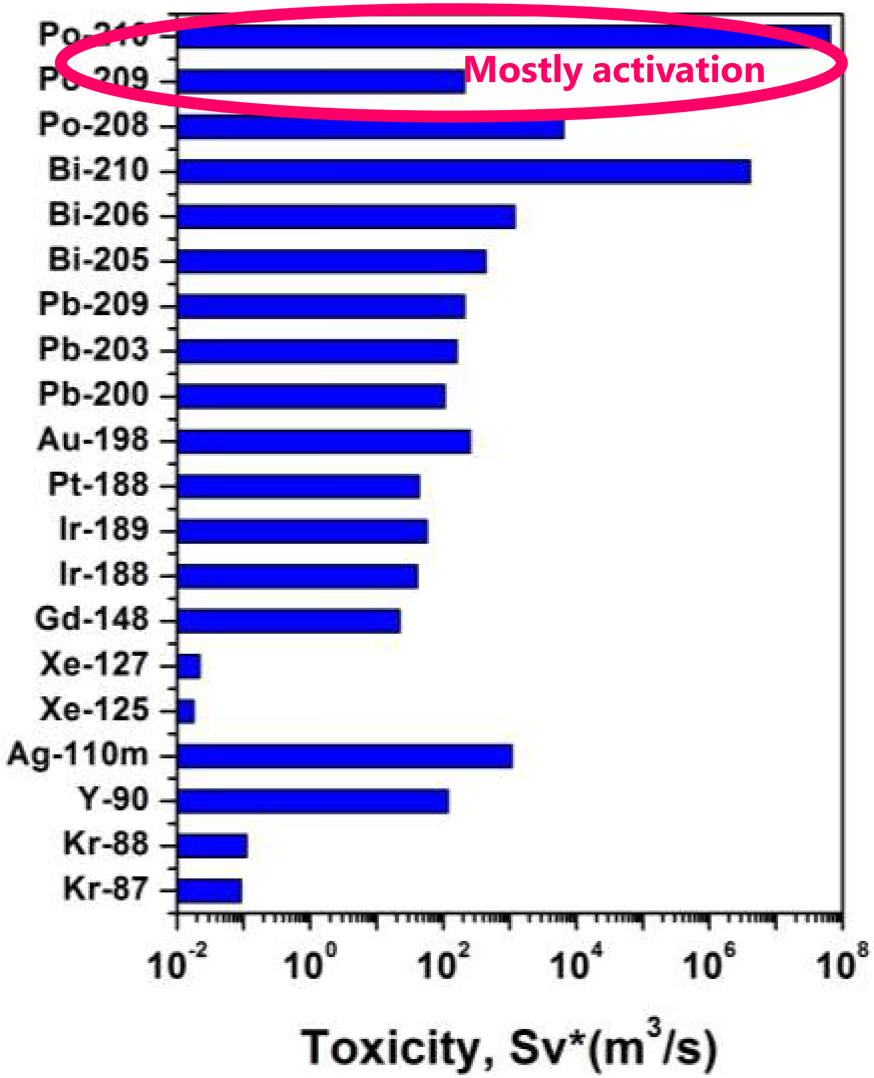
1500 MeV
core power 75 MW
(design limits on coolant capacity →beam reduction < 1 mA)

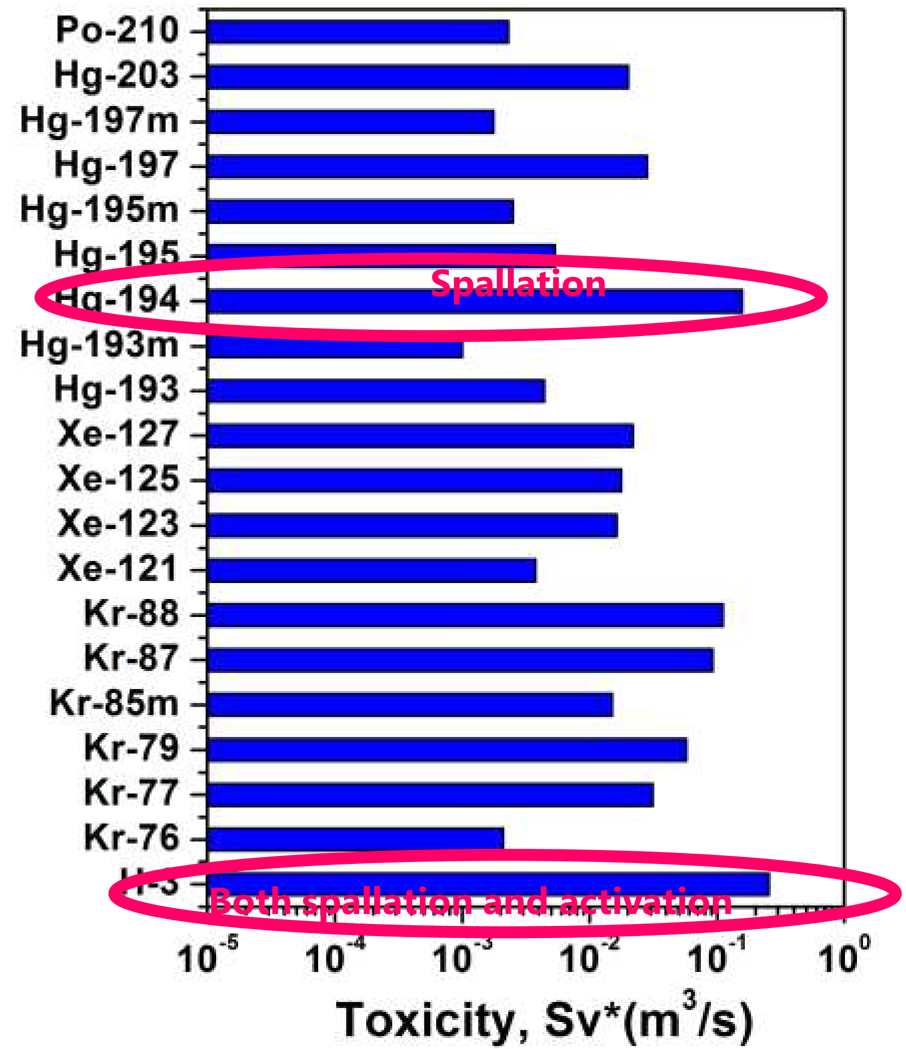


No changes in reactivity and fission power distribution !

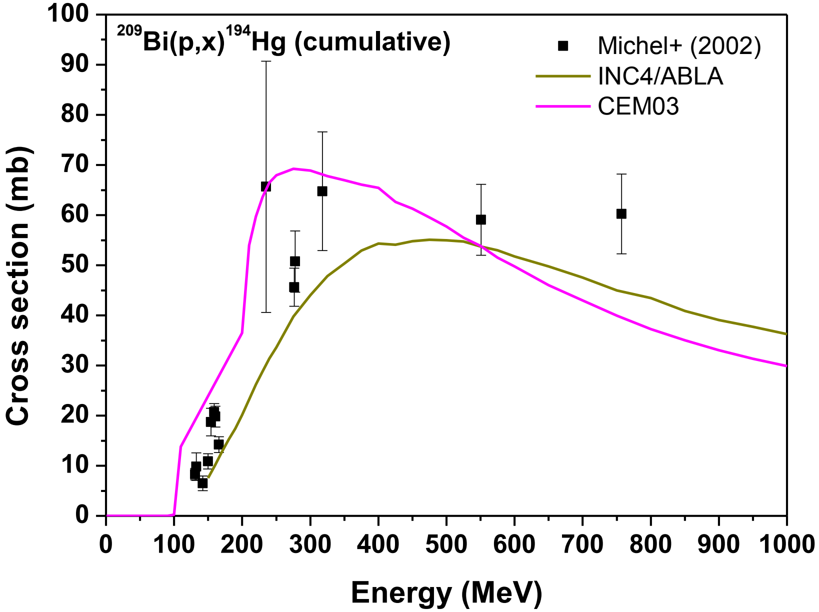
- **LBE data > 20 MeV are important**
- **High-energy fissions do not play role**

Radiotoxicity of LBE and cover gas

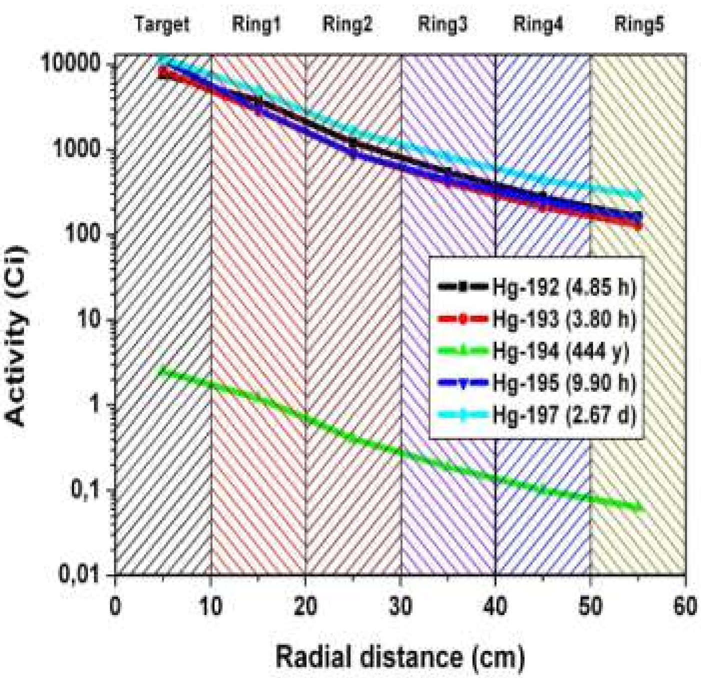




^{194}Hg



^{194}Hg is produced elsewhere (where neutrons > 60-70 MeV are present)

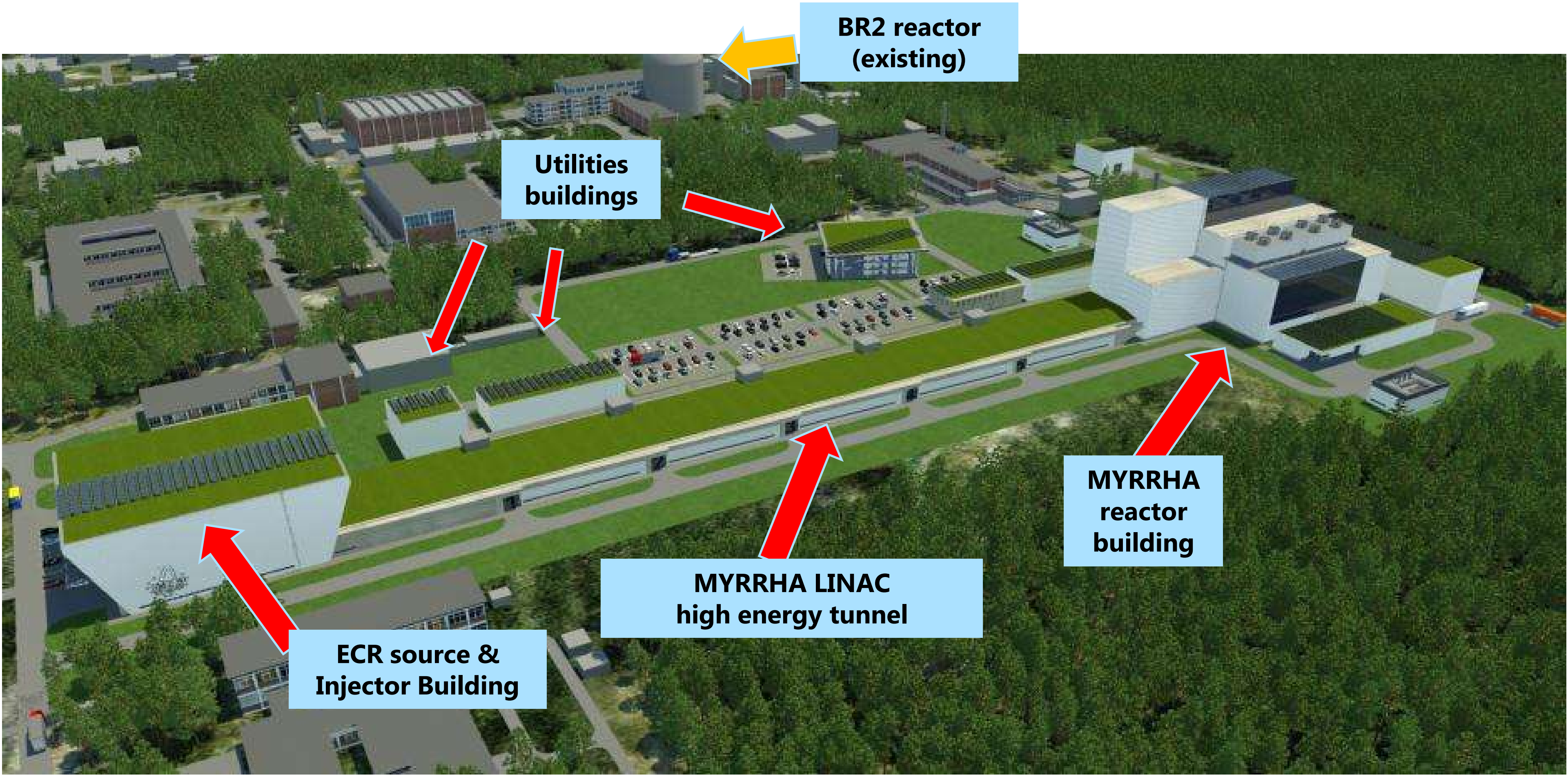


Differences between models for protons are up to 70%, for neutrons the same is expected

Conclusions

- Among reactor design options, a pool type with bottom loading is the reference one
- The scenario of MYRRHA implementation assumes the deployment of accelerator first and reactor later
- First section of accelerator up to 100 MeV will be built and commissioned in 2024
- Regarding the neutronic design, providing the best-estimates for safety parameters with associated uncertainties is a requirement of safety authorities
- The improvement of low-energy (< 20 MeV) nuclear data & uncertainties relevant to MYRRHA will increase confidence in the calculated reactor safety parameters
- For the upper energy region, the improvement of Pb and Bi data, namely neutron and recoils production, is of primary importance while other data such as high-energy fissions is less relevant.

MYRRHA fully developed as: An international, innovative and unique facility at Mol (BE)



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