OAK RIDGE National Laboratory

Status of the HPRR experiments evaluation to create a published shielding benchmark

NCSP Task ORNL IP&D-5
2024 Annual NCSP Technical Program Review

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Hosted by Brookhaven National Laboratory

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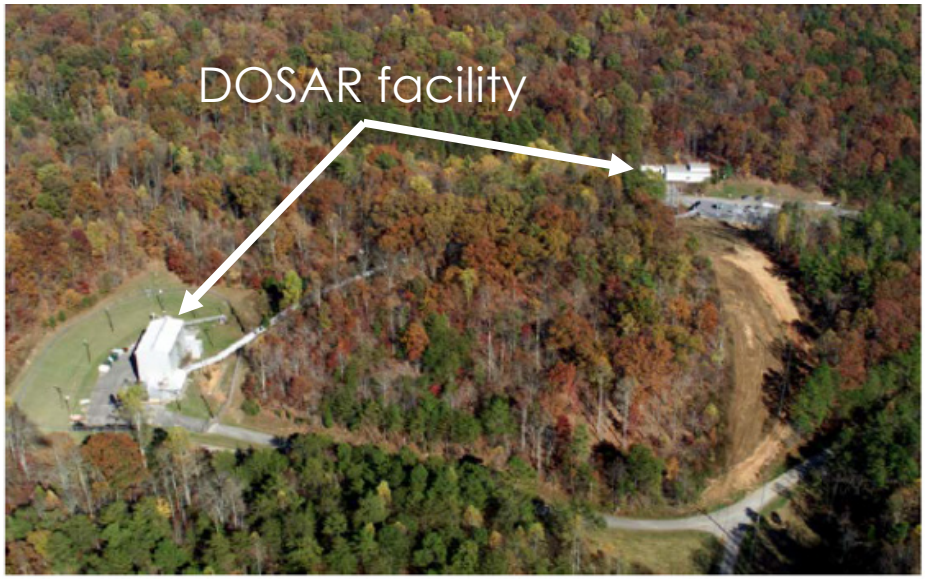
U.S. DEPARTMENT OF ENERGY

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

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

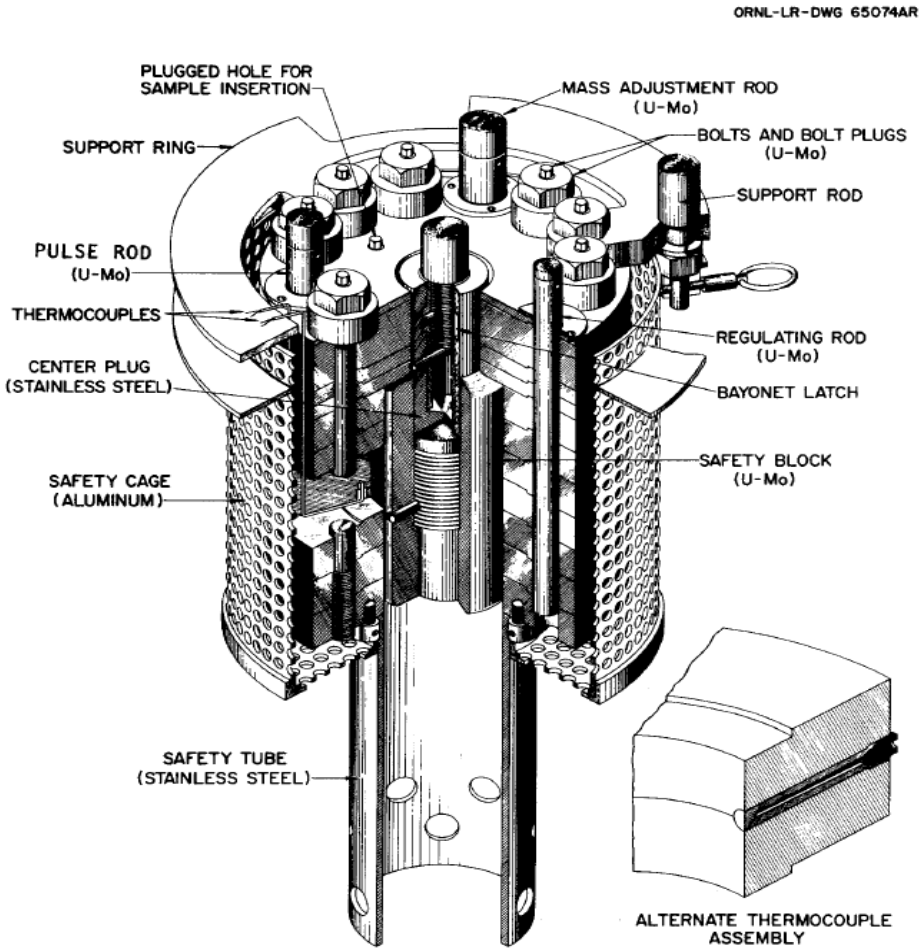


DOSAR Facility, A History of Research Reactors Division (1987)

The Health Physics Research Reactor

- The HPRR was a fast reactor: Unshielded, unmoderated, highly enriched (93.15%) 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)

The Health Physics Research Reactor

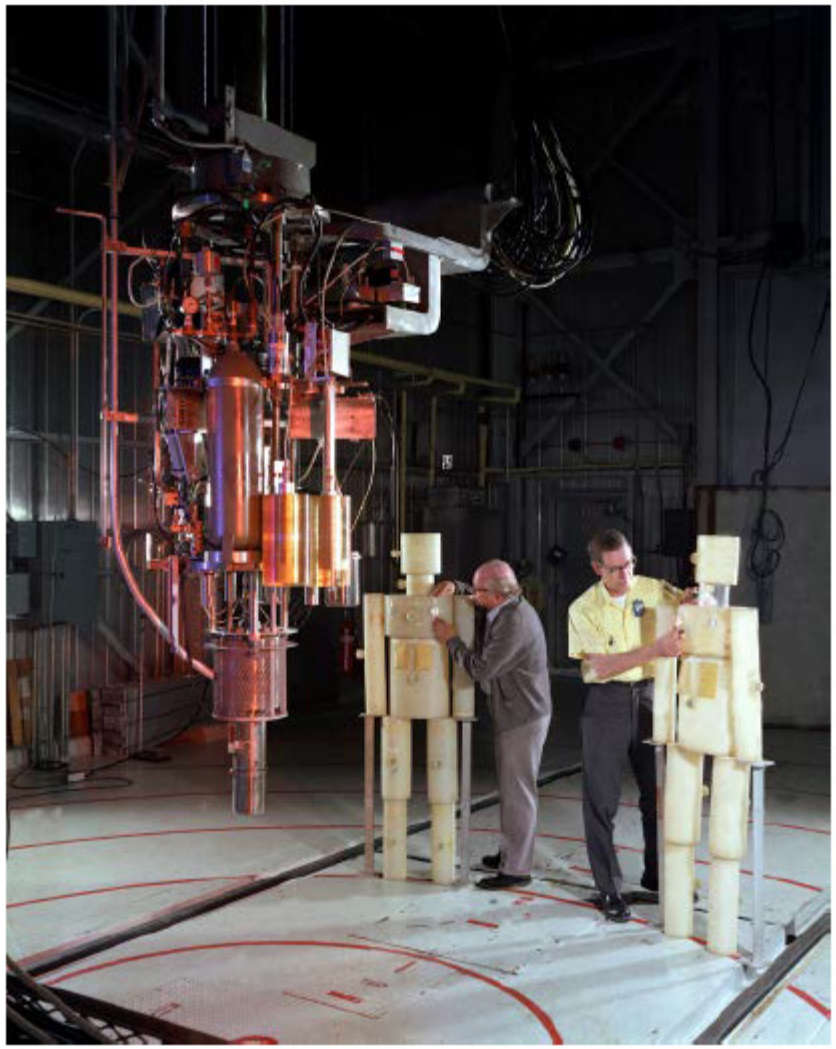


Figure 53: HPRR

A History of Research Reactors Division (1987)

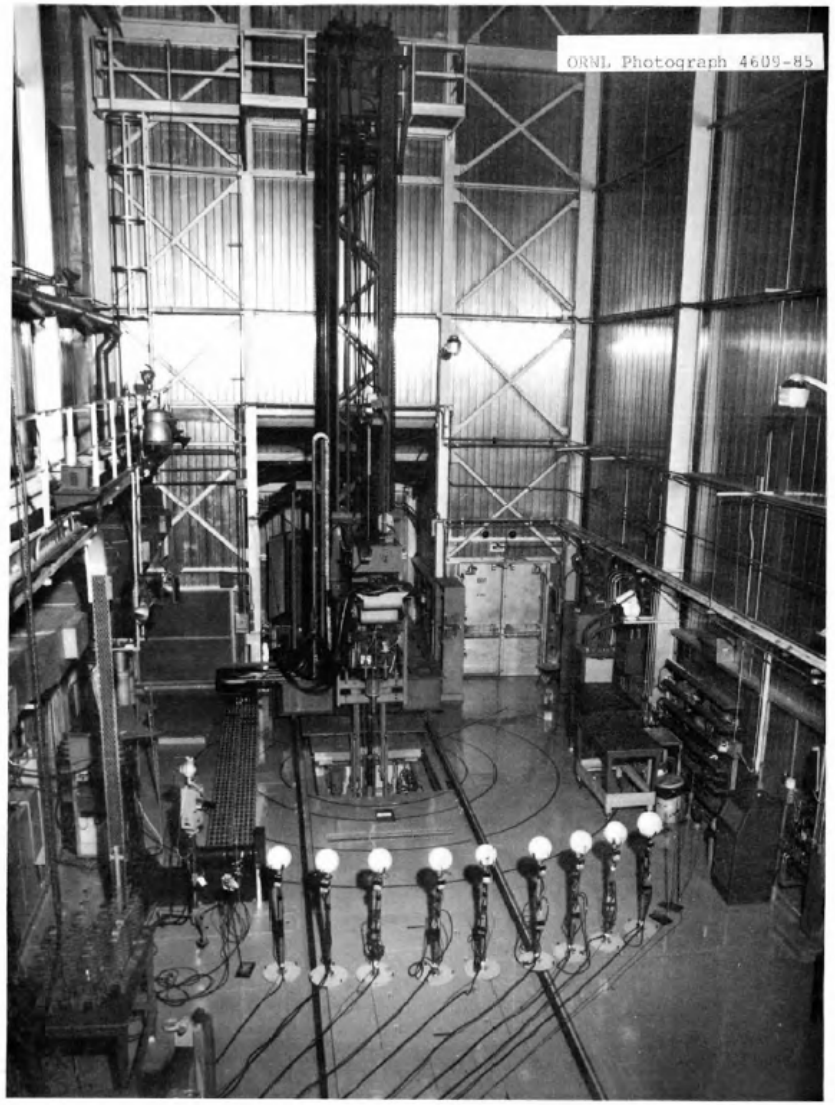


Figure 1. HPRR in experimental position

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
- Measurements are separated in four categories of potential value for a shielding benchmark creation:
  1. Sulfur pellet activation at different distances from a HPRR pulse, shielded and unshielded (FY20 work)
  2. Total neutron fluence from a HPRR pulse measured by Bonner Sphere Spectrometry, shielded and unshielded (FY21 and **FY23 work defended at ICSBEP TRG meeting in April 2023**)
  3. Derived neutron dose and kerma results from 1 (FY21 work)
  4. Gamma dose from a HPRR pulse measured by G-M counter and TLD (not evaluated)

Evaluation of Experimental Data: FY23 work

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

- Only bare and Lucite-shielded configurations are considered acceptable as a benchmark, too much uncertainty in the other shield dimensions, material compositions and unexplained C/E discrepancies (concrete, steel)
- 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
  - Lucite shield attenuation

Evaluation of Experimental Data: FY23 work

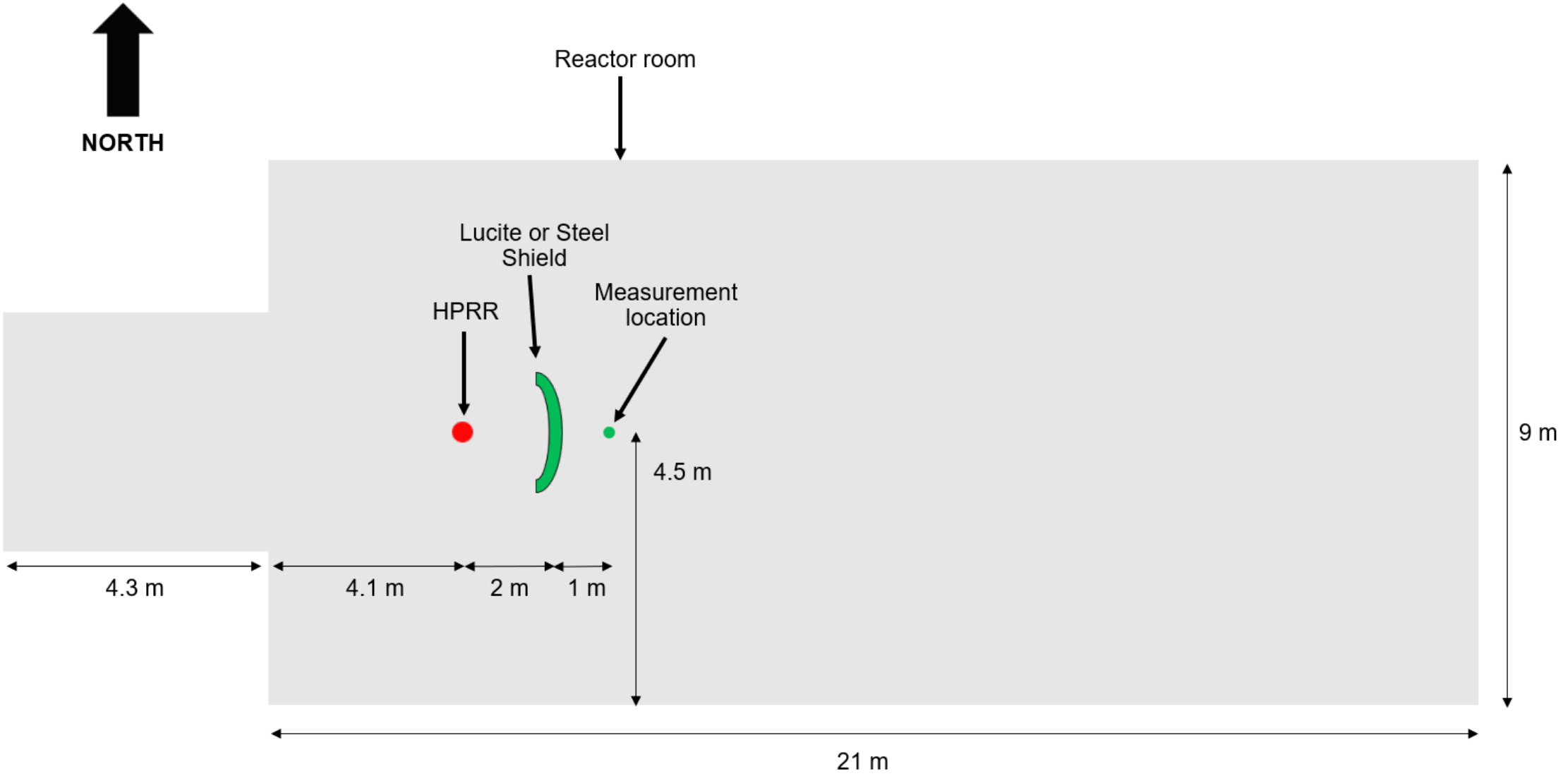
- **A lot of missing and contradictory data:**
  - U-Mo coating uncertainty
  - Building walls, shields, concrete material composition and dimensions
  - What was actually inside the building during operation
  - Lack of material and dimension information
  - **Lack of information about the Bonner sphere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

- A thorough sensitivity study was performed, with expected experimental uncertainties of ~17 % for the bare case and ~28 % for the Lucite-shielded case

Benchmark Model Overview

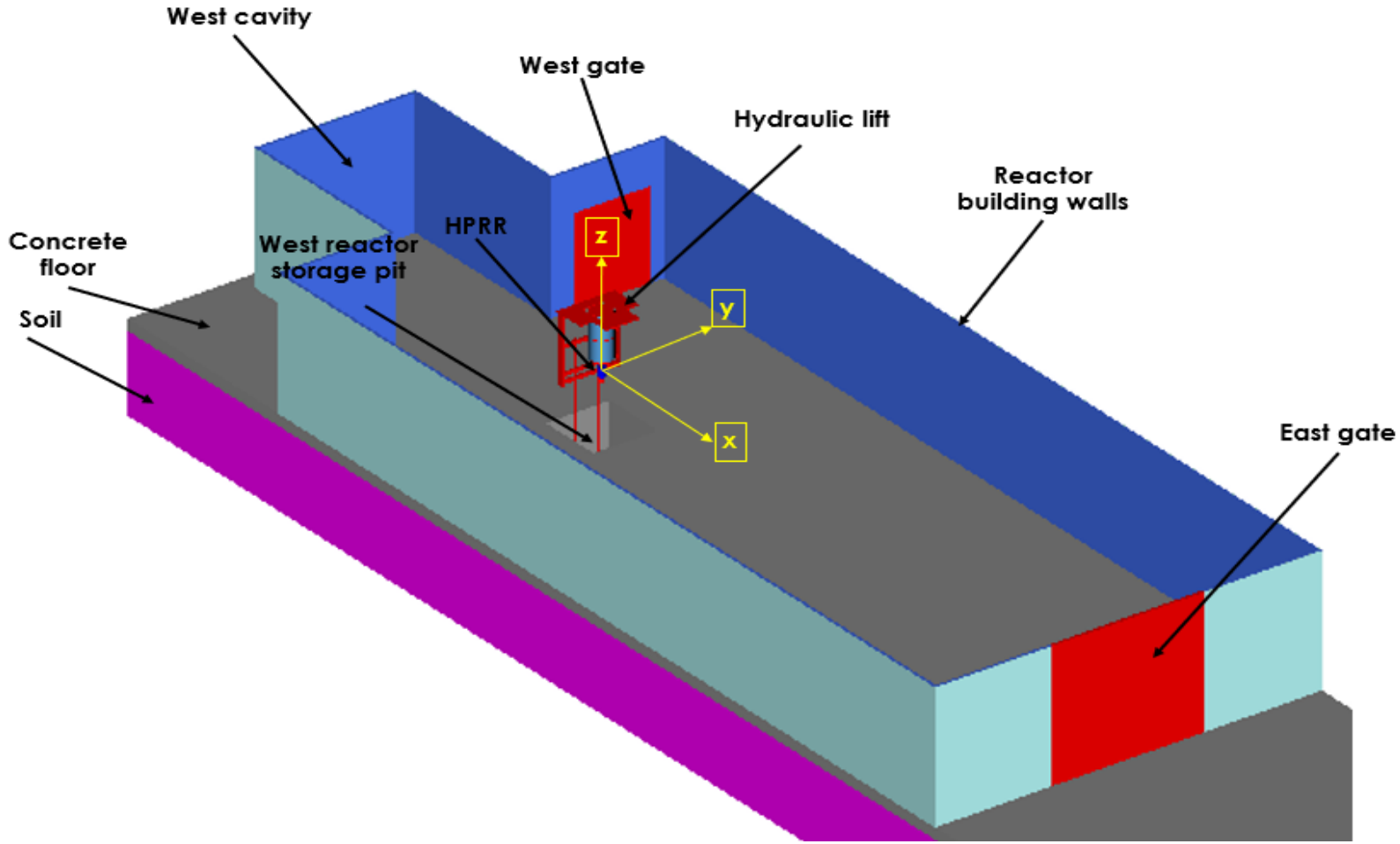
- A complete detailed model of the HPRR was built in SCALE 6.3
- A simplified model was also created from removing the statistically insignificant elements, defined as the benchmark model
- 2-step methodology:
  - KENO-VI run to create a fission source from the HPRR pulse operation
  - MAVRIC run to 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 Lucite-shielded)

Benchmark Model Overview



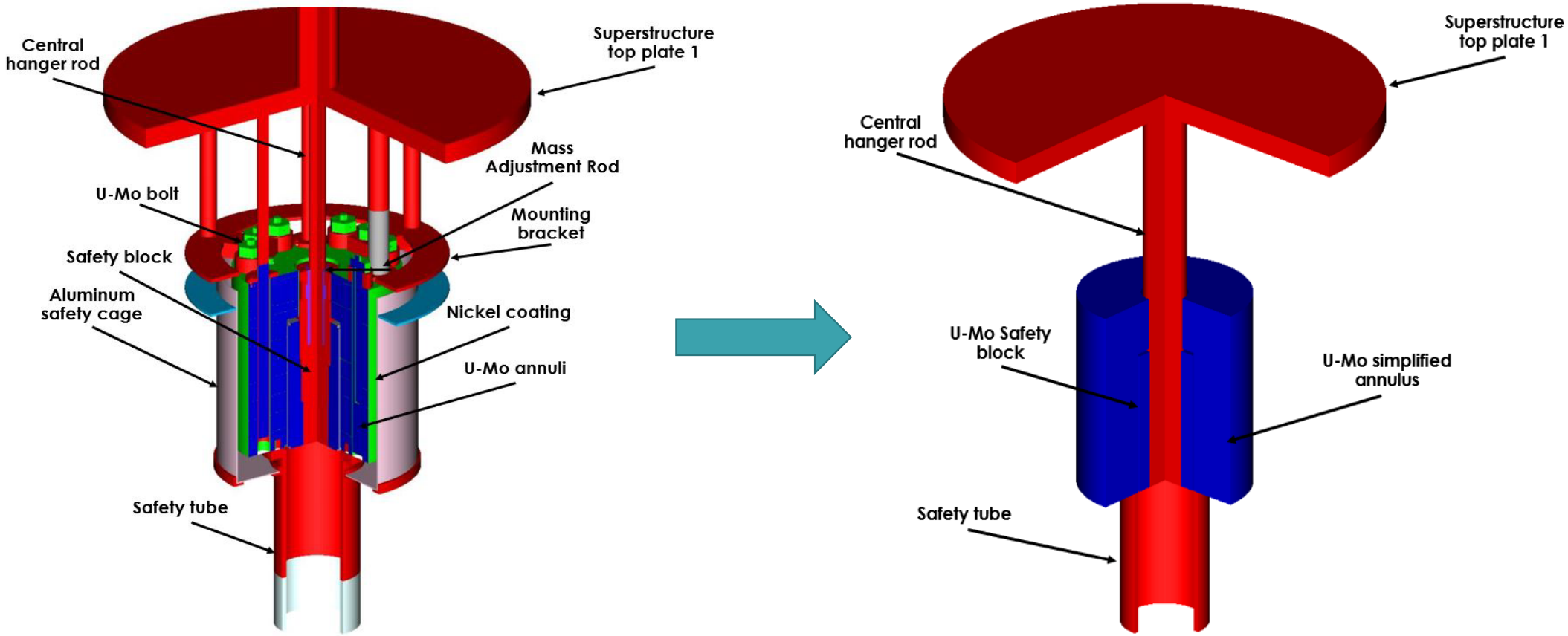
Overview of experiment configuration, top view (not in scale).

Benchmark Model Overview



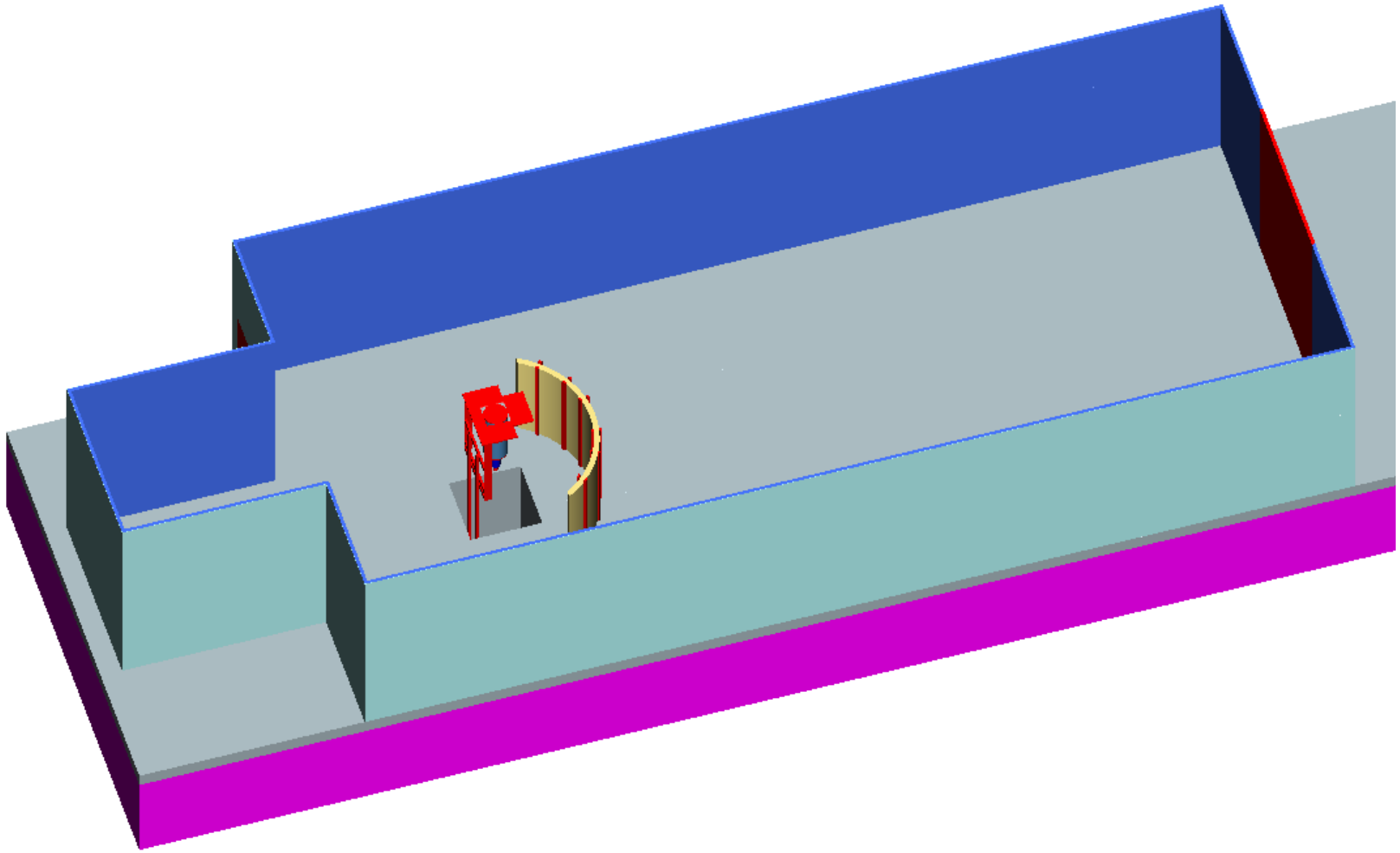
Overview of the bare configuration benchmark model

Benchmark Model Overview



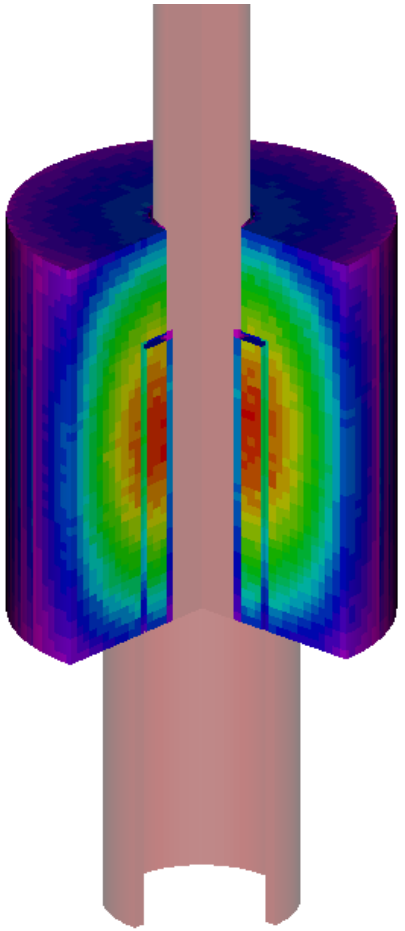
Overview of the detailed (left) and simplified (right) benchmark models, front right quarter

Benchmark Model Overview



Overview of the Lucite shield configuration benchmark model

FY23 Results of Sample Calculations

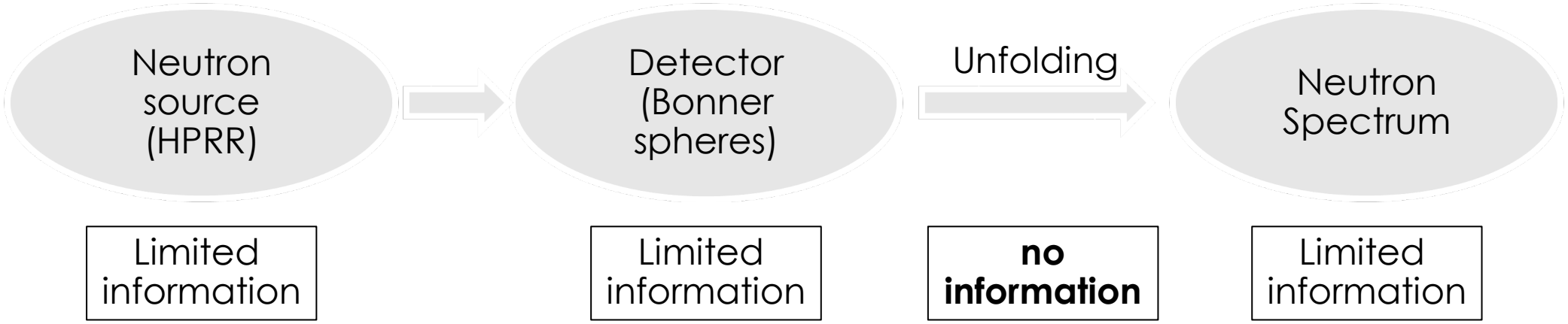


HPRR 3-dimensional spatial distribution of fission neutrons calculated with KENO-VI using ENDF/B-VIII.0 continuous energy cross section

FY23 Results of Sample Calculations

	Neutron fluence at 3 m from 10^{17} fissions of the HPRR				
	Expected		Calculated		C/E
Configuration	Neutron fluence (cm^{-2})	Relative Standard Uncertainty (%)	Neutron fluence (cm^{-2})	Relative Standard Uncertainty (%)	
Bare	1.66E+11	16.79	2.33E+11	0.04	1.40
Lucite Shield	3.57E+10	27.75	3.88E+10	0.10	1.09

Bonner spheres experiments: a lot of unknowns



Bonner spheres experiments: a lot of unknowns

Early in CY 1985, Dr. Ferenc Hajnal of the Department of Energy's Environmental Measurements Laboratory came to DOSAR to make Bonner sphere neutron energy spectrum measurements with the HPRR operating in the new experimental configuration. He used a BF_3 tube as the slow neutron detector and made measurements with a total of 12 different detector-moderator combinations for each HPRR spectrum. The 12 included

Dr. Hajnal used the response functions developed at ORNL for enriched uranium assemblies[11-12] and unfolded them to obtain the 56-group neutron energy spectrum for each HPRR shielding condition. Details associated with this work are documented by Hajnal.[13] Three

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

Does not exist

April 2023 ICSBEP TRG meeting

- Review of the evaluation page by page
- A lot of comments on the lack of information
- Technical Review Group stated that the limited information regarding Bonner sphere counts and unfolding to be a showstopper issue
  - It restricts uncertainty evaluation to judgment alone
- **Evaluation was not accepted in the ICSBEP handbook**

Next step: SINBAD

- The Shielding Integral Benchmark Archive and Database (SINBAD) focuses on shielding benchmarks
- Used to historical benchmarks
- SINBAD task force: Gitlab process, classification of benchmarks by maturity level, continuous updates possible
- A SINBAD subgroup was formed, evaluation is being updated to include all experiments evaluated
- No real deadline, but neutron fluence and kerma work (bare, steel an Lucite shield) will be described at the ICSBEP/IRPHE/SINBAD meeting in April 2024

Next step: SINBAD

- Overview of HPRR SINBAD evaluation:

Shield	Neutron fluence	Sulfur foil activation	Neutron Dose	Gamma Dose
Bare	✓	!	!	X
Steel	!	!	!	X
Lucite	✓	X	X	X

✓: Ready
! : Done before, needs update
X : Needs full evaluation

Acknowledgments

This presentation was supported by the Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy.

Selected HPRR publications FY20-FY23

- *Sulfur pellet activation at different distances from a HPRR pulse, shielded and unshielded* (ORNL/TM-2020/1731, **2020** https://doi.org/10.2172/1765486)
- *Health Physics Research Reactor Criticality Accident Alarm System Benchmark Overview* (ANS ICRS14/RPSD22, pp 406-409, **2022**)
- *Evaluation of Oak Ridge National Laboratory Health Physics Research Reactor Operation Data for Critical Benchmark Creation* (ANS NCSD2022, pp 725-734, **2022**)
- *NEUTRON FLUENCE RESPONSE TO A BARE AND TO A LUCITE-REFLECTED PULSE OF THE ORNL HEALTH PHYSICS RESEARCH REACTOR* (ALARM-REAC-LUC-SHIELD-001, **2023**, not published, ask me if interested)
- *NEUTRON FLUENCE AND ELEMENT 57 DOSE RESPONSES TO A BARE AND TO A STEEL-REFLECTED PULSE OF THE ORNL HEALTH PHYSICS RESEARCH REACTOR* (ALARM-REAC-SST-SHIELD-001, **2021**, not published, ask me if interested)