OAK RIDGE National Laboratory

NCSP Technical Program Review

NCSP Task ORNL IP&D-5

FY21 Progress of the Oak Ridge Health Physics Research Reactor CAAS Benchmark Evaluation

February 16th, 2022

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ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

NCSP Task IP&D-5: Goal

- **Use available data from Health Physics Research Reactor (HPRR) operation to create a benchmark report for inclusion in the ICSBEP, as a Criticality Accident Alarm System (CAAS) shielding benchmark**

  - FY 2019 proposal
    - First subtask (FY19) – research and document data needed for an ICSBEP benchmark based on the ORNL HPRR
    - Second subtask (FY20) – Evaluate and publish HPRR measurement data

  - This work represents a safe investment: potentially high benefits and low-risks.
    - High benefits: The increased number of available shielding benchmarks in the ICSBEP and other benchmark databases.
    - Low-risk: Facility and experiments data are available, meaning the bulk of the work is in the evaluation.

NCSP Task IP&D-5: Summary of FY20 work

- Analysis of available HPRR documentation for the creation of a shielding benchmark
- Creation of an evaluation report related to the Sulfur pellet activation at different distances from a HPRR pulse, shielded and unshielded (ORNL/TM-2020/1731 https://doi.org/10.2172/1765486)
  - The reactor was used in burst operation to irradiate sulfur pellets placed at different distances and shielded by different materials (steel, lucite, concrete)
  - **The results of the evaluation of those experiments were not satisfying, with high C/E ratios because of uncertainty in the sulfur pellets counting process.**

NCSP Task IP&D-5: Summary of FY21 work

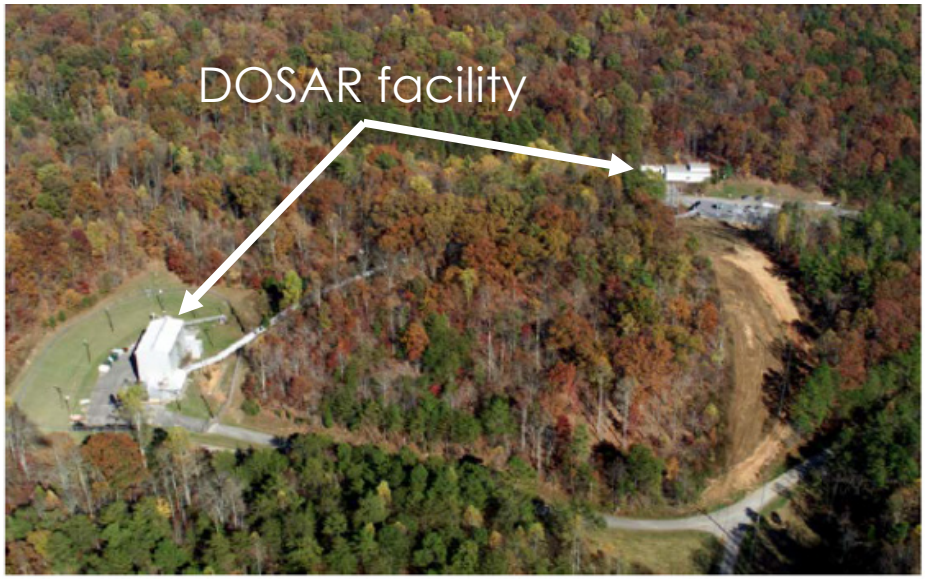
- Submission of the Sulfur pellets evaluation to the ICSBEP TRG mid-FY21
- After discussions with ICSBEP and independent reviewer, decision of changing the benchmark metric from sulfur fluence to element 57 dose (specific dose unit related to a phantom)
- Creation of an evaluation report related to the element 57 dose measured by Bonner Sphere spectrometry at 3 meters from a HPRR pulse, shielded and unshielded
- New evaluation presented at the ICSBEP 2021 Technical Review Group meeting in October 2021
- Overview of the evaluation progress presented at the 2021 ANS Winter meeting ("Mathieu N. Dupont, Cihangir Celik, "Evaluation of Oak Ridge National Laboratory Health Physics Research Reactor Operation Data for Criticality Accident Alarm System Benchmark Creation," Transactions of the American Nuclear Society, 125, 1137-1140 (Dec 2021)")

NCSP Task IP&D-5: Summary of FY21 work

- The element 57 dose evaluation was not accepted for 2022 publication in the handbook
- Main issue: The element 57 neutron dose should not be used as a benchmark metric as it is not directly measured, the neutron fluence should be used instead
- A subgroup involving different criticality safety and shielding benchmark experts was formed to help solve other issues identified in the evaluation during the TRG meeting
- The updated evaluation will be presented again at the 2022 ICSBEP TRG for publication in the 2023 handbook

The Health Physics Research Reactor

- The HPRR or Fast Burst Reactor (FBR), was designed and built at ORNL in 1961
- Part of the Dosimetry Application Research (DOSAR) facility in ORNL from 1963 to 1987
- Operated for thousands of hours, achieved criticality 10,000 times
- Numerous studies and publications, involving dosimetry, plants radiobiology, radiation alarms, teaching and training.
- Decommissioned in 1987



DOSAR Facility, A History of Research Reactors Division (1987)

The Health Physics Research Reactor

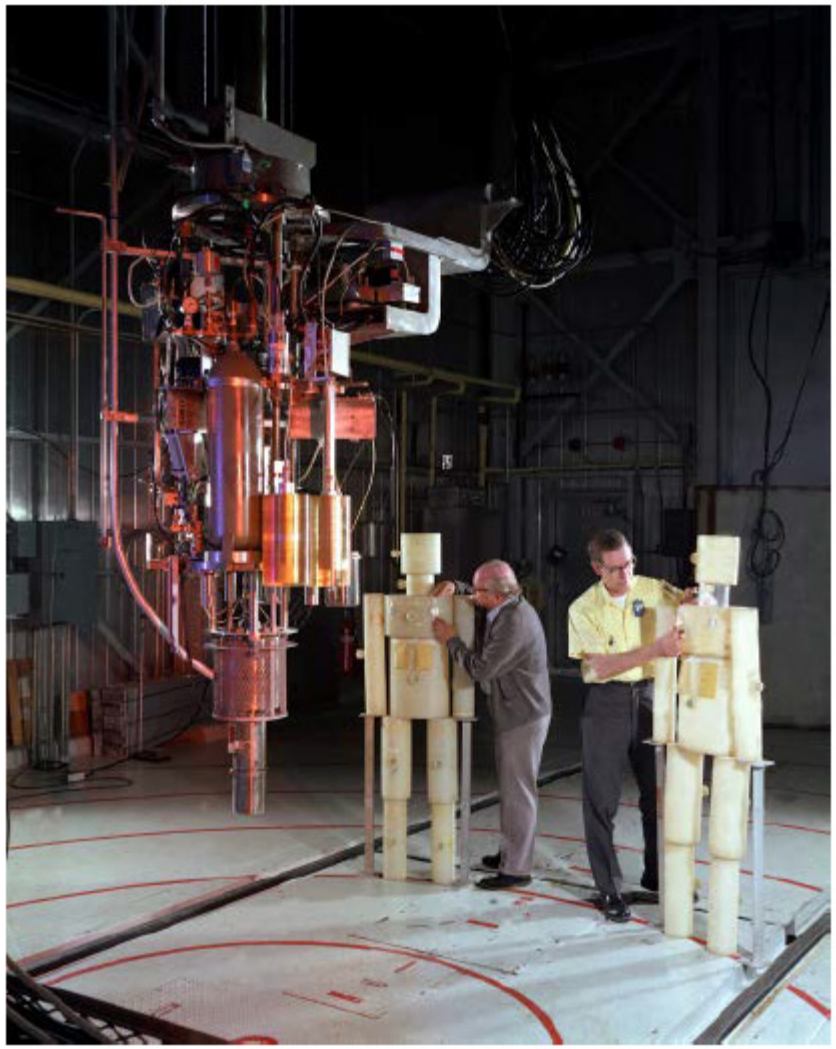


Figure 53: HPRR

A History of Research Reactors Division (1987)

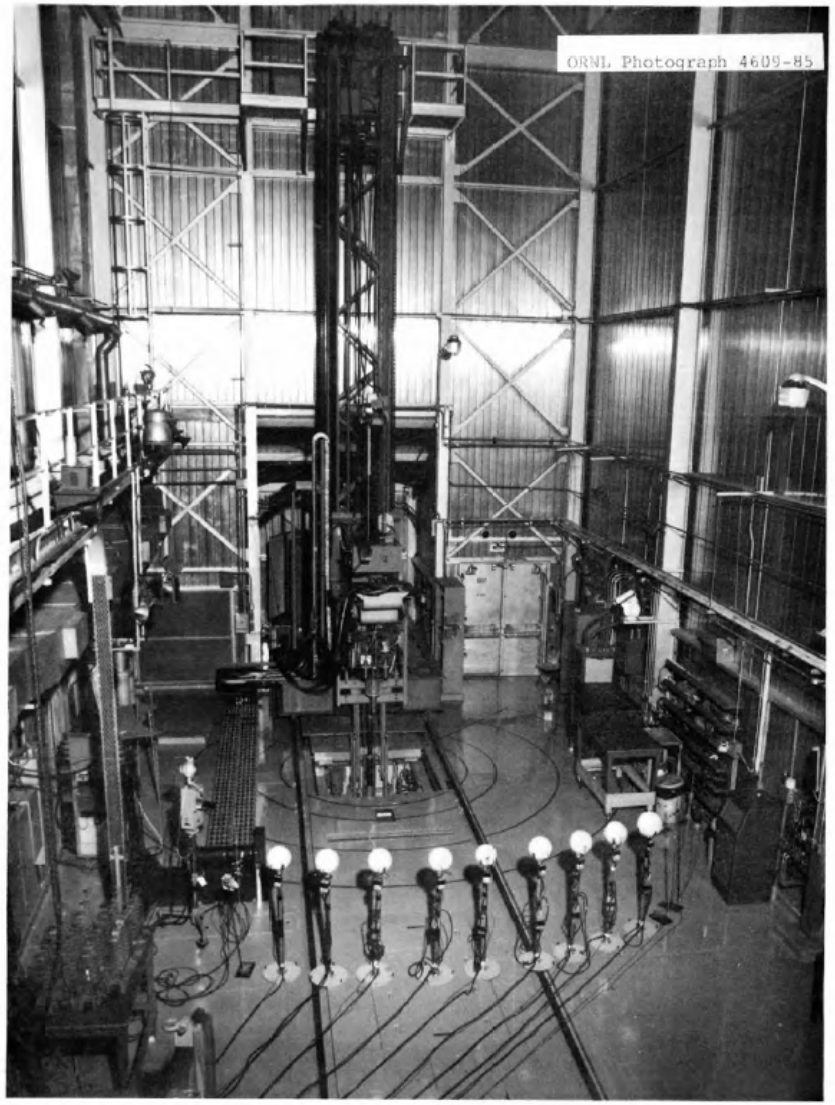


Figure 1. HPRR in experimental position

Health Physics Research Reactor Reference Dosimetry, ORNL-6240 (1987)

Evaluation of Experimental Data

- A lot of experimental data is available, with a varying level of detail. The evaluation work focused only on experimental data from ORNL-6240, the latest report available with the newest reactor configuration
- Four experimental candidates are considered of potential value for the benchmark:

1. Neutron source estimation from a HPRR pulse (energy spectrum, fission yield)
2. Threshold Detector Unit (TDU) measurements at different distances from a HPRR pulse, shielded and unshielded
3. Sulfur pellet activation at different distances from a HPRR pulse, shielded and unshielded
4. **Total neutron fluence from a HPRR pulse measured by Bonner Sphere Spectrometry, shielded and unshielded**

Evaluation of Experimental Data

4. Total neutron fluence from an HPRR pulse measured by Bonner Sphere Spectrometry, shielded and unshielded

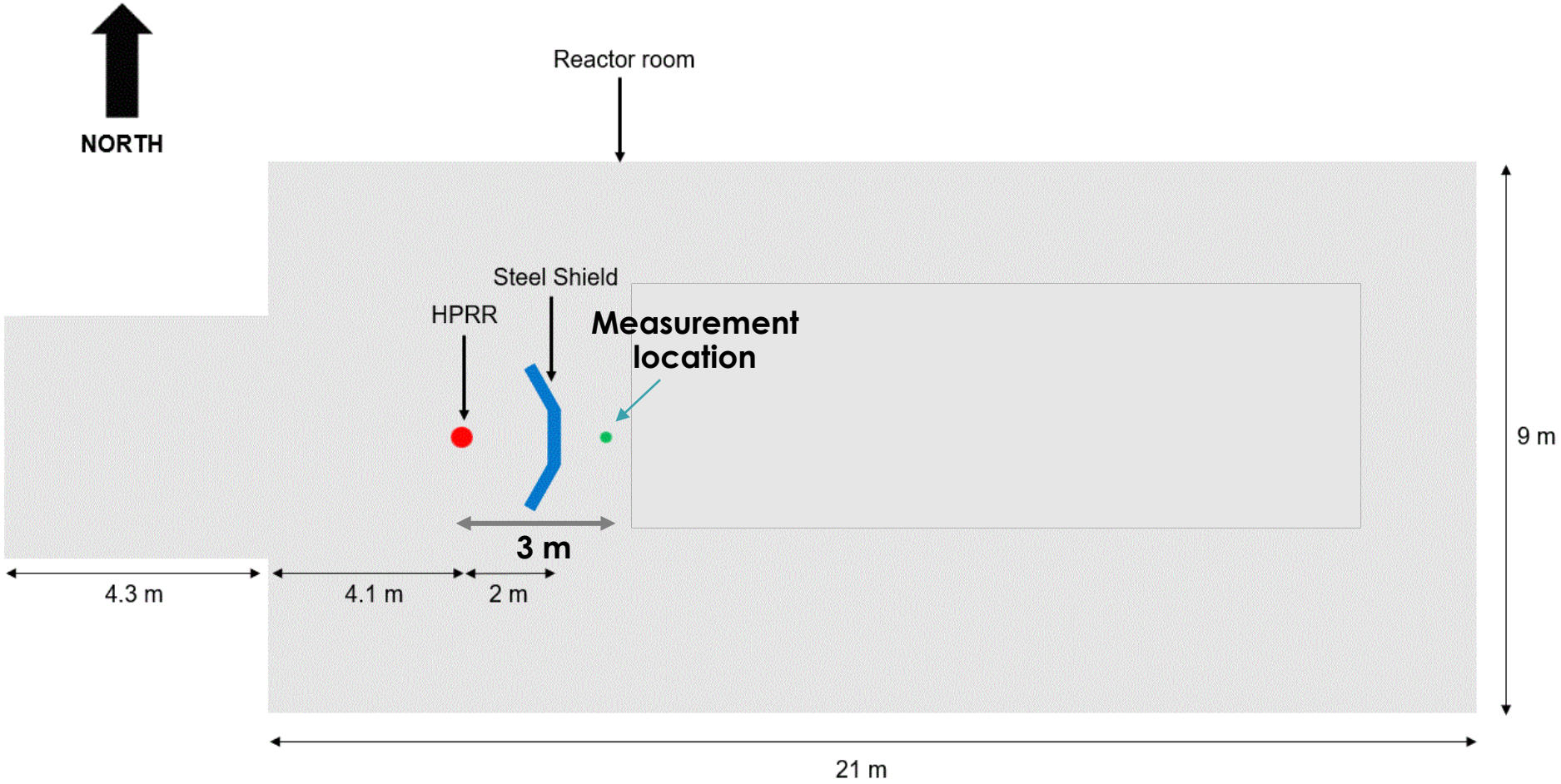
- Only bare and steel-shielded configurations are considered acceptable as a benchmark, too much uncertainty in the other shield dimensions and material compositions (concrete, lucite)
- The neutron fluences are computed from SCALE MAVRIC calculations at 3 meters from HPRR centerline from 10^{17} fissions
- Additional responses derived from the neutron fluence measurement are also available and computed:
  - Neutron spectrum shape
  - Element 57 neutron dose (Absorbed dose in region 57 of a tissue-equivalent Auxier phantom)
  - Element 57 neutron dose equivalent
  - Kerma in air
  - Dose per unit fluence
  - Steel shield attenuation

Evaluation of Experimental Data

- **A lot of missing and contradictory data:**
  - U-Mo coating uncertainty
  - Building walls, shields, concrete material composition and dimensions
  - What was actually inside the building during operation
  - Lack of material and dimension information

- A thorough sensitivity study was performed in FY20 for the sulfur fluence benchmark metric and FY21 for the neutron dose, and must be updated to focus on the neutron fluence for FY22
- Expected benchmark relative uncertainty around 70%

Evaluation of Experimental Data

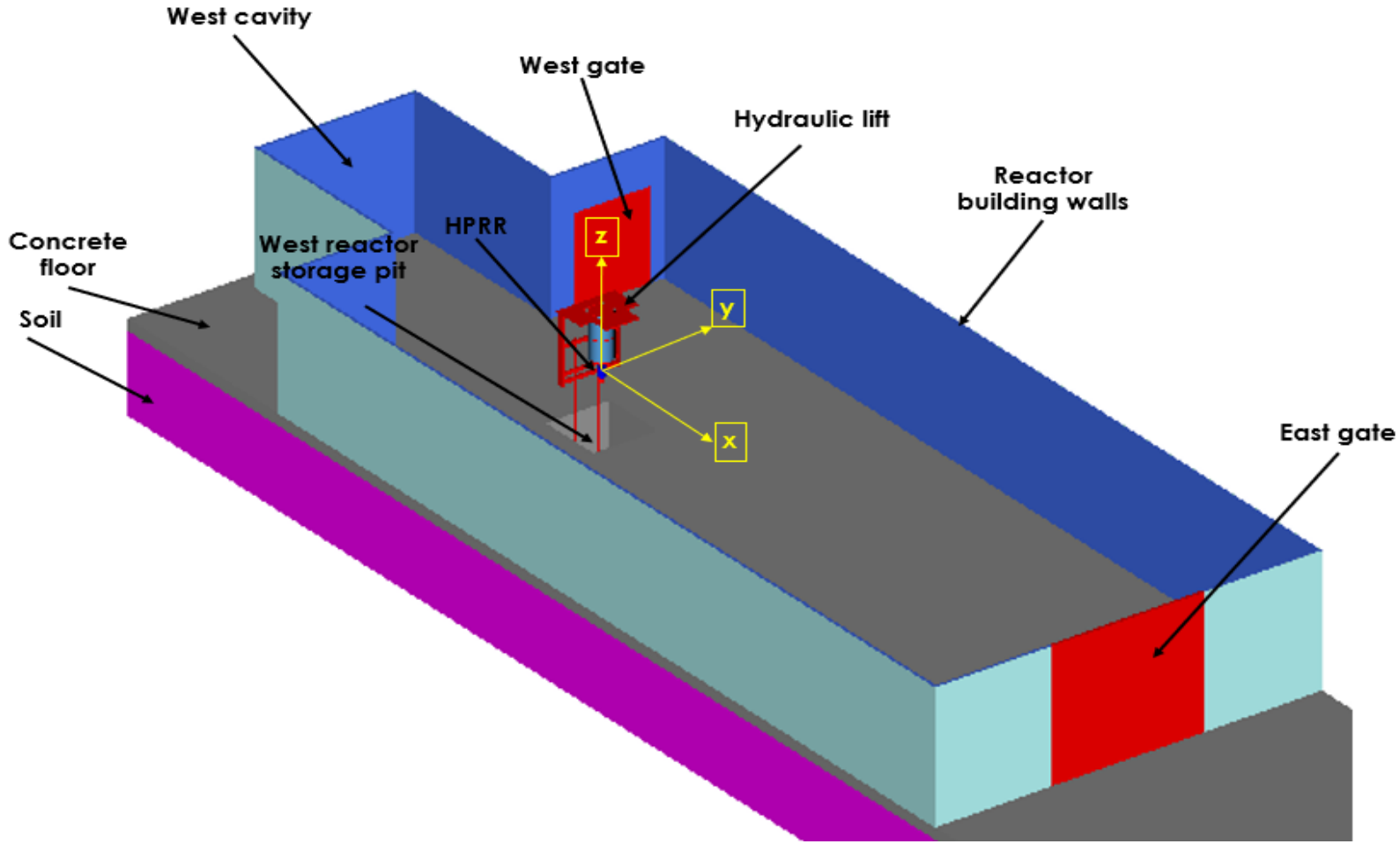


Overview of experiment configuration, top view (not in scale).

Benchmark Model Overview

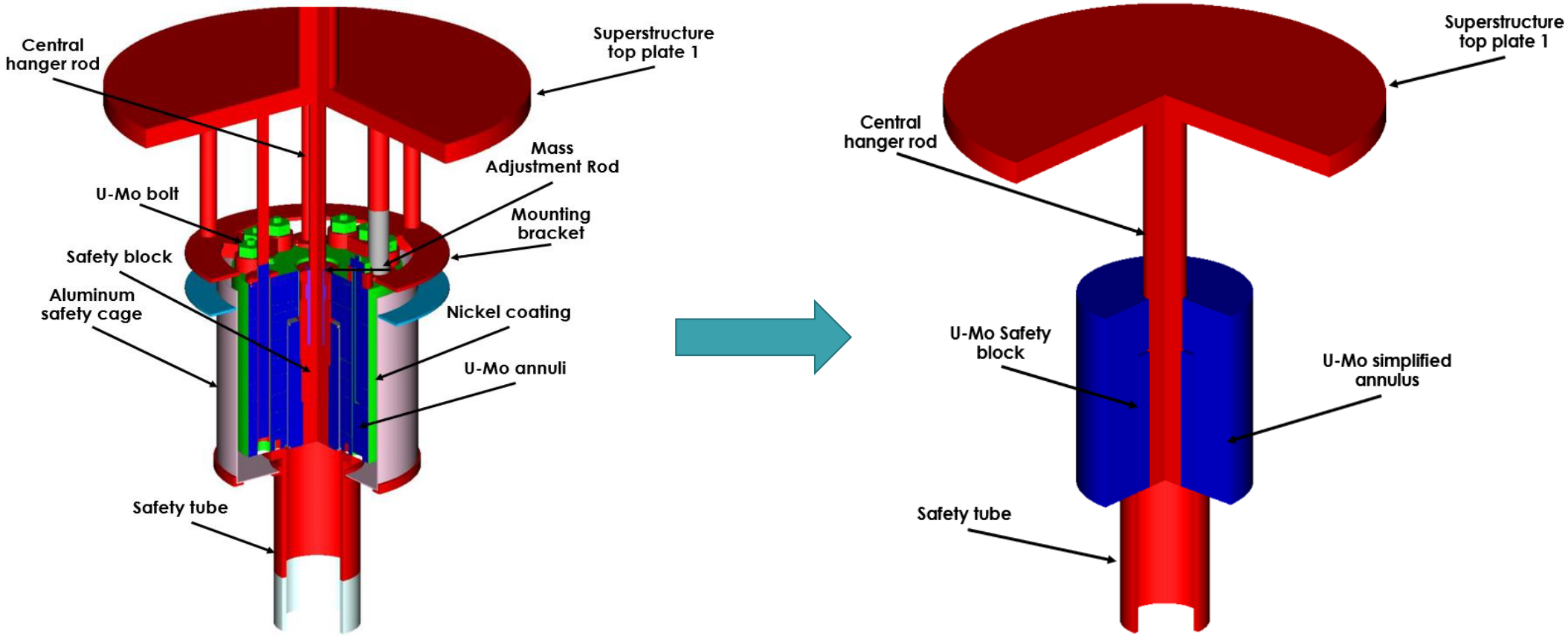
- A complete detailed model of the HPRR was built in SCALE 6.2.4
- A simplified model was also created from removing the statistically insignificant elements, defined as the benchmark model
- 2-step methodology:
  - KENO-VI run to create a fission source from the HPRR pulse operation
  - MAVRIC run to calculate the neutron fluence and chosen response at 3 meters (neutron fluence and others), using the fission source obtained by KENO as an input. Use of CADIS to reduce calculation time
- One KENO and one MAVRIC calculation per experiment configuration (bare and steel shielded)

Benchmark Model Overview



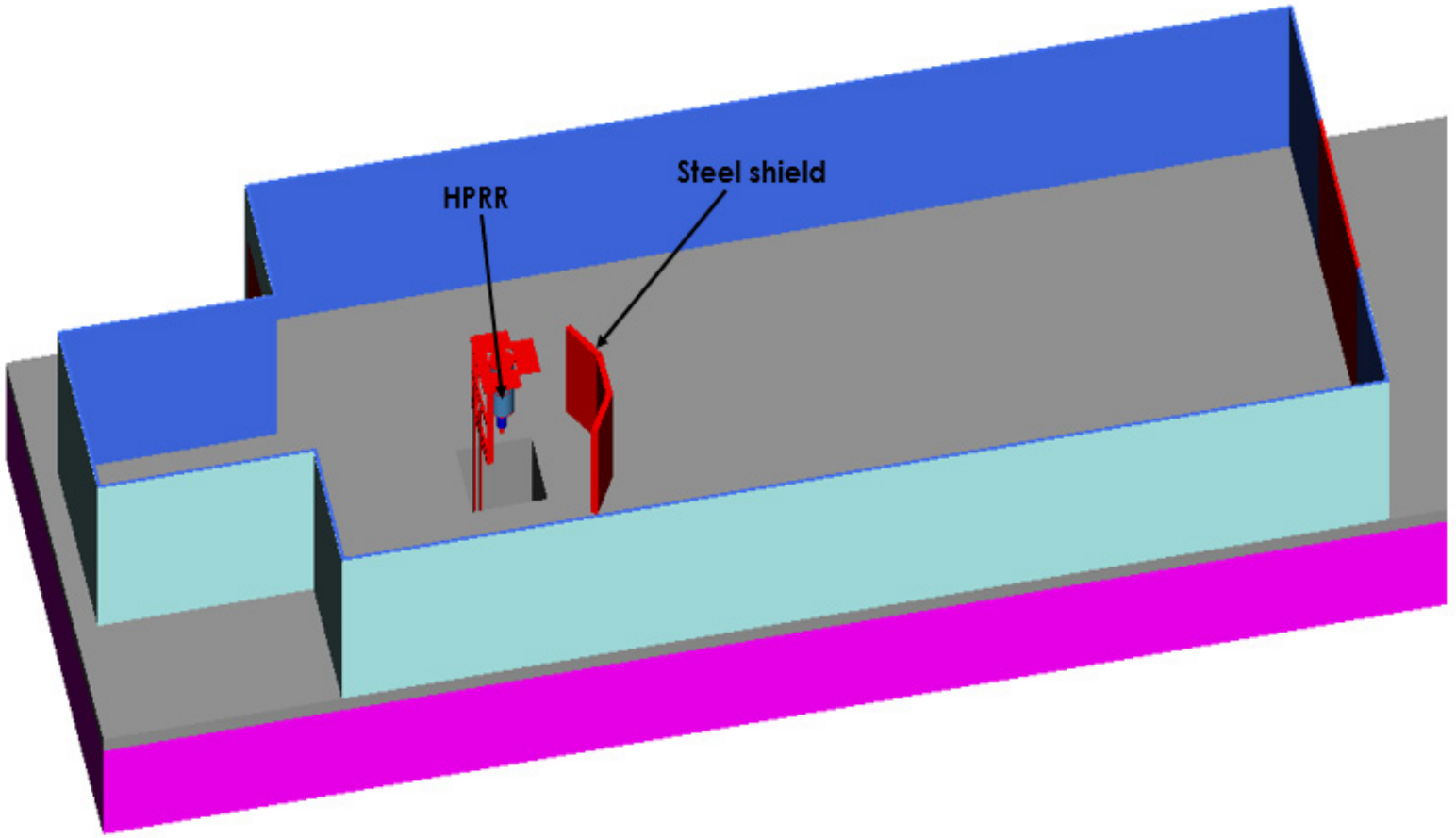
Overview of the bare configuration benchmark model

Benchmark Model Overview



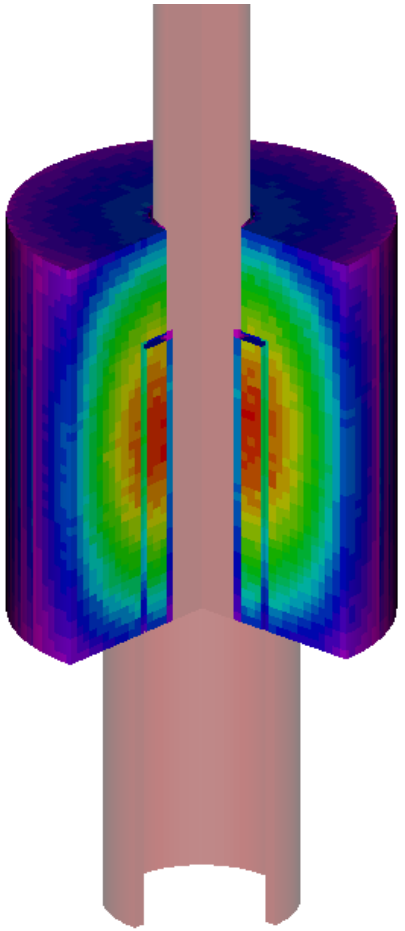
Overview of the detailed (left) and simplified (right) benchmark models, front right quarter

Model overview



Overview of the steel shield configuration benchmark model

Results of Sample Calculations



HPRR 3-dimensional spatial distribution of fission neutrons calculated with KENO-VI using ENDF/B-VII.1 continuous energy cross sections, ORNL/TM-2020/1731 (2020)

Preliminary Sample Calculations Results

	At 3 m from 10^{17} fissions of the HPRR					
	Neutron fluence (cm^{-2})			Element 57 Dose (Gy)		
Configuration	ORNL-6240	MAVRIC	C/E	ORNL-6240	MAVRIC	C/E
Bare	1.73E+11	2.41E+11	1.39	3.98	4.99	1.26
Steel Shield	9.50E+10	1.18E+11	1.24	1.63	1.83	1.12

Expected and calculated C/E ratios are around
1.3 for neutron fluence,
1.2 for element 57 dose

Preliminary Sample Calculations Results

$$Steel\ Shield\ Attenuation = \frac{Steel\ shielded\ HPRR\ Response\ at\ 3\ meters}{Bare\ HPRR\ Response\ at\ 3\ meters}$$

Steel Shield Attenuation of Element 57 dose		
ORNL-6240	MAVRIC	C/E
0.41	0.37	0.89

Expected and calculated attenuation ratios are statistically close

Conclusion

- Different HPRR experiments evaluations have been created from different benchmark metrics
- Sulfur fluence and Threshold Detector Unit experiment evaluations are kept aside for now
- Neutron fluence, element 57 dose and other dosimetry responses at 3 meters have C/E ratios below 1.5 for bare and steel shield configurations
- Additional promising metrics as dose per unit fluence and steel shield attenuation were computed

Conclusion

- The FY21 version of the evaluation, focusing on element 57 dose at 3 meters, was presented at the ICSBEP Technical Review Group meeting in October 2021 and was not accepted for 2022 publication in the handbook
- Main issue: Replace the element 57 neutron dose benchmark metric by neutron fluence, closer to what was measured
- A subgroup was formed, confident for the updated neutron fluence evaluation to be accepted in the ICSBEP handbook
- The updated evaluation will be presented again at the 2022 ICSBEP TRG for publication in the 2023 handbook

Thank you