Nuclear data needs for MYRRHA and MINERVA

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OECD/NEA, June 6th, 2019
Outline

MYRRHA & MINERVA

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

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

**Accelerator**

<table>
<thead>
<tr>
<th>Particles</th>
<th>Protons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>600 MeV</td>
</tr>
<tr>
<td>Beam current</td>
<td>up to 4 mA</td>
</tr>
</tbody>
</table>

**Reactor**

<table>
<thead>
<tr>
<th>Power</th>
<th>65 to 100 MW&lt;sub&gt;th&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k_{\text{eff}} )</td>
<td>0.95</td>
</tr>
<tr>
<td>Spectrum</td>
<td>Fast</td>
</tr>
<tr>
<td>Coolant</td>
<td>LBE</td>
</tr>
</tbody>
</table>

Target

- Main reaction: Spallation
- Output: \( 2 \cdot 10^{17} \) n/s
- Material: LBE (coolant)
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
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
MYRRHA Phase 1: ongoing

Consists of

- MINERVA (MYRRHA Isotopes productionN coupling the linEar acceleRator to the Versatile proton target fAcity)

  ➢ 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
MYRRHA & MINERVA

Needs for Criticality Safety

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

Increase of confidence by improving the uncertainties is needed for:

- $^{239}$Pu: $(n,\gamma)$ both in resonance and fast energy region, $(n,f)$ fast, $\chi$ and $\bar{v}$ fast
- $^{238}$U: $(n,n')$ fast, $(n,\gamma)$ resonance and fast, $(n,n)$ resonance and fast
- $^{56}$Fe: $(n,\gamma)$ resonance and fast
- $^{235}$U: $\bar{v}$, $(n,f)$, $(n,\gamma)$ resonance and fast
- $^{209}$Bi $(n,\gamma)$ 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: $\bar{v}$ fast
- $^{238}$Pu: $(n,f)$ both resonance and fast

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

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

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

MYRRHA: hybrid Research reactor
- MOX fuel (7-30% $^{239}$Pu), Pb-Bi (LBE) coolant

Source: R. Capote (IAEA), Presentation given at ND2019, Beijing, 24th May 2019, L450
Challenges: Pu-241 example

Recent experimental data

+old experimental data

Only recent experimental data considered: libraries overestimate

+old data: consistency of libraries with many data sets
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)

Pb reflector

SS

Neutron spectrum

Neutron energy [MeV]

total core
fuel
coolant

Reaction rate in fuel

Neutron energy [MeV]

235U(n,f)
238U(n,f)
235U(n,g)
238U(n,g)
Criticality C/E

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

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!

<table>
<thead>
<tr>
<th>Core</th>
<th>#FAs</th>
<th>FA composition</th>
<th>Reflector</th>
<th>In-Pile Section</th>
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<tbody>
<tr>
<td>CR0</td>
<td>97</td>
<td>9 U+16 Pb</td>
<td>Pb</td>
<td>-</td>
</tr>
<tr>
<td>CC5</td>
<td>41</td>
<td>13 U+8 Pb+4 Al₂O₃</td>
<td>Pb</td>
<td>-</td>
</tr>
<tr>
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<td>41</td>
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</tr>
<tr>
<td>CC7</td>
<td>41</td>
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<td>Pb+C</td>
<td>-</td>
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<tr>
<td>CC8</td>
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<td>Pb+C</td>
<td>thermal spectrum</td>
</tr>
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<td>-</td>
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<tr>
<td>CC11</td>
<td>50</td>
<td>13 U+Pb+8 Bi+4 Al₂O₃</td>
<td>Pb+C</td>
<td>thermal and fast spectrum</td>
</tr>
</tbody>
</table>

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

JEFF needs improvement

JENDL gives best agreement

Source: A. Kochetkov, 2019
• MYRRHA & MINERVA
• Needs for Criticality Safety

Needs for Shielding
• Needs for Radioactive Source Terms & Waste Management
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
5.9 MeV beam dump shielding

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

Source: JEFFDOC-1956, 2018

Impact on doses behind shielding

Concrete block 1
Concrete block 2
Air

Shield thickness (m)

H*(10) [μSv/h]
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

Neutron production cross section, \( b \)
Energy, MeV
Thresholds:
\( ^{12}\text{C}(p,x)^{1}n = 19.642 \text{ MeV} \)
\( ^{13}\text{C}(p,x)^{1}n = 3.236 \text{ MeV} \)

Neutron fluence, \( n/cm^2/MeV/s.p. \)
Neutron energy, MeV
Neutron spectra from \( p(100 \text{ MeV}) + W \)

Source: JEFFDOC-1956, 2108
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Needs for Radioactive Source Terms & Waste Management
Polonium-210 in MYRRHA

- Produced by neutron capture: $^209_{83}Bi(\text{n},\gamma)^{210}_{83}Bi \rightarrow ^{210}_{84}Po \rightarrow ^{206}_{82}Pb$
- Assuming no release, during 1 irradiation cycle $5.5\times 10^4$ 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
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)
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 $k_{eff}$ uncertainty from ~1000 to 300 pcm (< 1 $\beta_{eff}$)

- 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
A jump in the future for innovation in Belgium