OAK RIDGE National Laboratory

WPEC Subgroup 47

Experiments for SINBAD

Evaluation of ORNL Oak Ridge Health Physics Research Reactor Operation Data for CAAS Benchmark Creation

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

U.S. DEPARTMENT OF ENERGY

Project overview

- **FY19-20 NCSP funded project: NCSP Task IP&D-5**
- **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**

- A FY20 report summarizing the evaluation is publicly available (ORNL/TM-2020/1731 https://doi.org/10.2172/1765486)
- Ongoing discussions to include the evaluation in the ICSBEP, IRPhEP and/or SINBAD
- A potentially different benchmark metric is being studied to improve the benchmark quality

HPRR facts

- 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.

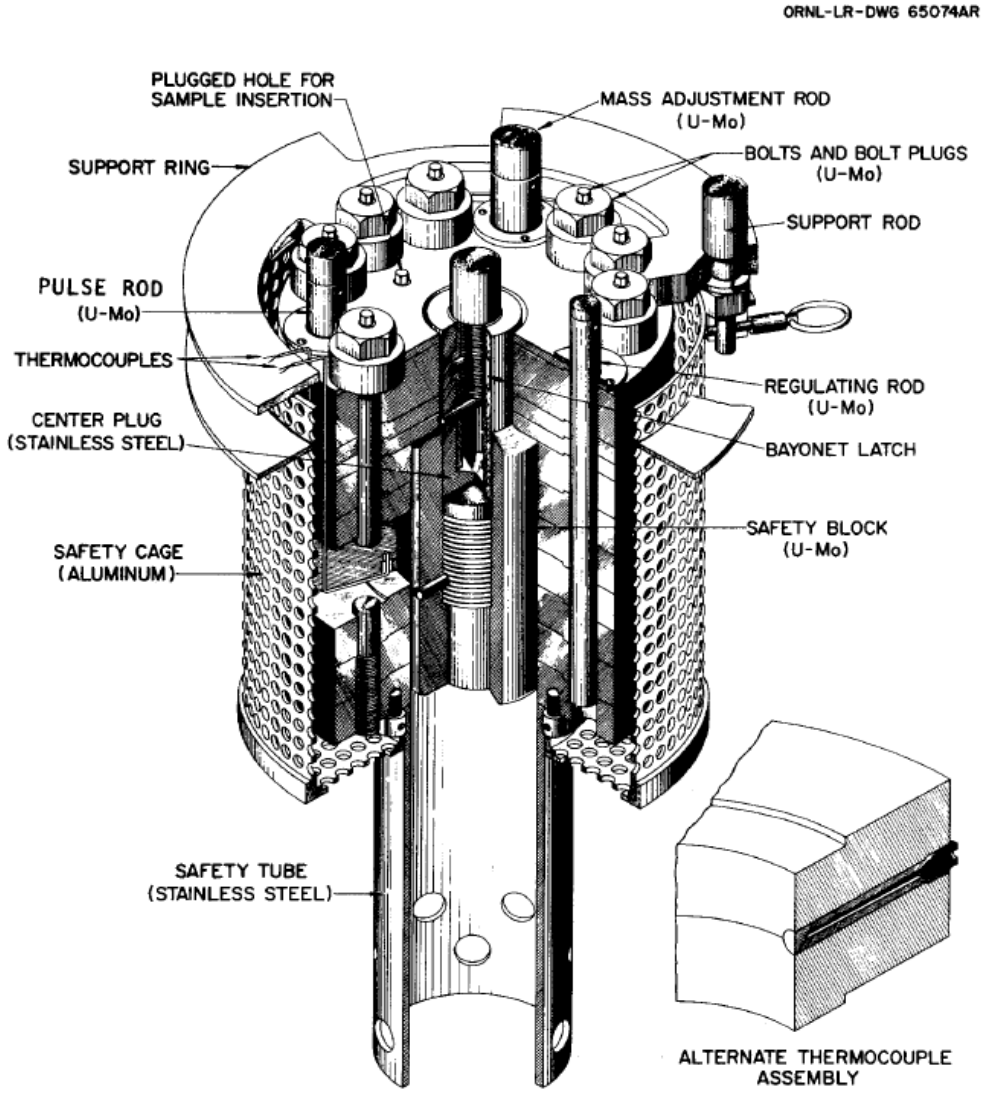
- Decommissioned in 1987

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

HPRR facts

- The HPRR is a fast reactor: Unshielded, unmoderated, highly enriched (93.14%) U-Mo alloy (90% U) core

- U-Mo inventory:
  - 11 U-Mo annulus plates
  - 9 U-Mo partially hollow bolts
  - 9 bolt inserts
  - 3 control rods
  - 1 sample irradiation hole
  - 1 safety block (center cylinder)



Operation Bren, CEX 62-02 (1965)

HPRR facts

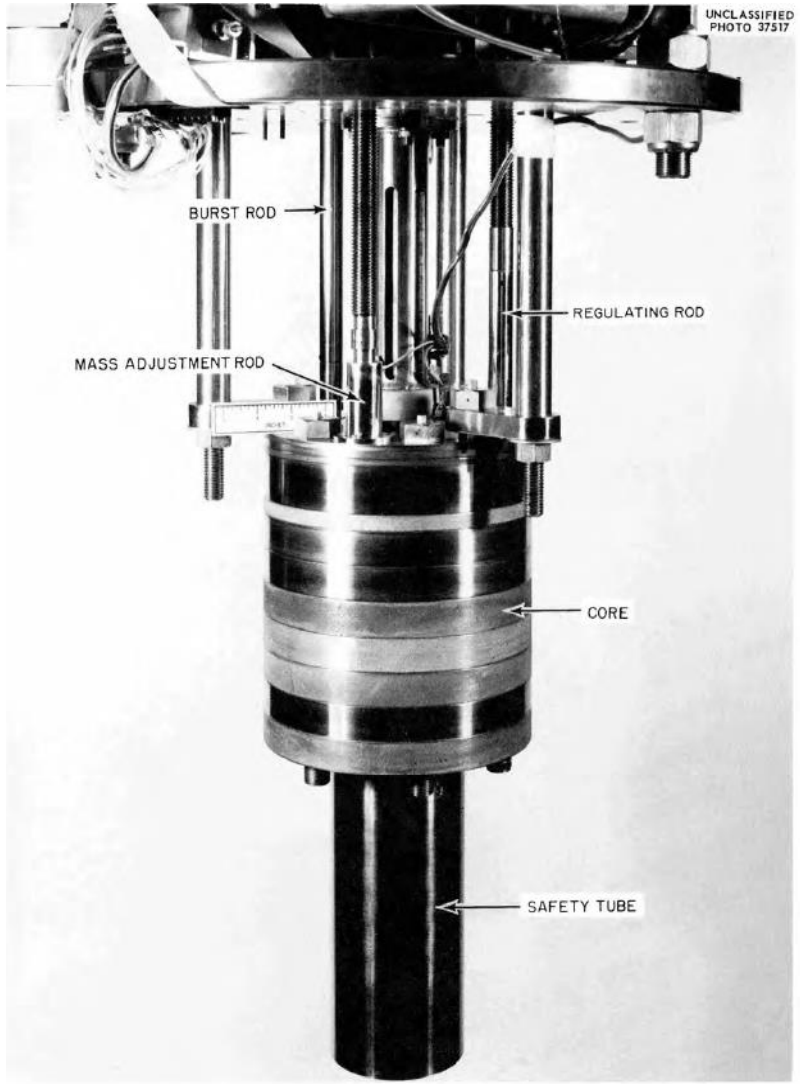


Fig. 3.5. Core with Safety Tube Attached.

Health Physics Research Reactor Hazards Summary, ORNL-3248 (1962)

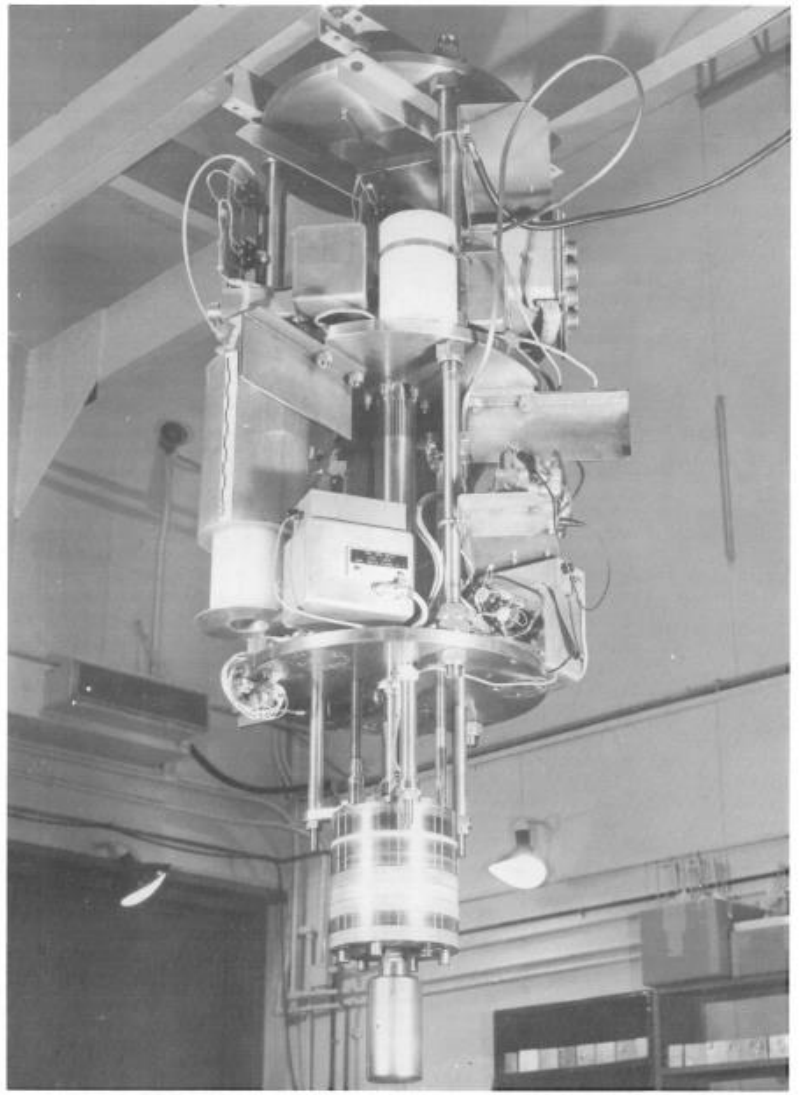


Fig. 3.1—ORNL Health Physics Research Reactor.

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Operation Bren, CEX 62-02 (1965)

HPRR facts

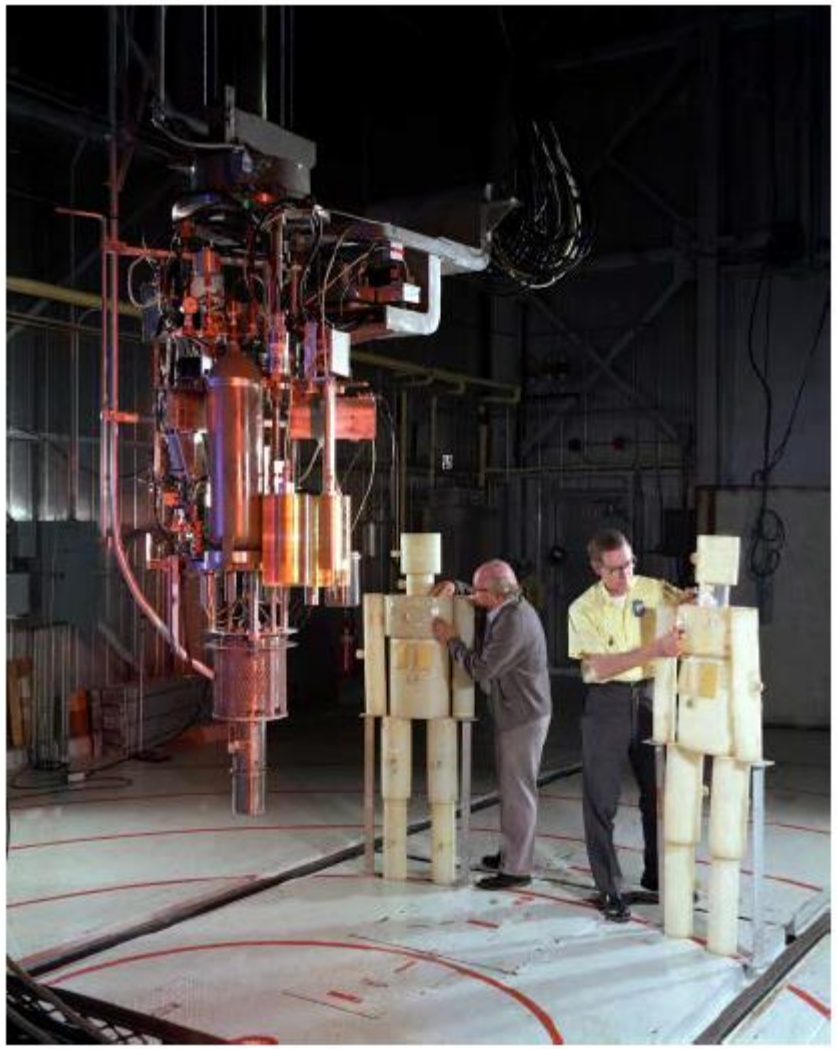


Figure 53: HPRR

A History of Research Reactors Division (1987)

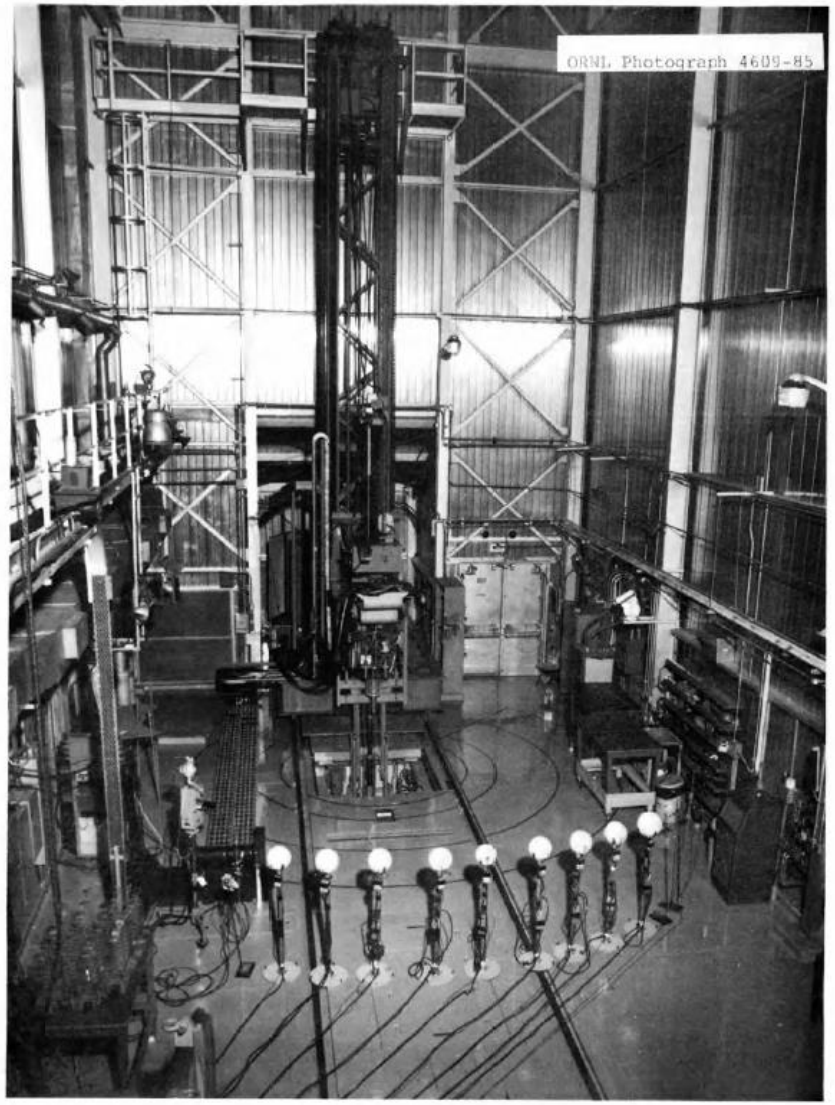
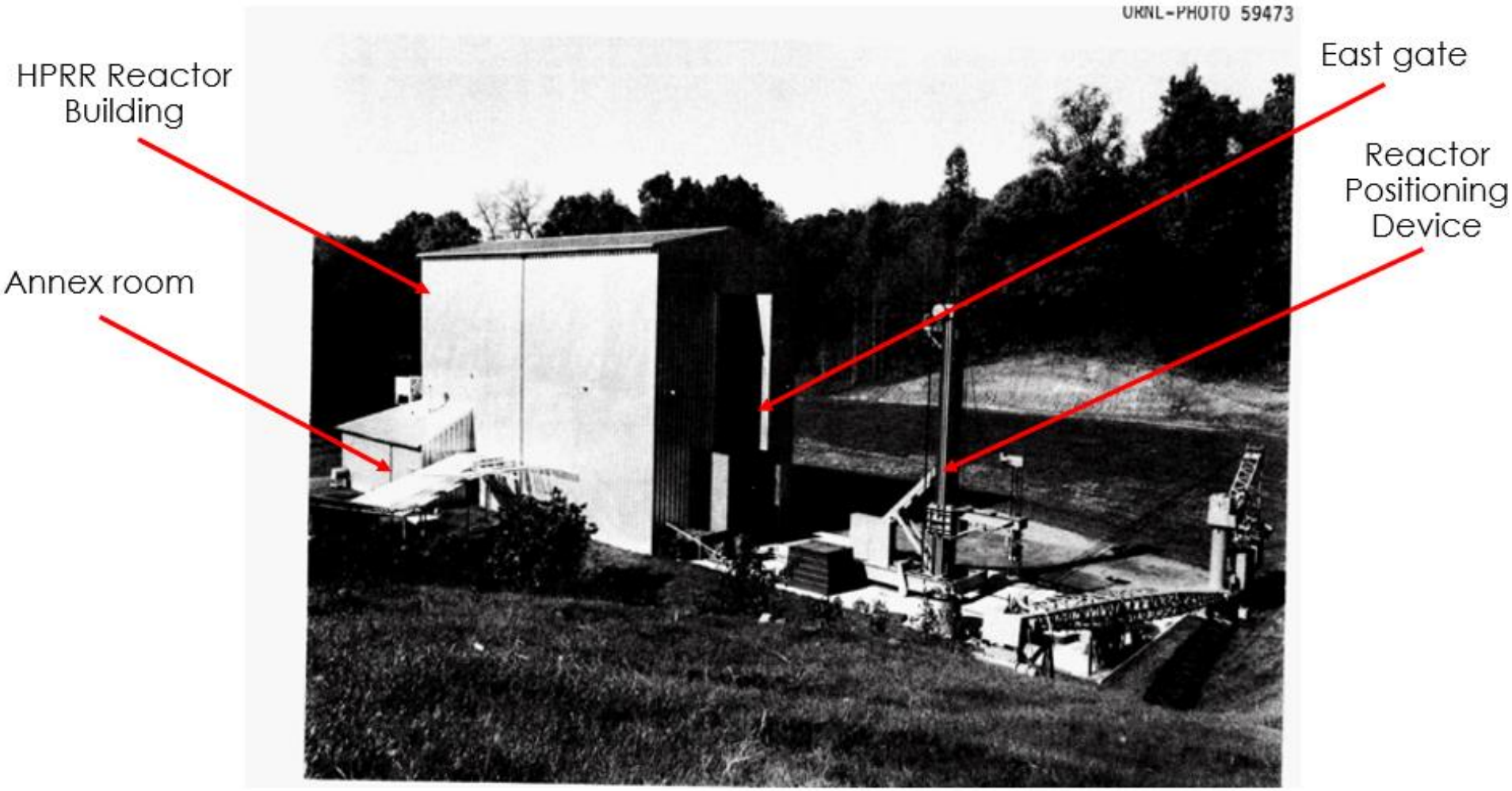


Figure 1. HPRR in experimental position

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

HPRR facts



Operating Manual for the Health Physics Research Reactor, ORNL/TM-9870 (1985)

HPRR facts

Picture taken on 06/03/2021

HPRR facts

Picture taken on 06/03/2021

HPRR facts

Picture taken on 06/03/2021

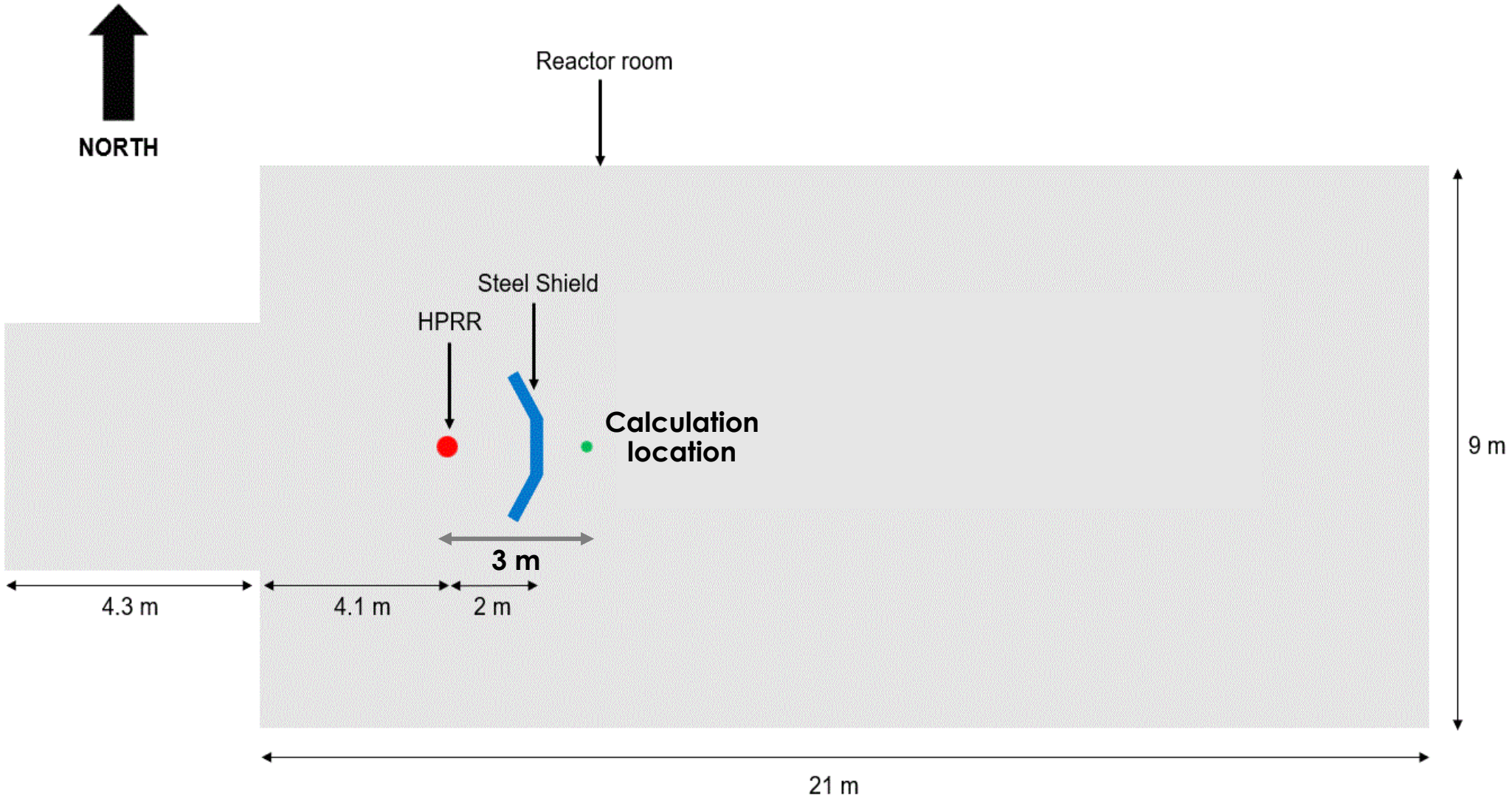
Experiments evaluated

- A lot of experiment data is available, with a varying level of detail. The evaluation work focused only on experiment data from ORNL-6240, the latest report available with the newest reactor configuration
- First step of the evaluation: sulfur pellets activation (see ORNL/TM-2020/1731)
  - The reactor was used in burst operation to irradiate sulfur pellets placed at different distances and shielded by different materials (steel, lucite, concrete)
  - Sulfur is activated and measured later, and a fluence at the sulfur location can be obtained
  - Focus is only on bare and steel shield configuration because of lack of data/confidence on other measurements
  - **The results of the evaluation are not satisfying, with high C/E ratios, probably due to the lack of information on the sulfur pellets counting calibration**

Experiments evaluated

- Second step of the evaluation (ongoing, almost completed): different benchmark metric
- ORNL-6240 contains other experiment results, with potentially less unknowns
- New responses are computed from SCALE MAVRIC calculations at 3 meters from HPRR centerline from 1e17 fissions, bare and steel shield configurations:
  - **Neutron spectrum shape**
  - **Neutron fluence**
  - **Element 57 dose**
  - **Element 57 dose equivalent**
  - **Kerma in air**
- Additional C/E comparisons of **dose per unit fluence**, **steel shield attenuation**
- Experiment results, energy groups and conversion coefficients are all from ORNL-6240

Experiment configuration



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

Neutron flux and element 57 dose: 1987 data

- Flux at 3 meters was determined experimentally with Bonner spheres, obtained spectrum and group structure is described in ORNL-6240
- Element 57 dose flux to dose coefficients are obtained from ORNL-6240 (similar for other responses)

Table 1. HPRR spectra: unshielded, Lucite, steel

Logarithmic mean energy, MeV	Neutron fluence at 3m from HPRR operated to 10^{17} fissions, n/cm²		
	Unshielded	Lucite	Steel
2.50E-08	1.35E+09	4.43E+09	5.59E+08
5.90E-07	8.43E+08	6.26E+08	6.17E+08
1.20E-06	8.72E+08	6.01E+08	7.82E+08
2.44E-06	9.36E+08	6.56E+08	7.81E+08
4.94E-06	9.77E+08	6.79E+08	6.81E+08
1.00E-05	9.90E+08	6.95E+08	6.31E+08
2.04E-05	1.01E+09	7.14E+08	5.73E+08
4.14E-05	1.03E+09	7.30E+08	5.00E+08
8.41E-05	1.04E+09	7.45E+08	4.59E+08
1.71E-04	1.06E+09	7.57E+08	4.23E+08
3.46E-04	1.09E+09	7.66E+08	3.98E+08
7.03E-04	1.13E+09	7.82E+08	4.14E+08
1.20E-03	5.83E+08	4.22E+08	2.55E+08
1.71E-03	6.18E+08	4.26E+08	3.47E+08
2.44E-03	6.08E+08	4.29E+08	3.36E+08
3.47E-03	6.47E+08	4.31E+08	1.53E+08
4.94E-03	6.72E+08	4.37E+08	3.71E+07
7.04E-03	7.05E+08	4.49E+08	3.82E+07
1.00E-02	7.45E+08	4.65E+08	3.96E+07
1.43E-02	7.81E+08	4.70E+08	6.14E+07
2.04E-02	9.40E+08	4.94E+08	1.93E+08
2.90E-02	1.16E+09	5.51E+08	5.99E+08
4.14E-02	1.42E+09	5.73E+08	8.71E+08
5.90E-02	1.93E+09	6.37E+08	1.45E+09
8.39E-02	2.75E+09	7.15E+08	2.30E+09
1.10E-01	2.82E+09	4.74E+08	2.48E+09
1.31E-01	4.06E+09	5.46E+08	4.25E+09
1.56E-01	4.08E+09	5.54E+08	4.31E+09
1.87E-01	3.97E+09	5.45E+08	4.25E+09
2.23E-01	3.88E+09	5.36E+08	4.22E+09
2.66E-01	3.92E+09	5.47E+08	4.37E+09
3.18E-01	3.79E+09	5.31E+08	4.32E+09
3.79E-01	4.12E+09	5.67E+08	4.43E+09
4.52E-01	8.19E+09	1.01E+09	4.90E+09
5.40E-01	8.20E+09	1.01E+09	5.14E+09
6.44E-01	8.13E+09	9.88E+08	5.36E+09
7.69E-01	8.23E+09	9.81E+08	5.78E+09
9.17E-01	8.52E+09	1.15E+09	4.55E+09
1.10E+00	9.36E+09	1.33E+09	4.01E+09
1.31E+00	9.25E+09	1.27E+09	4.21E+09
1.56E+00	8.69E+09	1.50E+09	2.95E+09
1.87E+00	8.46E+09	1.57E+09	2.46E+09
2.23E+00	8.64E+09	1.54E+09	2.65E+09
2.66E+00	9.19E+09	1.57E+09	2.99E+09
3.18E+00	5.73E+09	1.10E+09	1.24E+09
3.79E+00	5.04E+09	9.91E+08	8.66E+08
4.52E+00	5.25E+09	9.85E+08	9.50E+08
5.40E+00	2.28E+09	2.99E+08	4.28E+08
6.44E+00	1.73E+09	2.48E+08	2.98E+08
7.69E+00	5.72E+08	1.77E+08	1.22E+07
9.17E+00	5.47E+08	1.70E+08	1.13E+07
1.10E+01	4.79E+07	1.68E+07	1.06E+07
1.31E+01	4.55E+07	1.63E+07	9.51E+06
1.56E+01	1.14E+07	4.89E+06	3.43E+06
1.87E+01	3.89E+05	5.69E+05	6.63E+05
2.23E+01	8.99E+03	8.61E+03	8.40E+03
Total fluence	1.73E+11	4.09E+10	9.50E+10

Table 1 HPRR spectra, ORNL-6240 (1987)

Table 6. Element 57 dose per unit fluence for neutrons of various energies

Neutron energy (eV)	Element 57 dose, 10^{-12} Gy·n^{-1} cm²		
	Recoiling charged particles and capture gamma-rays	Capture gamma-rays	Recoiling charged particles
1.40E7	83.10	7.210	75.89
1.00E7	72.50	3.790	68.71
7.00E6	57.00	1.680	55.32
5.00E6	57.20	1.480	55.72
2.50E6	39.90	1.840	38.06
1.00E6	30.14	2.230	27.91
5.00E5	18.110	2.800	15.310
1.00E5	8.018	3.309	4.709
1.00E4	4.338	3.420	0.918
1.00E3	4.322	3.827	0.495
1.00E2	4.449	3.888	0.561
1.00E1	5.179	4.492	0.687
1.00E0	5.890	5.143	0.747
2.50E-2	4.680	4.000	0.680
	Column A	Column B	Column C

Notes: I. Data from Columns A and B are from ref. 15. Column C is the element 57 dose equivalent due to recoiling charged particles and is obtained by subtracting Column B from Column A.

II. 10^{-12} Gy·n^{-1} cm² = 10^{-10} rad·n^{-1} cm².

Table 6 Element 57 dose per unit fluence, ORNL-6240 (1987)

Calculation methodology: KENO and MAVRIC FW-CADIS

- A complete detailed model of the HPRR was built in SCALE 6.2.4

- 2-steps methodology:
  - KENO-VI run to create a fission source
  - MAVRIC run to calculate the neutron flux and chosen response at 3 meters (element 57 dose and others), using the fission source obtained by KENO as an input. Use of CADIS to reduce calculation time

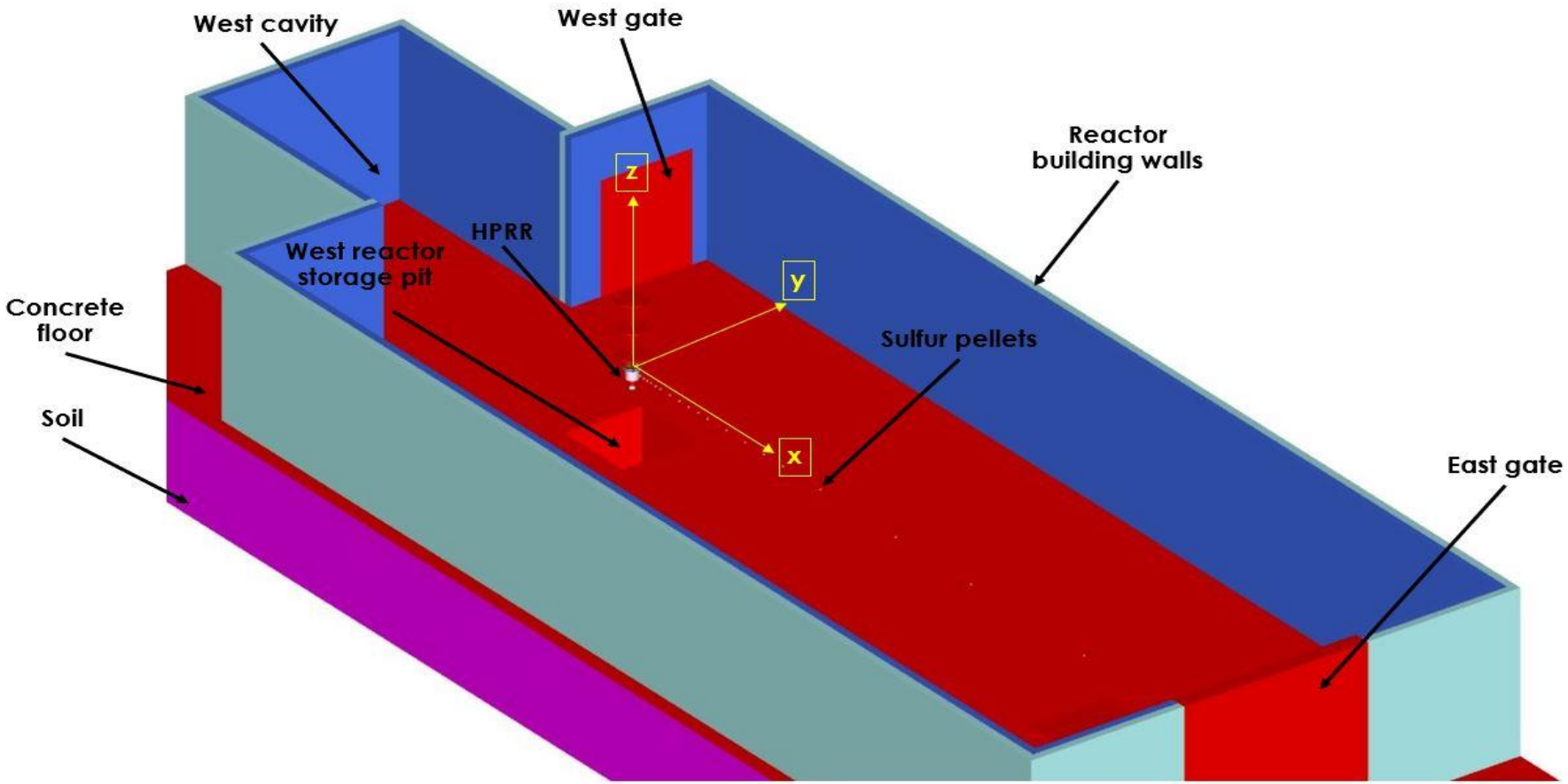
- One KENO and one MAVRIC calculation per experiment configuration (bare and steel shielded)

Evaluation of Experimental Data

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

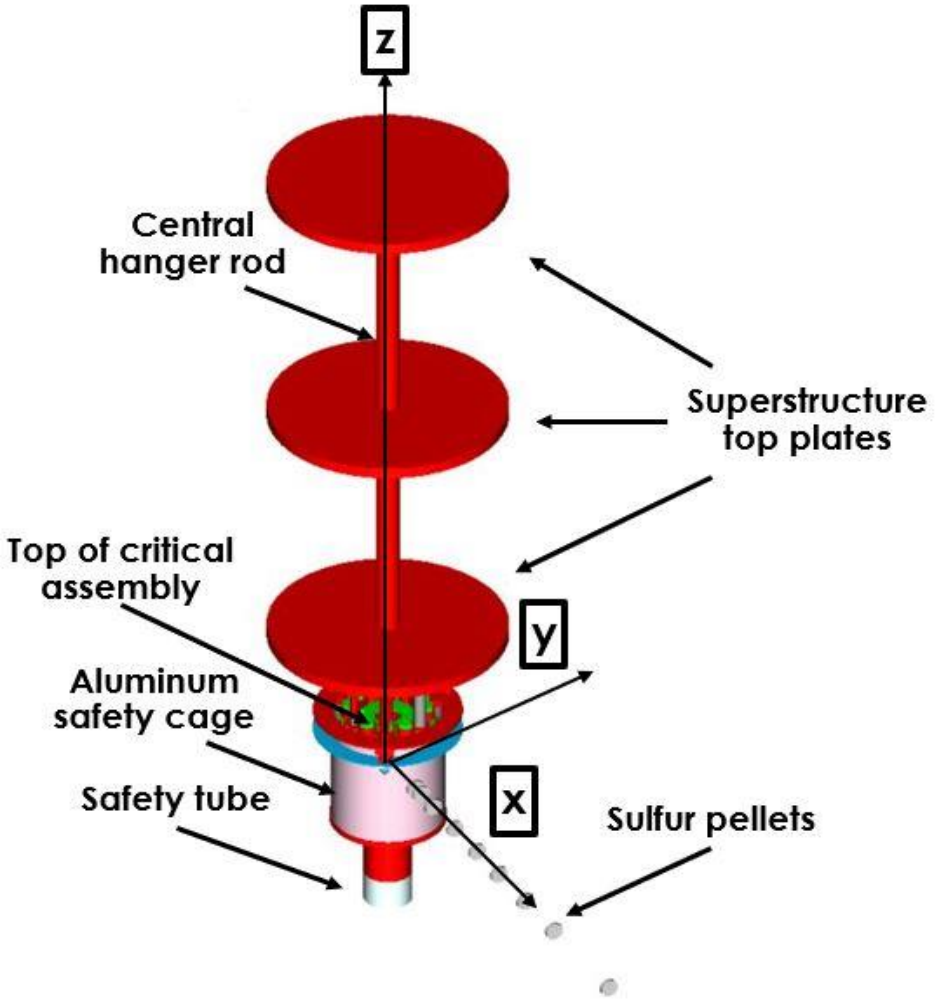
- A thorough sensitivity study was performed in FY20 for the sulfur fluence benchmark metric, and must be updated for the neutron fluence and element 57 dose
- Expected benchmark relative uncertainty around 50%

Model overview



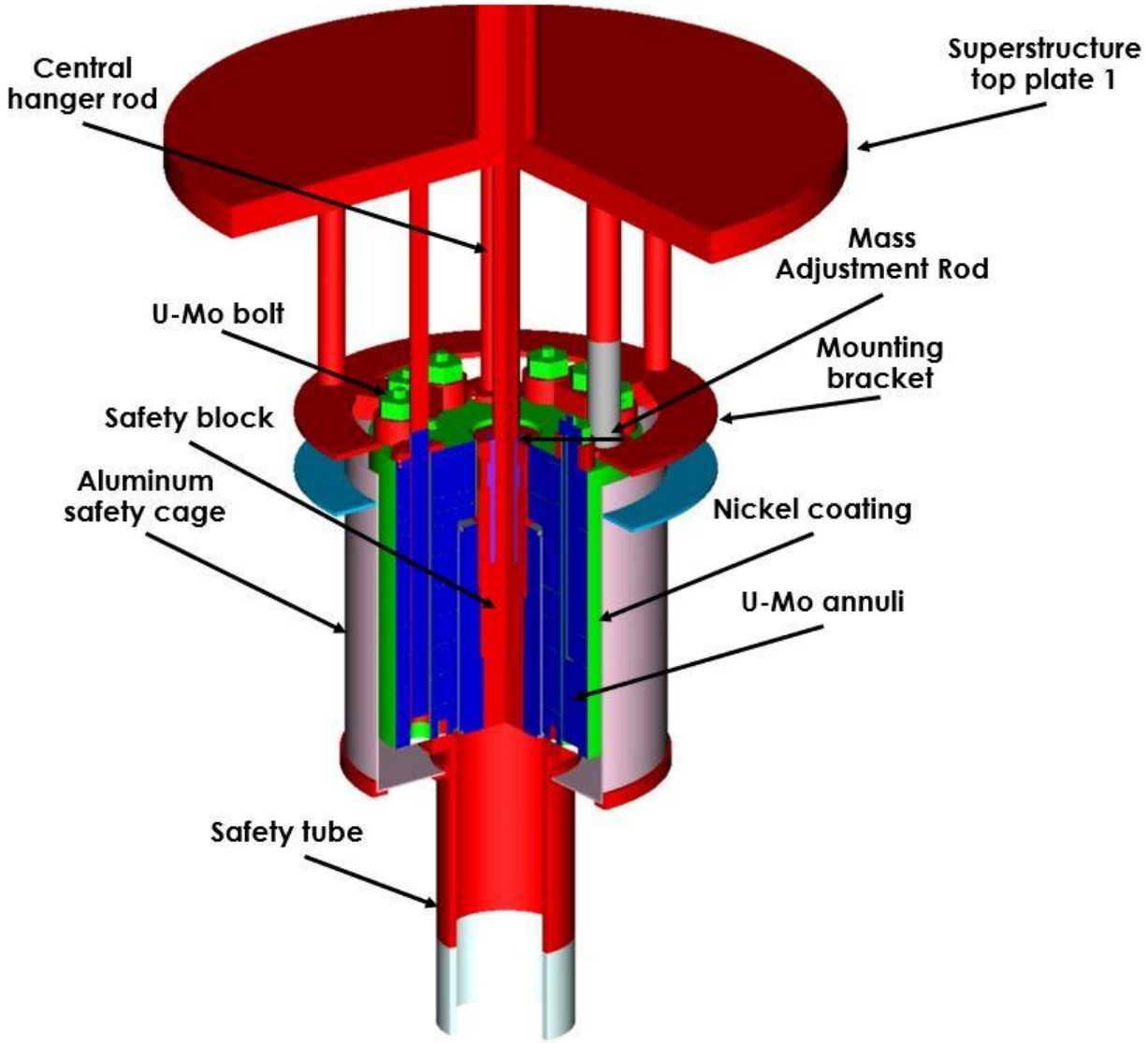
Overview of the bare configuration benchmark model, ORNL/TM-2020/1731 (2020)

Model overview



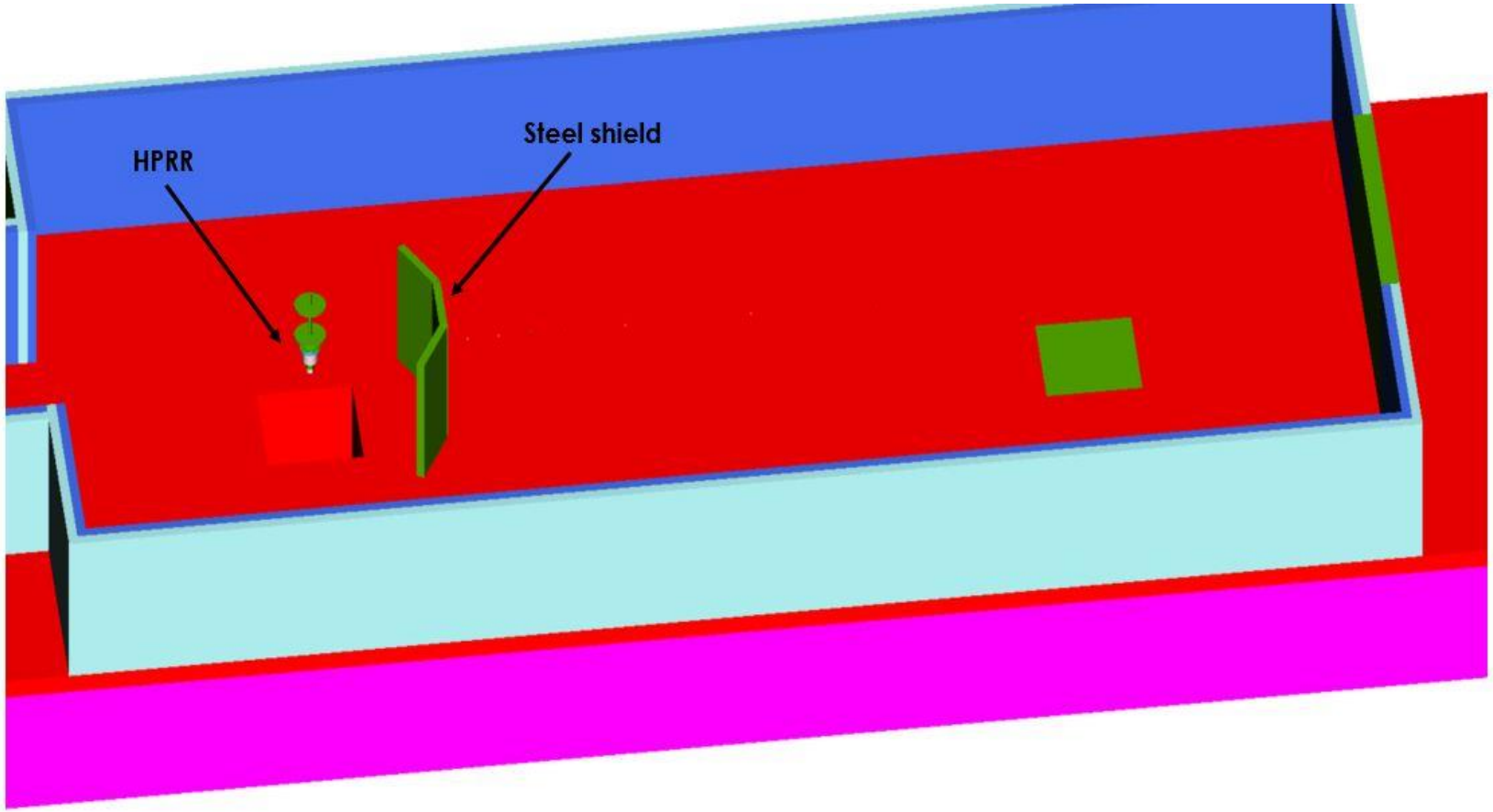
Overview of the bare configuration benchmark model zoomed in on the HPRR, ORNL/TM-2020/1731 (2020)

Model overview



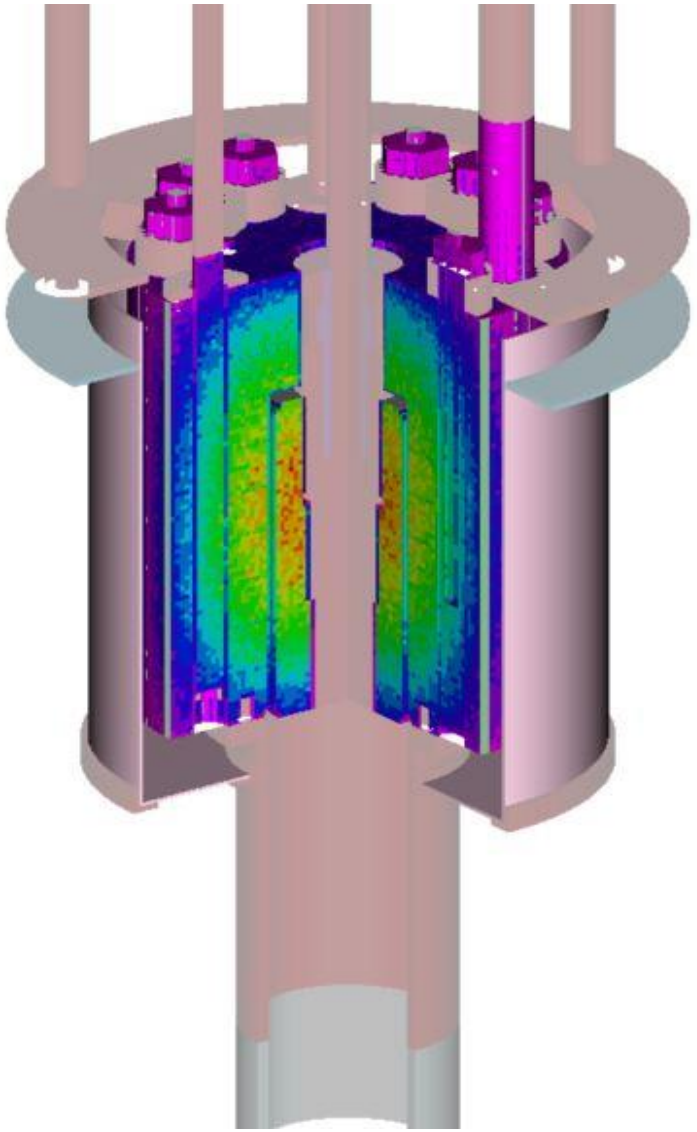
Overview of the bare configuration benchmark model front right quarter zoomed in on the HPRR, ORNL/TM-2020/1731 (2020)

Model overview



Overview of the steel shield configuration benchmark model, ORNL/TM-2020/1731 (2020)

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)

Results of Sample Calculations with MAVRIC CADIS

	At 3 m from 1e17 fissions of the HPRR								
	Neutron fluence ($n.\,cm^{-2}$)			Element 57 Dose (Gy)			Element 57 Dose (Gy per unit fluence)		
	ORNL-6240	MAVRIC	C/E	ORNL-6240	MAVRIC	C/E	ORNL-6240	MAVRIC	C/E
Bare	1.73E+11	2.26E+11	1.31	3.98	4.76	1.20	2.30E-11	2.11E-11	0.92
Steel Shield	9.50E+10	1.10E+11	1.16	1.63	1.74	1.07	1.72E-11	1.59E-11	0.93

Experimental and calculated C/E ratios are around 1.5 for neutron fluence, 1.3 for element 57 dose and 0.9 for element 57 dose per unit fluence

Results of Sample Calculations with MAVRIC CADIS

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

Experimental and calculated attenuation ratios are statistically close

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

Conclusion

- A real information preservation and dissemination work, a lot of legacy content was found and used
- Abundance of uncertainty, discrepancy, contradictory information
- Yet, a detailed, functional SCALE model was built, and the benchmark created is useful for shielding and CAAs validation work
- Sulfur fluence C/E ratios are large (2 to 5), so different benchmark metrics were studied
- Neutron fluence, element 57 dose and other dosimetry responses at 3 meters C/E ratios are below 1.5 for bare and steel shield configurations
- Additional promising metrics as dose per unit fluence and steel shield attenuation were computed

Next Steps

- Update of the uncertainty/sensitivity study to accommodate for the different benchmark metric
- A simplified model of the HPRR was built and has a relatively low influence on the new benchmark metric, a decision must be taken on which benchmark model to use and detail
- Update of the evaluation report
- Ongoing discussion with the ICSBEP committee to decide in which benchmark database this evaluation would fit the best, ICSBEP, IRPhEP or SINBAD?

Thank you