Nuclear data needs for MYRRHA and MINERVA

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SCK•CEN, Blegium
OECD/NEA, June 6th, 2019

Outline

MYRRHA & MINERVA

- Needs for Criticality Safety
- Needs for Shielding
- Needs for Radioactive Source Terms & Waste Management

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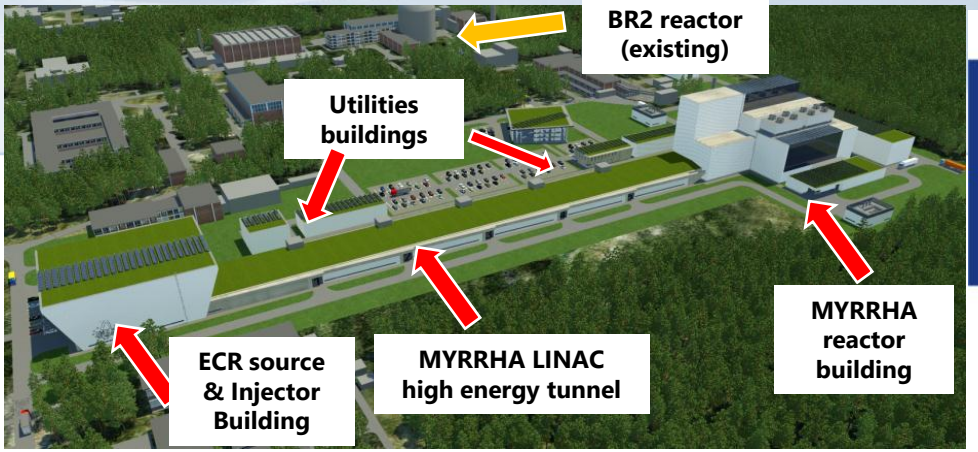
MYRRHA



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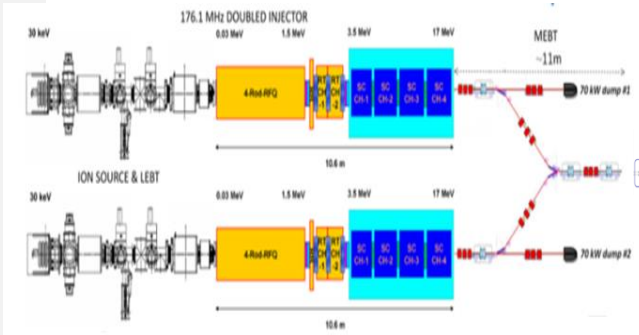
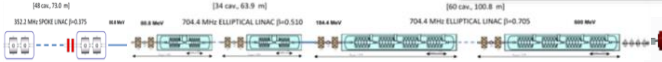
Construction of an Accelerator-Driven System (ADS) consisting of

- A 600 MeV, 4 mA proton linear accelerator
- A spallation target/source
- A lead-Bismuth Eutectic (LBE) cooled reactor able to operate in subcritical & critical mode

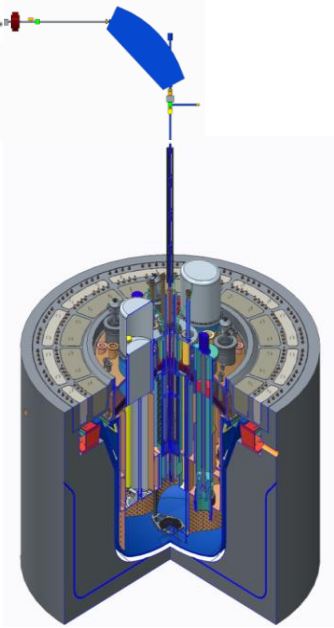




Target	
main reaction	spallation
output	$2 \cdot 10^{17}$ n/s
material	LBE (coolant)

Accelerator	
particles	protons
beam energy	600 MeV
beam current	up to 4 mA

Reactor	
power	65 to 100 MW_{th}
k_{eff}	0,95
spectrum	fast
coolant	LBE



Key technical objective: An Accelerator Driven System
- Demonstrate the ADS concept at pre-industrial scale
  - Can operate in critical and sub-critical modes
- Demonstrate transmutation
- Fast neutron source → multipurpose and flexible irradiation facility

Source: SCK•CEN MYRRHA Project Team, MYRRHA Business Plan

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Applications of MYRRHA

- Belgium decided to build a new large research infrastructure MYRRHA to remain at the forefront worldwide in :
  - Transmutation (Partitioning & Transmutation) of radioactive waste.
  - Nuclear medicine and medical radioisotope production
  - Demonstrate ADS technology
  - Research in new materials
  - Contribute to development of lead fast reactors

September 7, 2018: Belgian government decided to finance (558 M€) design, construction and operation of MYRRHA for the period 2019 – 2038

Source: SCK•CEN MYRRHA Project Team

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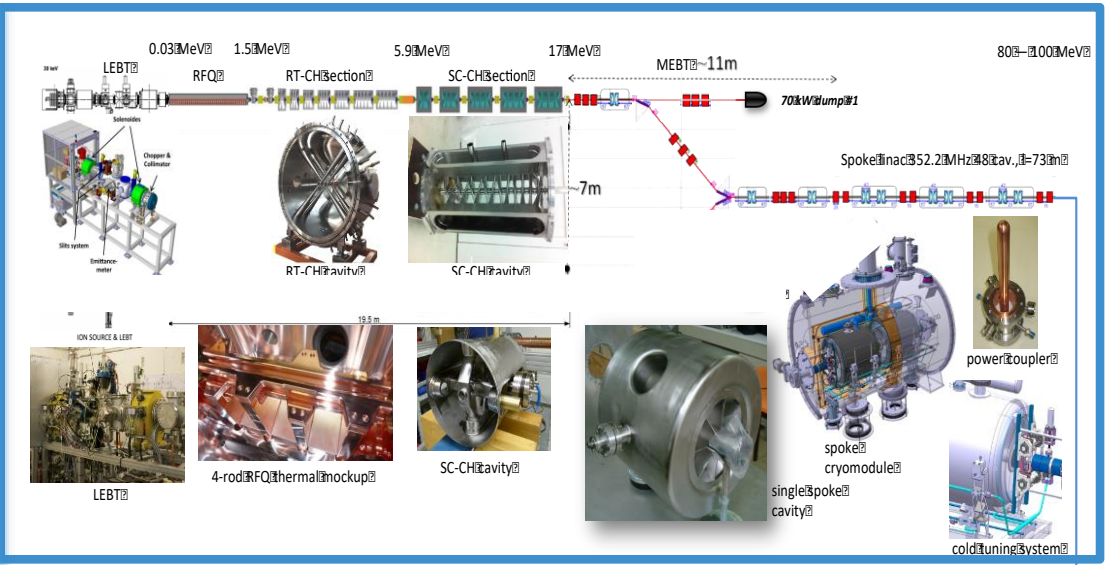
MYRRHA's phased implementation strategy

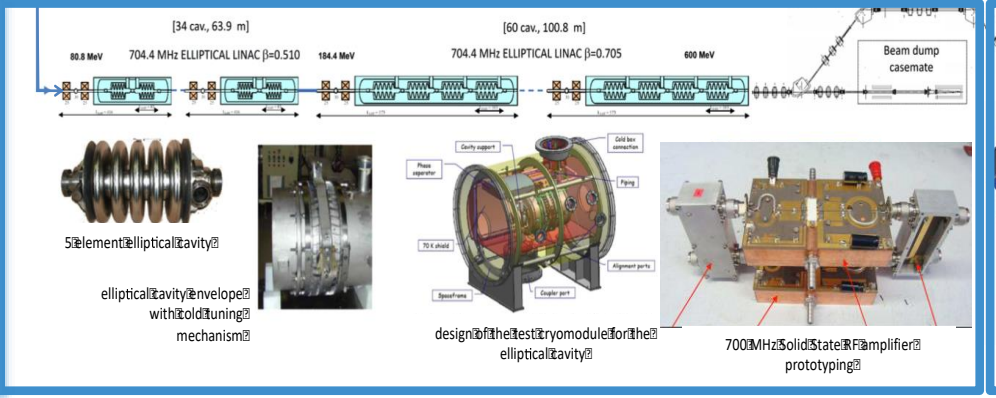
Benefits of phased approach:

- Reducing technical risk
- Spreading investment cost
- First R&D facility available in Mol end of 2024

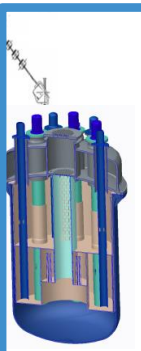
Phase 1 – 100 MeV



Phase 2 – 600 MeV



Phase 3 – Reactor



Source:SCK•CEN MYRRHA Project Team

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MYRRHA Phase 1: ongoing

Consists of

- MINERVA (**M**YRRHA **I**sotopes productio**N** coupling the lin**E**ar accele**R**ator to the **V**ersatile proton target f**A**cility)

➢ Build and test the first part of the MYRRHA accelerator, up to 100 MeV. Extreme reliability of accelerator is required:

  - Less than 10 beam trips longer than 3 sec per 3-month operation period,
  - Less than 100 beam trips longer than 0.1 sec per day,
  - Mean Time between Failures MTBF > 250 hrs.

➢ Design, build and operate a 100 MeV Proton Target Facility (PTF)

- Production of radioisotopes - ISOL
  - Fundamental physics experiments
  - Innovative medical isotopes production
- Structural material irradiation (eg. for fusion applications)

- MYRRHA reactor design and research on-going in parallel

Source:SCK•CEN MYRRHA Project Team

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Outline

- MYRRHA & MINERVA
- **Needs for Criticality Safety**
- Needs for Shielding
- Needs for Radioactive Source Terms & Waste Management

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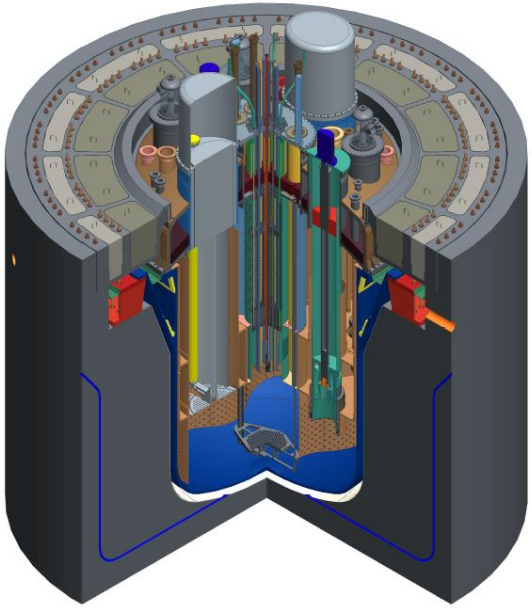
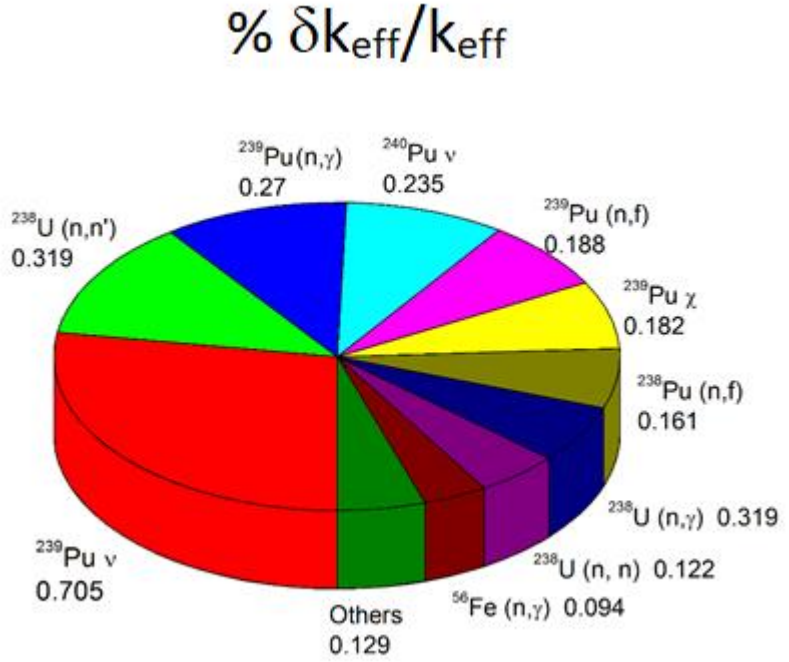
Criticality uncertainties





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
- ^{56}Fe: (n,γ) resonance and fast
- ^{235}U: $\bar{\upsilon}$, (n,f), (n,γ) resonance and fast
- ^{209}Bi (n,γ) and (n,n') resonance and fast
- ^{208}Pb (n,n) and (n,n') resonance and fast
- ^{241}Pu (n,f) resonance and fast
- ^{242}Pu (n,f) fast
- ^{240}Pu: $\bar{\upsilon}$ fast
- ^{238}Pu: (n,f) both resonance and fast

Total $\frac{\delta k_{eff}}{k_{eff}} = 0.945\%$ ~1000 pcm

Target accuracy : $\frac{\delta k_{eff}}{k_{eff}} \sim 300pcm$ ($<\beta_{eff}$)

^{239}Pu(n,f) reaction rate can be measured in VENUS-F with the spectrum close to MYRRHA one (see further)

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Needs in Plutonium data

R. Capote (IAEA) @ ND2019, Beijing, 24th May 2019: Importance of reliable Pu evaluation

OUTLINE

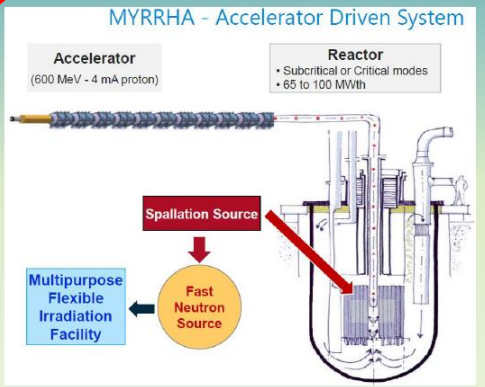
- Background: ADS and data needs
- New experimental results: PFNS
- Integral feedback; IDA trends
- Update of resonance parameters & TNC
- Evaluation in the fast neutron range
- New modelling developments
- Integral and quasi-differential data
- Summary

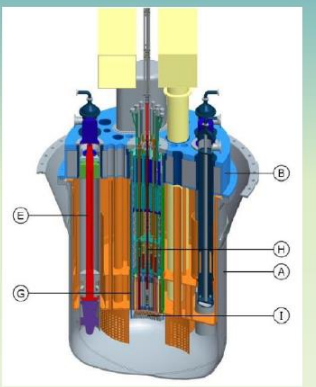
ND2019

MYRRHA as an important customer for Pu data !

MYRRHA: hybrid Research reactor

MOX fuel (7-30% ^{239}Pu), Pb-Bi (LBE) coolant





P. Schuurmans et al, @ https://asrc.jaea.go.jp/soshiki/gr/chiba_gr/workshop3/&Schuurmans.pdf
D. J De Bruyn et al, Phys. Procedia **66** (2015) 75-84; doi: 10.1016/j.phpro.2015.05.012

ND2019

Source: R. Capote (IAEA), Presentation given at ND2019, Beijing, 24th May 2019, L450

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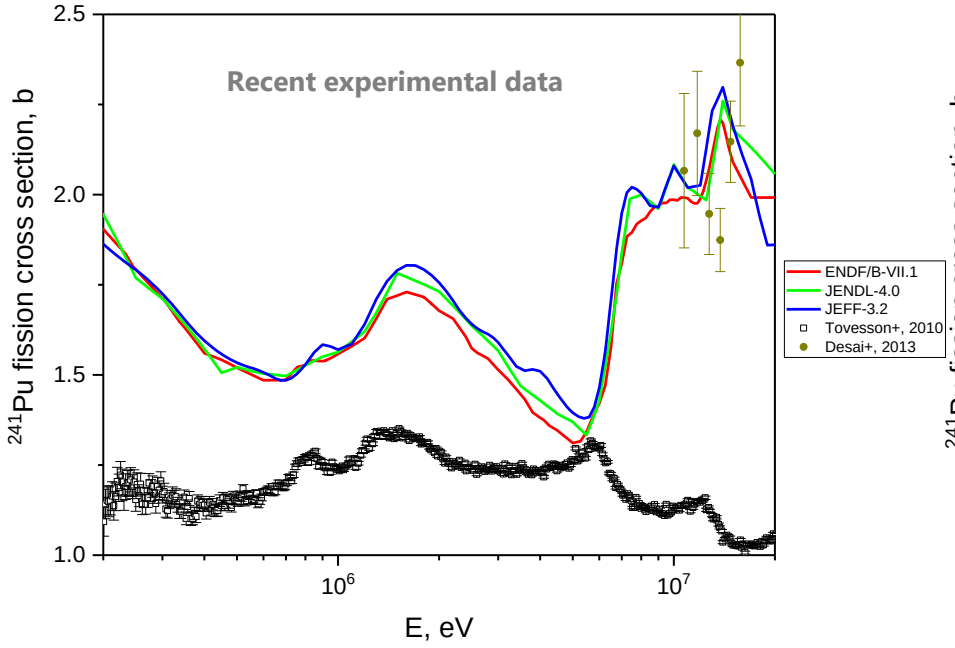
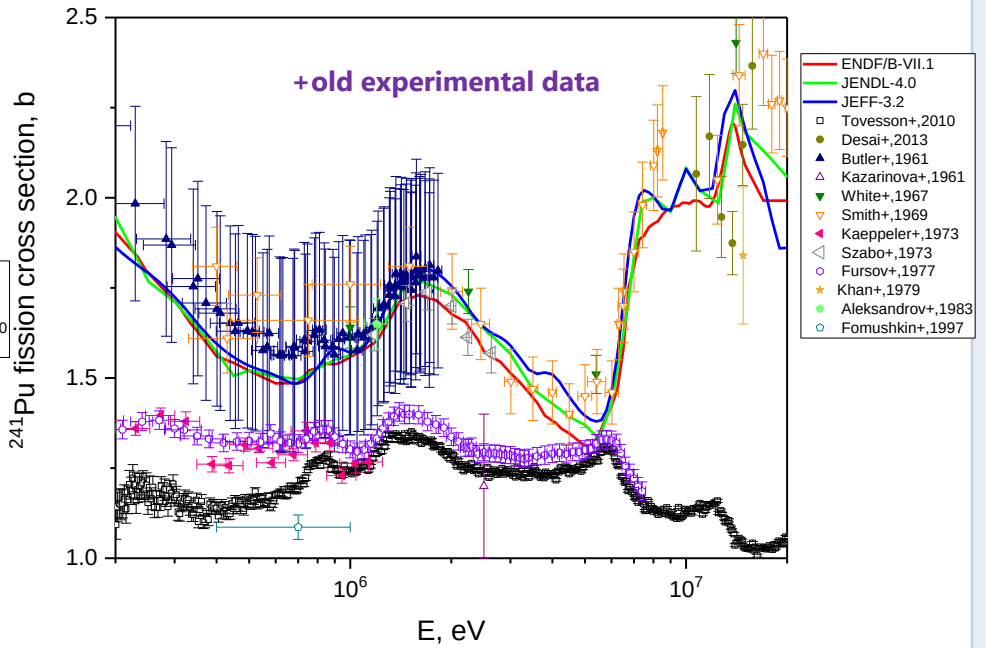
Challenges: Pu-241 example





Only recent experimental data considered: libraries overestimate

+old data: consistency of libraries with many data sets

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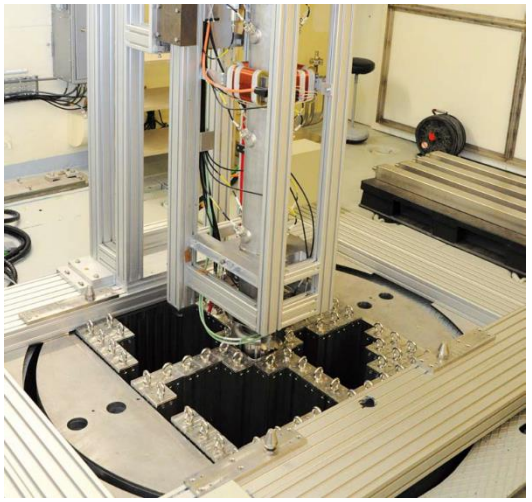
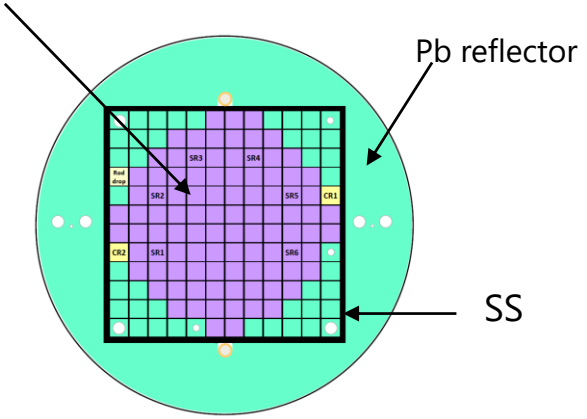
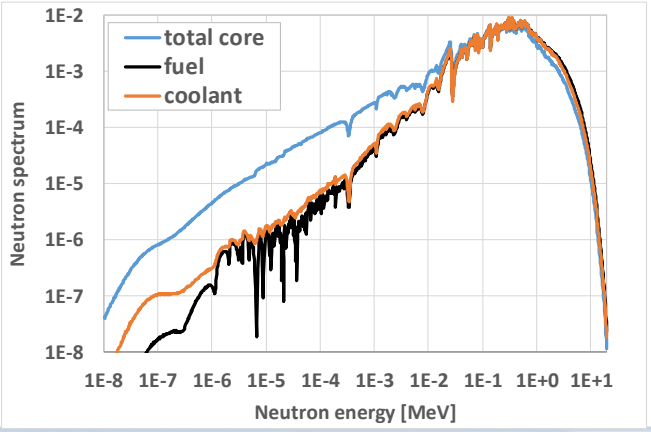
Integral validation: VENUS-F

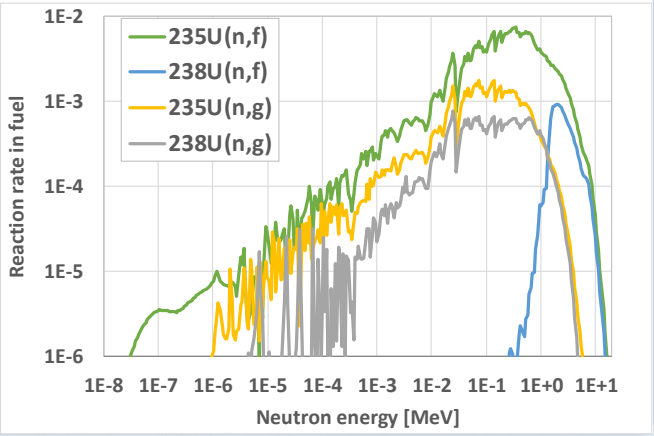
VENUS-F zero power reactor coupled to GENEPI -3C deuteron accelerator (14 MeV neutrons from D+T)



30% U metallic fuel + Pb "coolant" (solid Pb, alternatively Bi)







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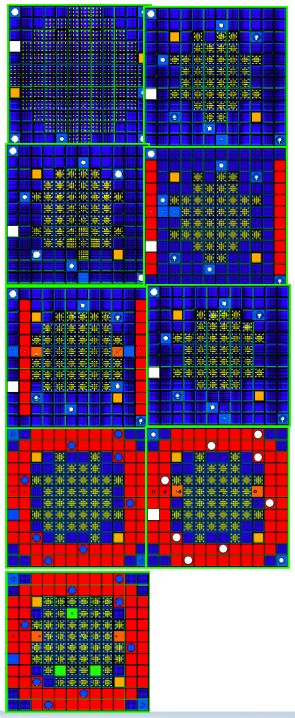
Criticality C/E

9 core configurations studied within EU Projects FREYA, MYRTE, MIRACL, MIPSA in 2011-2019

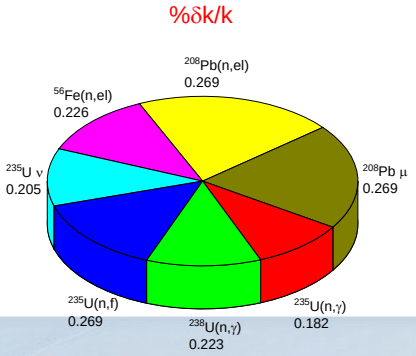
Core	#FAs	FA composition	Reflector	In-Pile Section
CR0	97	9 **U**+16 **Pb**	Pb	-
CC5	41	13 **U**+8 **Pb**+4 **Al_2O_3**	Pb	-
CC6	41	13 **U**+8 **Pb**+4 **Al_2O_3**	Pb	-
CC7	41	13 **U**+8 **Pb**+4 **Al_2O_3**	Pb+C	-
CC8	47	13 **U**+8 **Pb**+4 **Al_2O_3**	Pb+C	thermal spectrum
CC9	41	13 **U**+8 **Bi**+4 **Al_2O_3**	Pb	-
CC10	41	13 **U**+Pb+8 **Bi**+4 **Al_2O_3**	Pb+C	-
CC10b	47	13 **U**+Pb+8 **Bi**+4 **Al_2O_3**	Pb+C	thermal spectrum
CC11	50	13 **U**+Pb+8 **Bi**+4 **Al_2O_3**	Pb+C	thermal and fast spectrum



Besides criticality C/E, we have:

- Kinetic parameters
- CR curve
- Spectral indices
- Axial and radial traverses
- Pb-Bi void
- Fuel Doppler

Extensive database for ND validation !



Sensitivity analysis shows large contribution of ^{208}Pb elastic scattering and average scattering angle cosine
These data for ^{208}Pb are very close to each other in all the libraries

Source: A. Kochetkov, 2019

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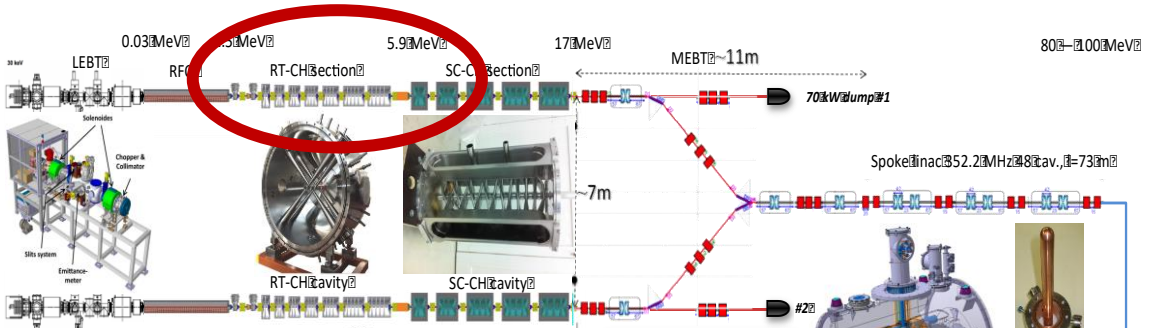
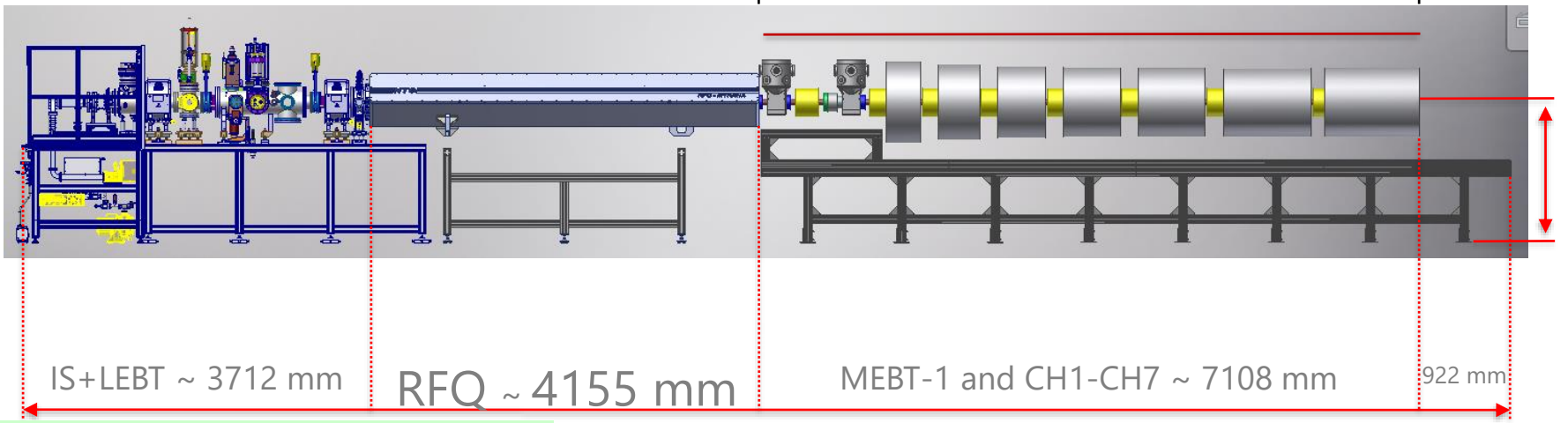
Beam line at the Centre des Ressources du Cyclotron in Université Catholique de Louvain





IS – ion source
LEBT – low energy beam transport, up to 30 keV
RFQ - radio frequency quadrupole, up to 1.5 MeV
MEBT – medium energy beam transport and
CH – cross-bar H-type cavities, up 5.9 MeV

Source: JEFFDOC-1956, 2018

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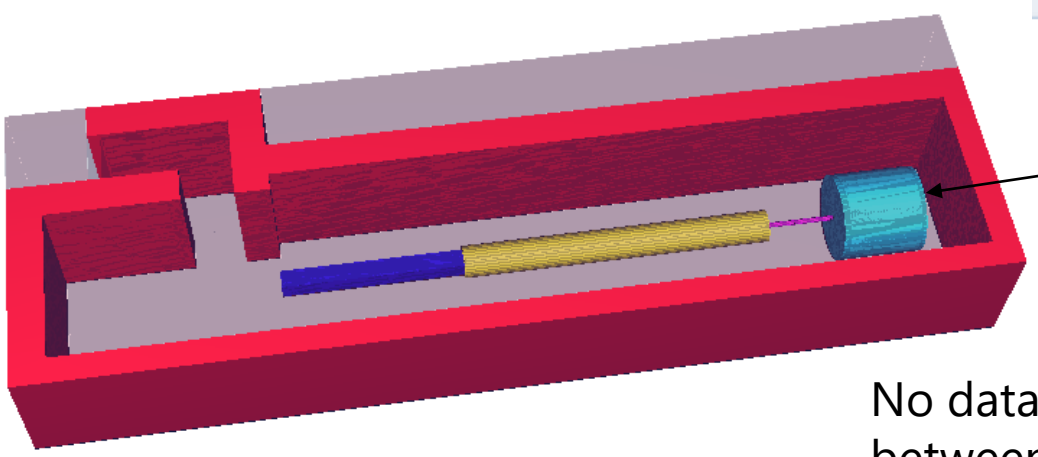
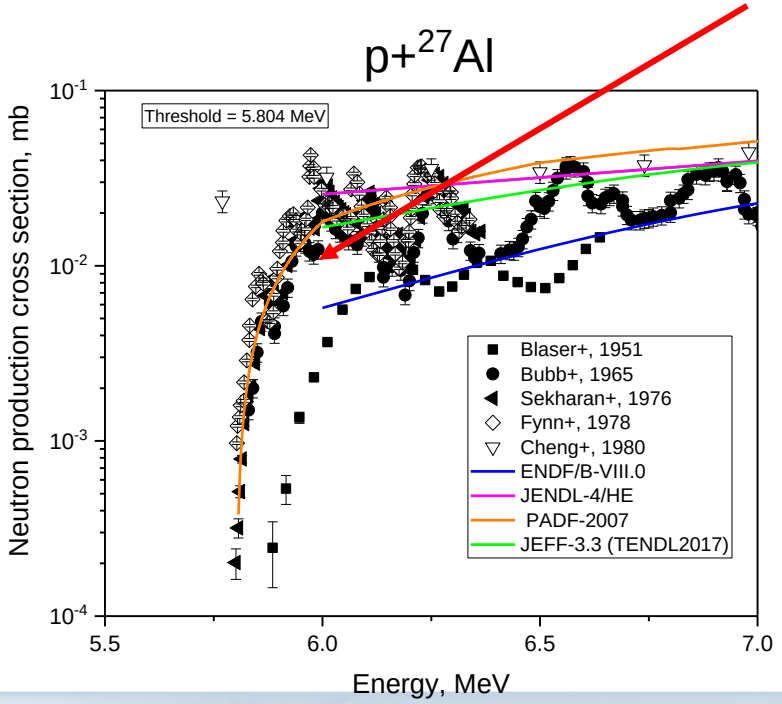
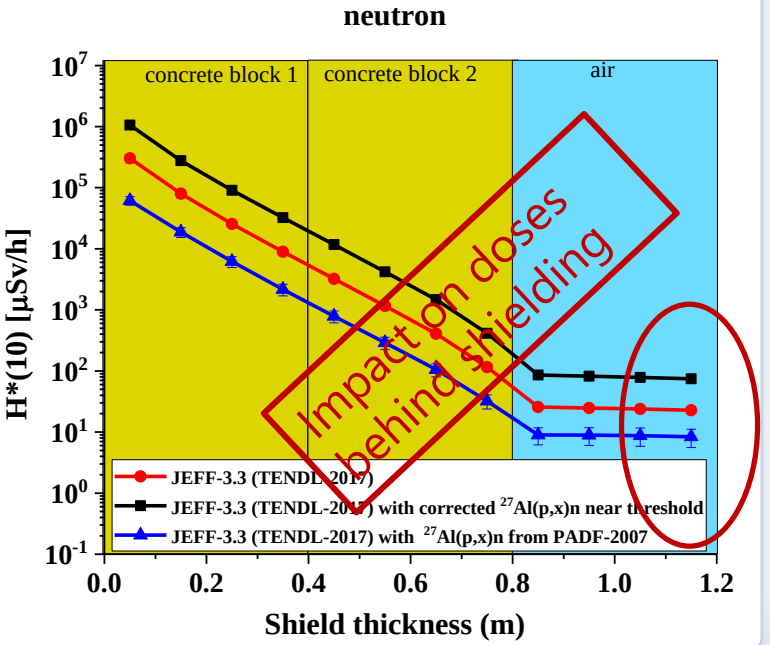
5.9 MeV beam dump shielding



Beam dump

No data on neutron production in JEFF between 5.8 (threshold) and 6 MeV





Source: JEFFDOC-1956, 2018

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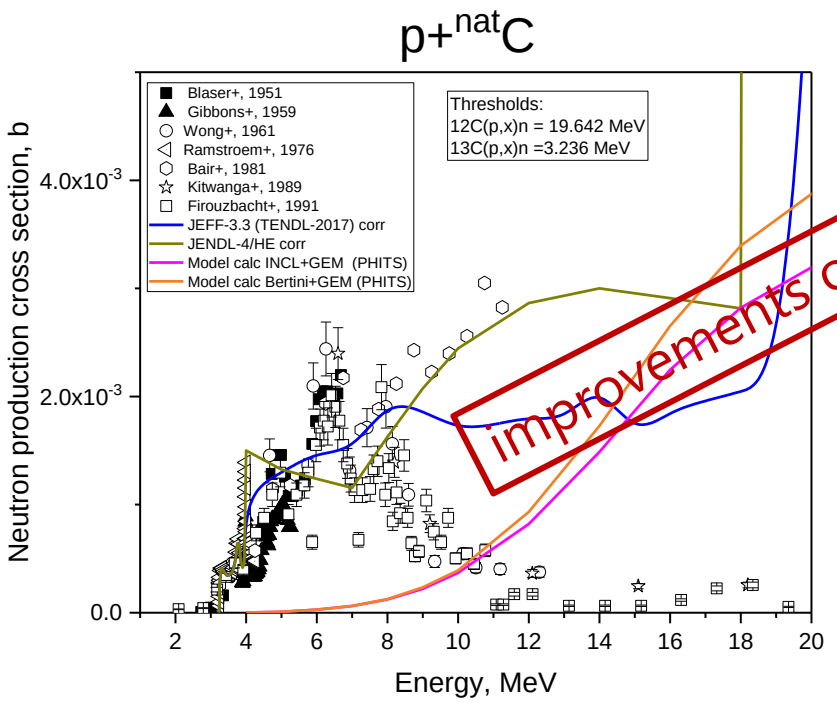
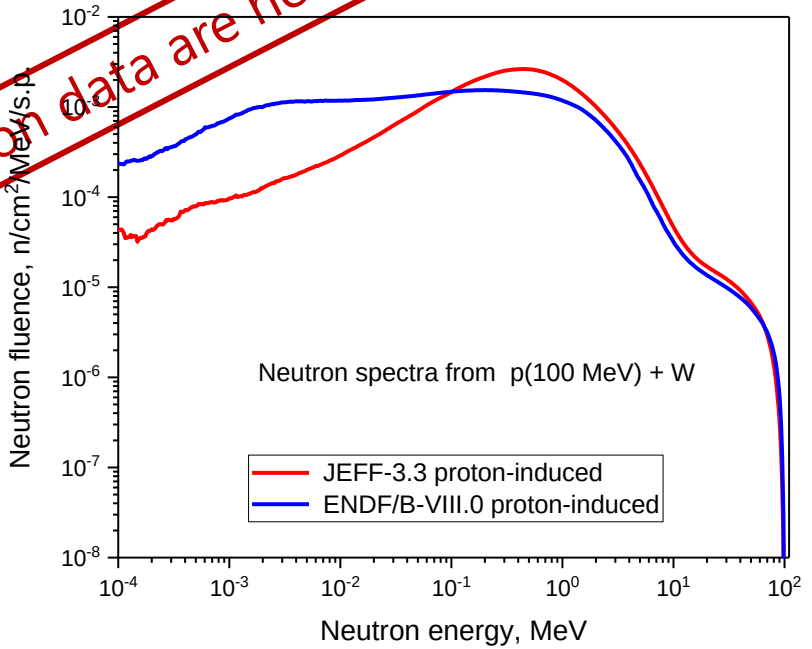
MINERVA: Shielding of 100 MeV accelerator + target for fusion materials irradiation

Shielding of ISOL targets:
Huge discrepancies between libraries/experimental data, especially for protons + light nuclei

Material irradiation (fusion targets):
Huge discrepancies both in neutron spectra and total neutron yield from p+W





improvements of proton data are needed!

Source: JEFFDOC-1956, 2108

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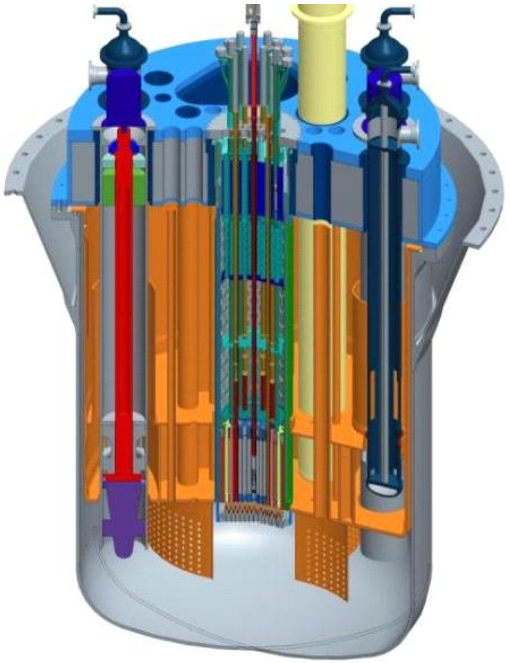
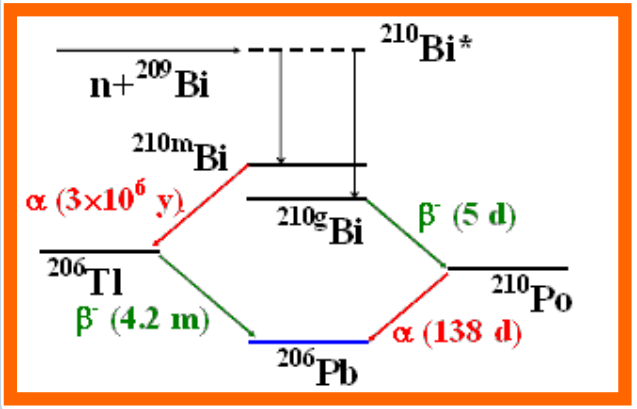
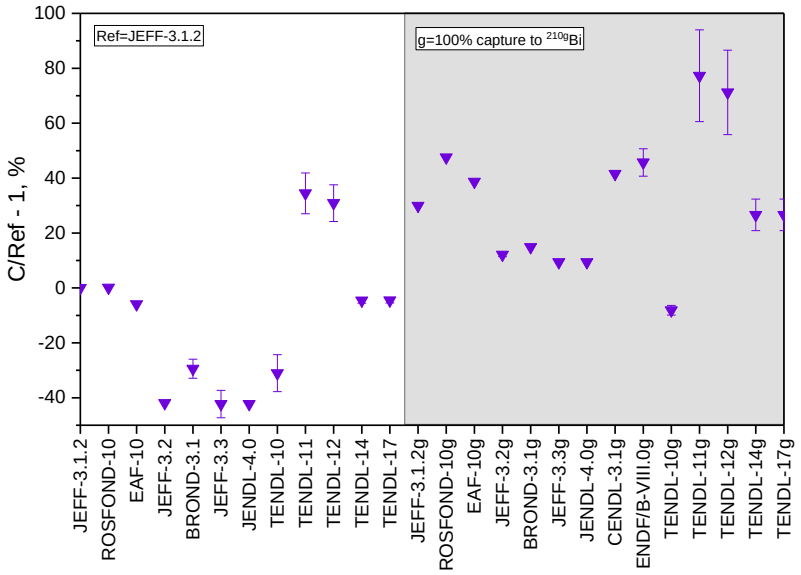
Polonium-210 in MYRRHA





- Produced by neutron capture $^{209}_{83}Bi \xrightarrow{(n,\gamma)} ^{210}_{83}Bi \xrightarrow{5.013d,\beta^-} ^{210}_{84}Po \xrightarrow{138d,\alpha} ^{206}_{82}Pb$
- Assuming no release, during 1 irradiation cycle 5.5e+4 TBq of ^{210}Po is produced from ~7600 ton of LBE
- Decay heat: 48 kW of LBE pool
- Normal operation: partially migrates in cover gas
- Failures or leaks: evaporation in contact with ambient air, formation of highly volatile species in presence of moistures and/or hydrogen

Accurate prediction of ^{210}Po production by neutronic codes is needed



- Grey shadow: consideration of neutron capture to ground state only = maximum possible ^{210}Po production
- Available covariance data have been propagated for some libraries
- The uncertainties do not cover differences between libraries

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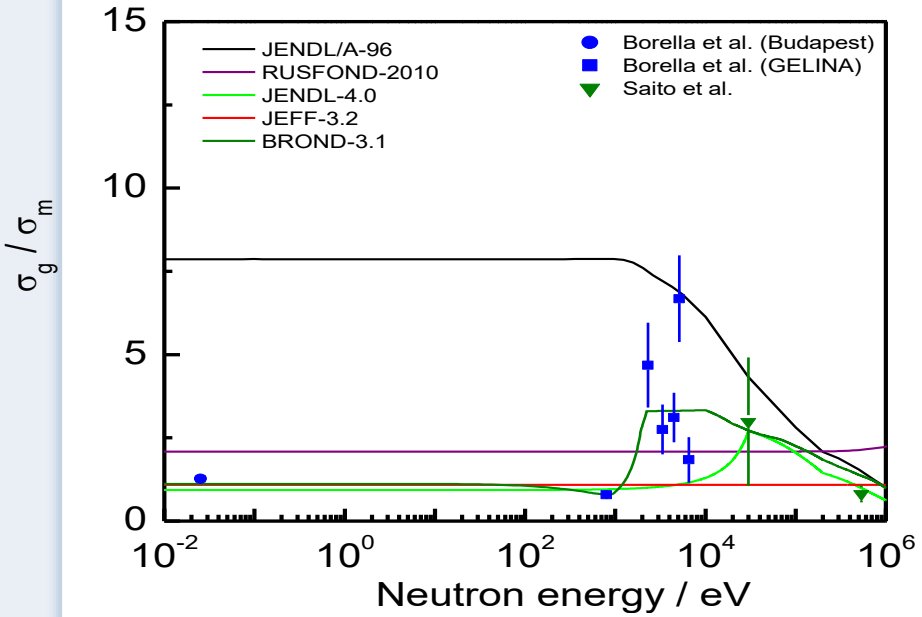
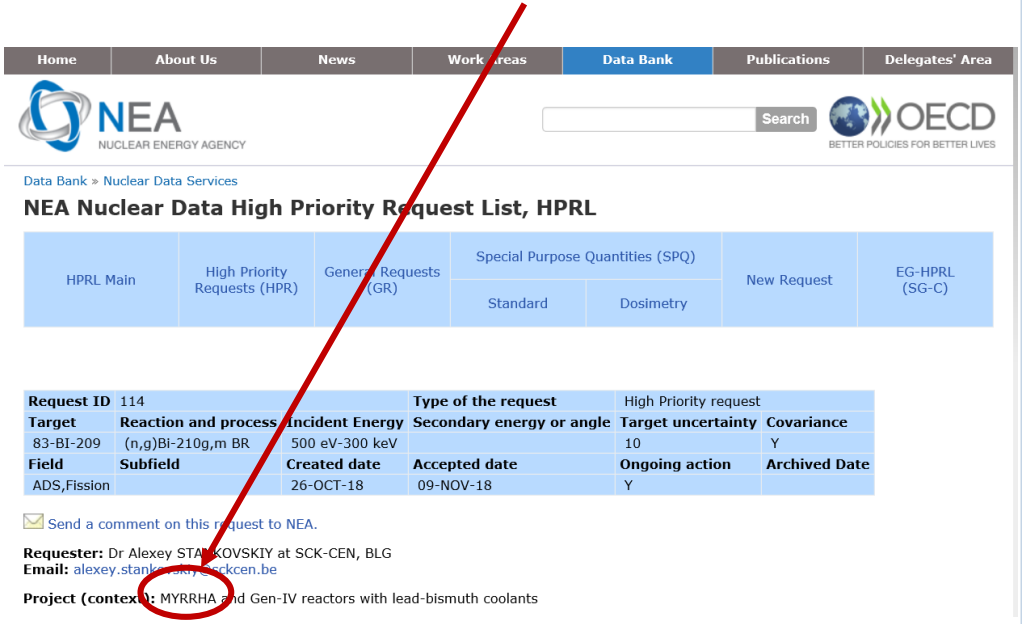
Polonium-210 in MYRRHA

Yield (branching ratio)



A new entry added to High Priority Request List



- A new experimental programme to measure BR and total neutron capture was launched by JRC and SCK•CEN
- First measurements have been performed in 2019 at J-PARC/ANNRI (Japan)
- They will be complemented by measurements at GELINA (JRC)

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Conclusions

- To design and license MYRRHA and its Phase I MINERVA, reliable nuclear data with covariances are needed to provide reliable central values and uncertainties for safety related parameters: criticality, reactivity effects, shielding, waste management, radioactive source terms, etc.

- For criticality safety, we need to reduce the keff uncertainty from ~1000 to 300 pcm (< 1 β_{eff})

- For shielding design for MINERVA, reliable proton-induced data, especially for light nuclides, are required

- For waste management, one of key points is accurate prediction of Po-210 production: an experimental programme has been launched with ultimate goal to produce new JEFF evaluation for Bi-210

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A jump in the future for innovation in Belgium

Source: SCK•CEN MYRRHA Project Team

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MYRRHA

...?

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