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Applications of Reactor Dosimetry Measurements at the Advanced Test Reactor Critical

Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy

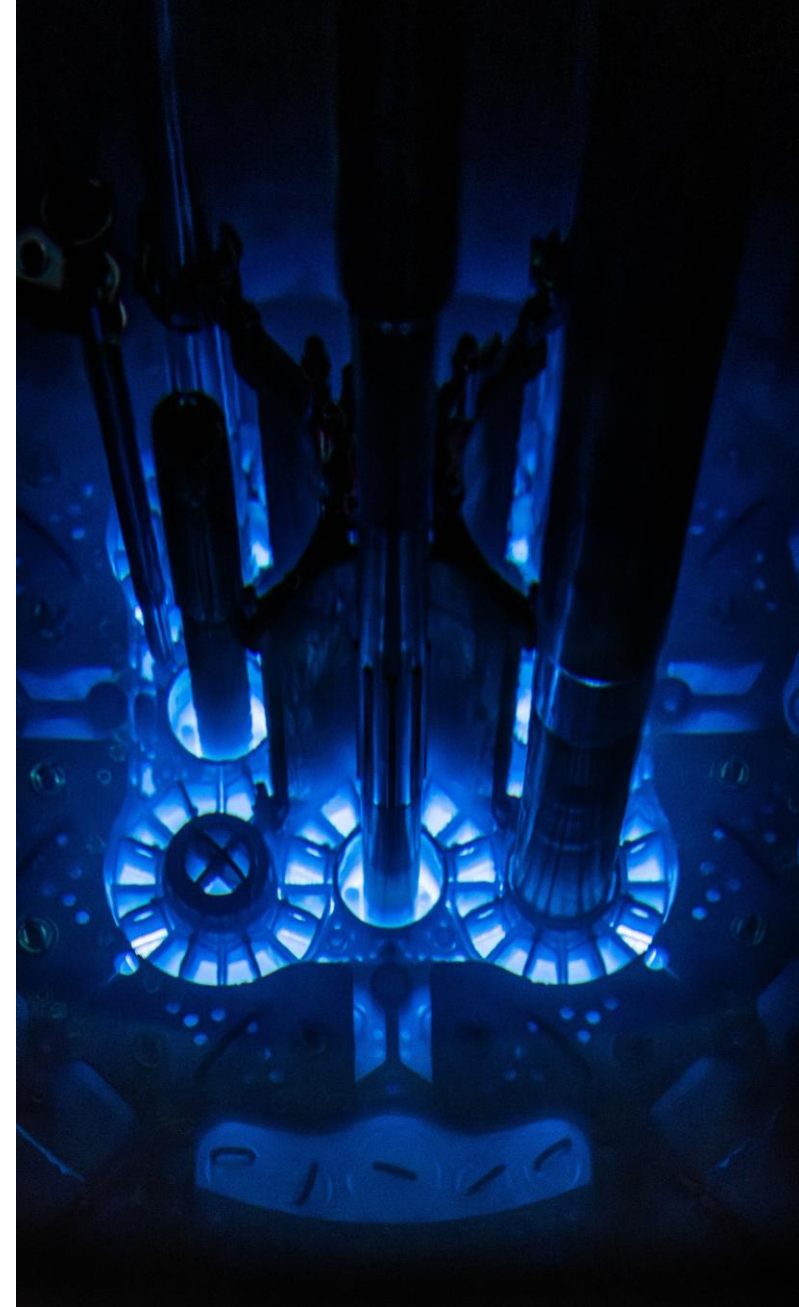


Idaho National Laboratory

The Advanced Test Reactor (ATR)

- Light Water Cooled; Beryllium Moderated
- Nominal thermal power capacity: 250 MW
- Max Thermal Neutron Flux: $1.0 \times 10^{15} \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$
- Max Fast Neutron Flux: $5.0 \times 10^{14} \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$
- Flux Traps: 9
- Fuel Assemblies: 40
- Fuel Plates per Assembly: 19
- Length of Assembly: 1.2 m (4 feet)
- Operating Pressure: 2.5 Mpa (360 psig)
- Design Temperature: 115°C (240°F)

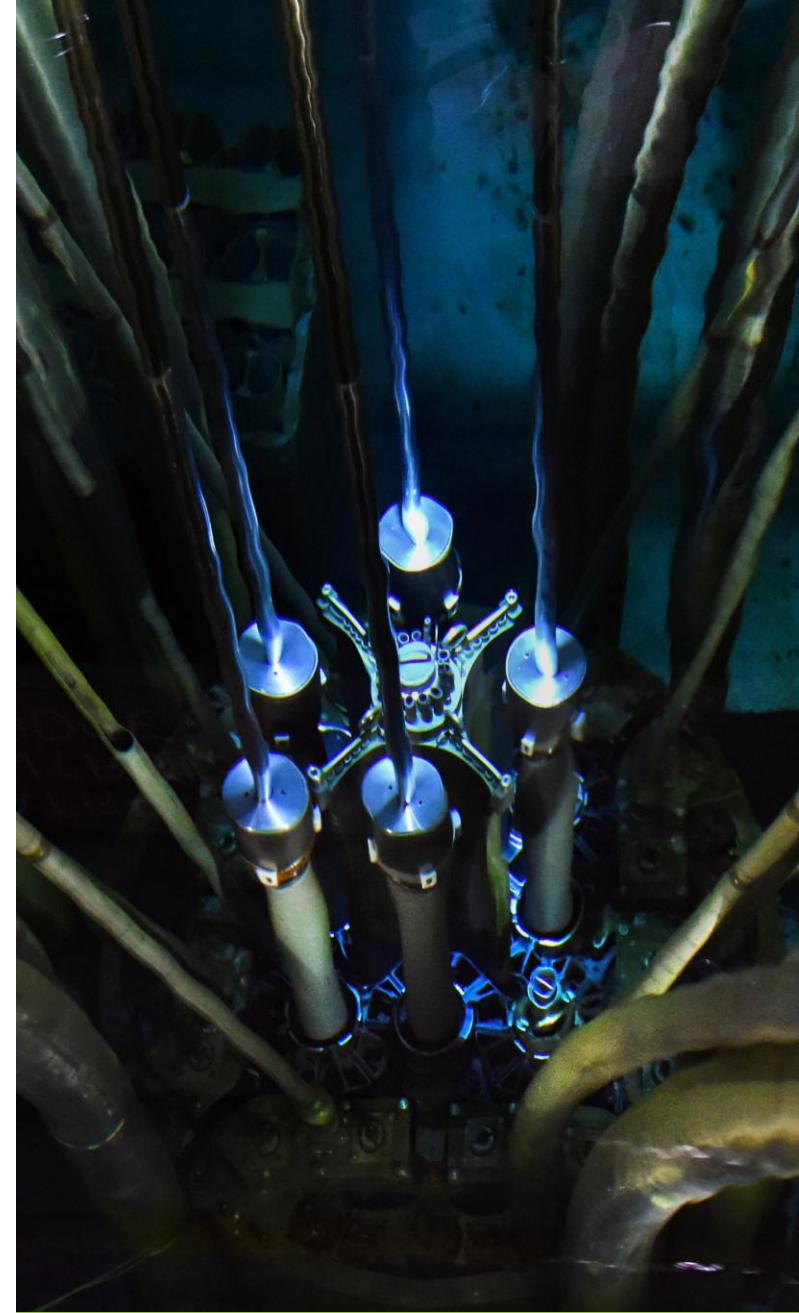
Information from Campbell, Joseph L. ATR User Guide. United States: N. p., 2021.



The Advanced Test Reactor Critical (ATR-C)

- 1:1 replica of the ATR's core
- Operates at ≤ 600 watts
- Typical Uses:
 - Physics testing
 - Instrumentation testing
 - Experiment reactivity testing
 - R&D
- Measurements in ATR-C are scalable to ATR

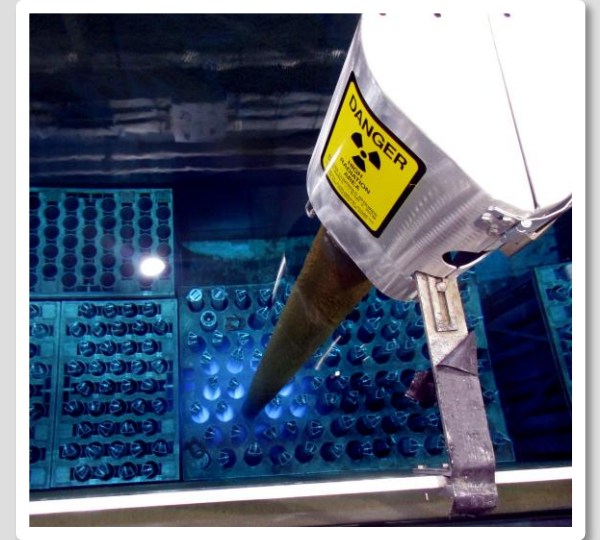
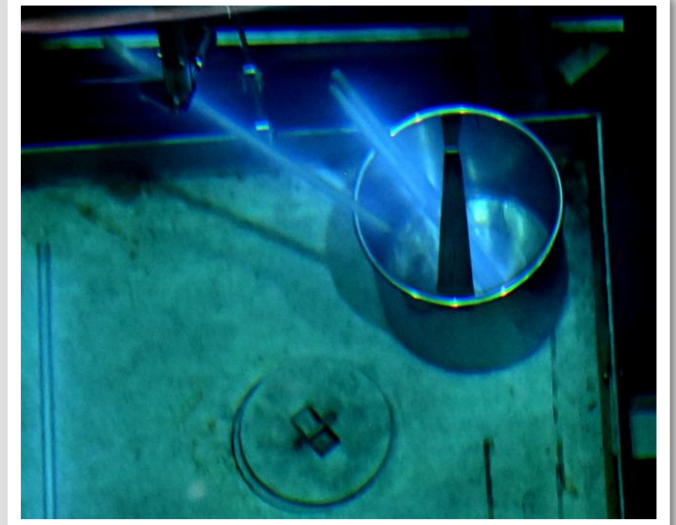
Information from Campbell, Joseph L. ATR User Guide. United States: N. p., 2021.



Radiation Measurement Laboratory (RML)

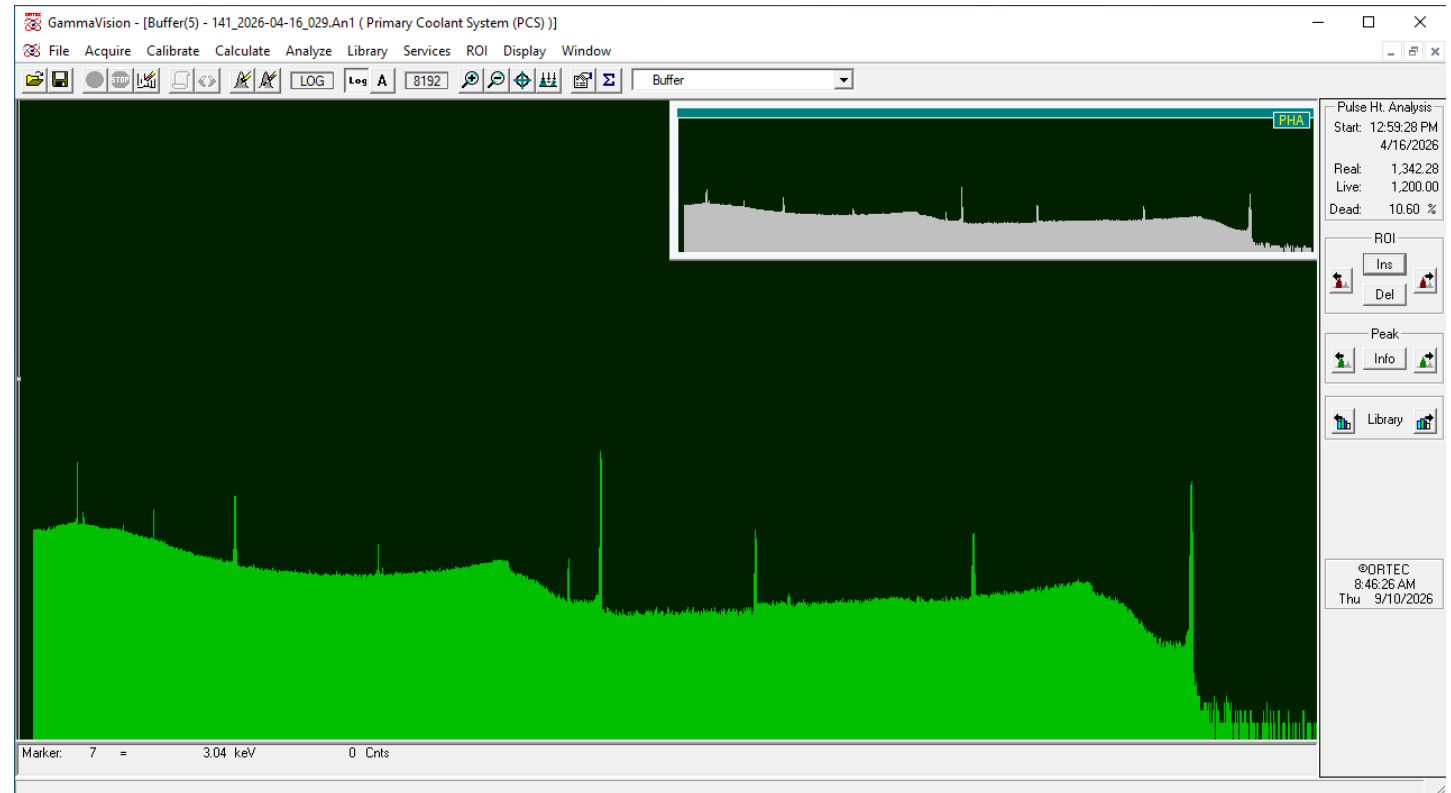
Analytical Research Laboratory

- ATR Cycle Neutron Dosimetry
- Gamma Spectroscopy
- Gross α/β
- Fission-Rate Monitor Measurements
- High dose ion chamber measurements
- Environmental Reporting
- NDA of Suspect Radiological Material
- Emergency Response



Gamma Spectroscopy

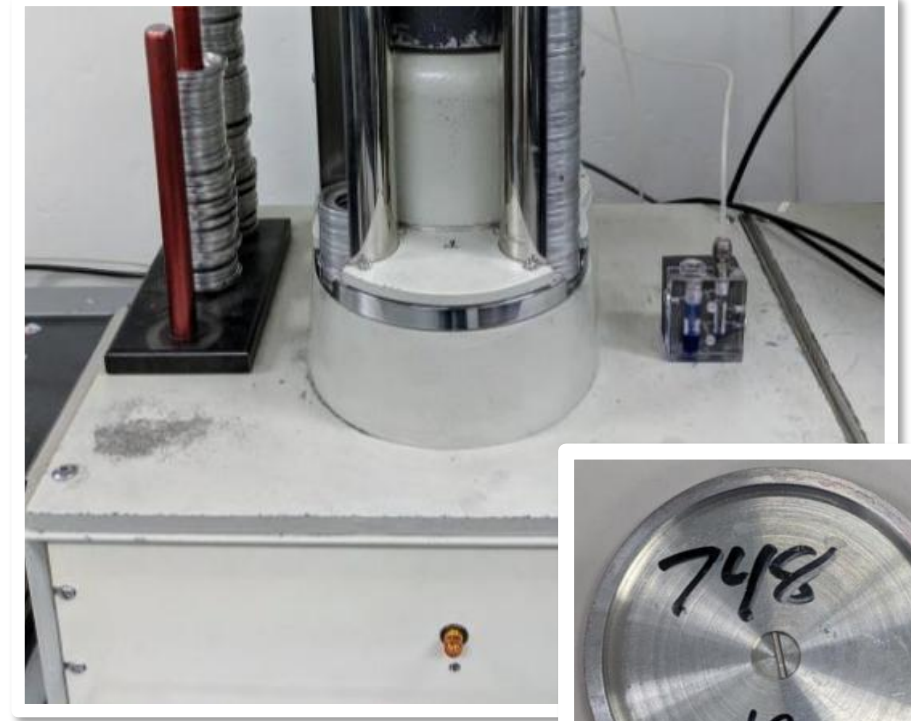
- 12 HPGe detectors
 - 5 traditional dewars
 - 7 newer recyclers
 - Stack Effluent Monitor
- Flexible sample geometry positioning
 - Sample matrix
 - Activity considerations
- Complex spectra



Fission-Rate Monitor Measurements

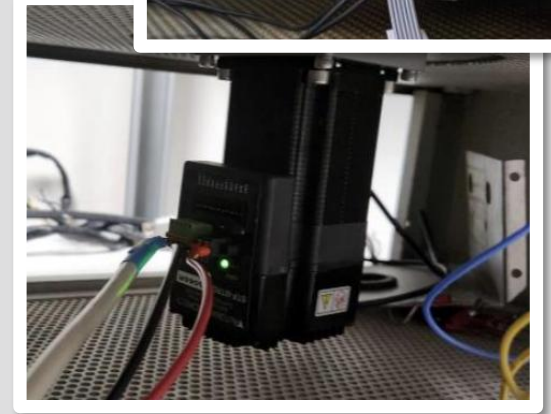
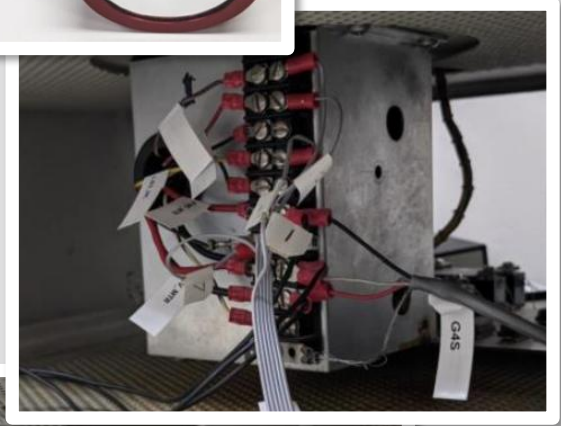
- U-Al wires in ATR-C core (min. 340)
- Simultaneous Gross β count on 4 channels
- Analog decay correction
- Custom built system
- Develop fission rate map of ATR-C
- Simulation/Model Verification

B. W. Howes, C. H. Hogg and L. D. Weber, "Use of U235 Wire as a Fission Rate and Thermal Flux Monitor PTR-759," National Reactor Testing Station, US Atomic Energy Commission, Idaho Falls, ID, 1965.



Fission Rate Measurement System (FRMS) Hardware

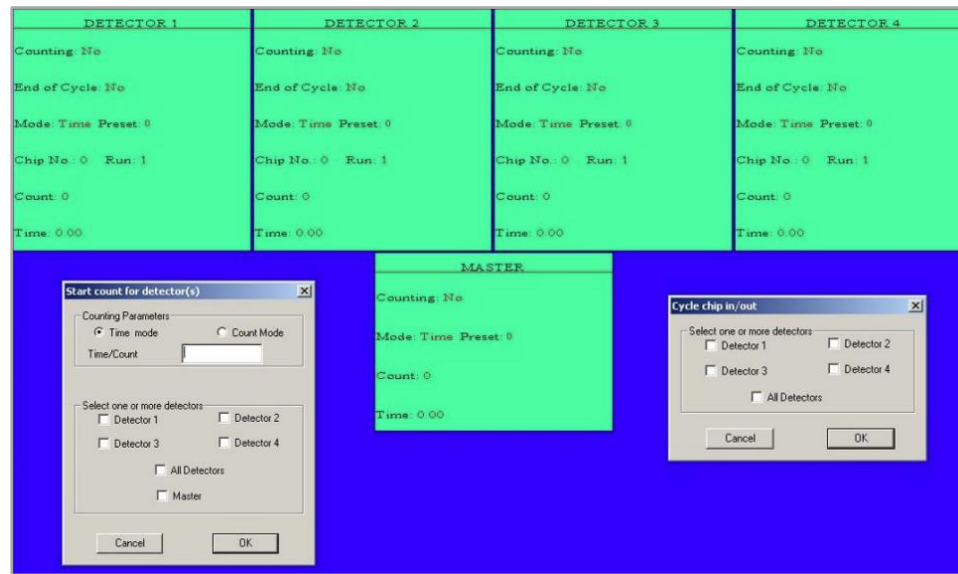
- Dated mechanical and measurement systems
- Replaced custom gas flow proportional counters with off the shelf commercially available scintillators and preamps.
- Updated motor hardware for reliable sample changing
- Custom hardware
- Exposed electronics



Fission Rate Measurement System (FRMS) Software

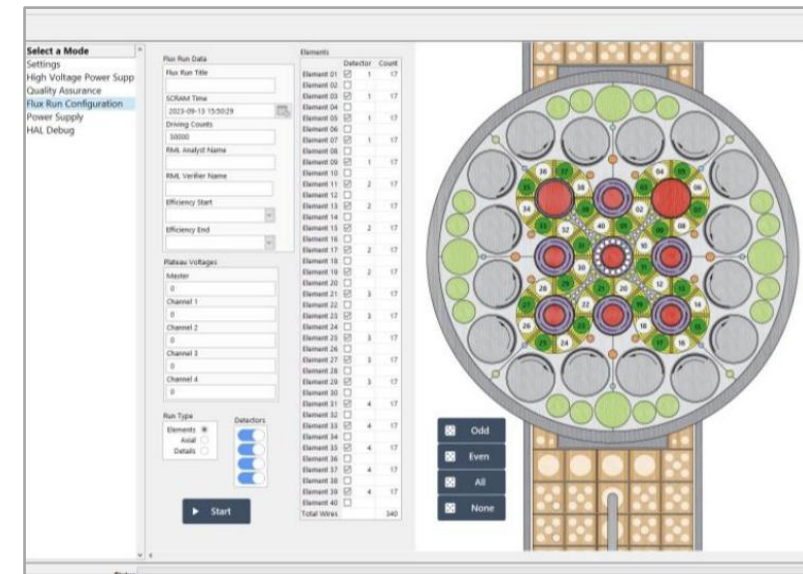
Previously:

- Software crashes
- Usability
- Data loss



Now:

- HPI upgrades
- Independent motor control
- Independent channel count control



Fission Rate Measurement System Science

- Historical K-factor determination
- New K-factor calculation:
 - Fission Wire gamma spectroscopy
 - Fission product quantification
 - Correlation to gross beta counts
 - Closer agreement with simulations
- Knowledge preservation and continuation

$$FR_i = \frac{A_{j,i} \cdot m_i}{\frac{E_{U235} \cdot W_{U235} \cdot m_i}{1000} \cdot (1 - e^{-\lambda_i \cdot T_{irrad}}) \cdot Y_j}$$

Where:

FR_i = Fission Rate of wire 'i' $\left(\frac{FR}{g \text{ of } U235} \right)$

$A_{j,i}$ = Measured specific activity, decay corrected to the time of SCRAM, of nuclide 'j' of wire 'i'

m_i = mass of wire 'i' (mg)

E_{U235} = Enrichment of U235 (0.93)

W_{U235} = Weight percent of U (0.1)

λ_j = Decay constant for nuclide 'j'

Y_j = Cumulative fission yield for nuclide 'j'

T_{irrad} = Irradiation Time

Isotope	Fission Yield (%)	Fission Yield Uncert.	FY Energy Uncert. (%)	Half-Life (hr.)	Half-Life Uncert.
Sr-91	5.798%	0.0414%	1.82%	9.68	0.02
Zr-97	5.957%	0.0447%	1.34%	16.749	0.008
Mo-99	6.073%	0.0632%	2.79%	65.936	0.0009
Ce-143	5.948%	0.0260%	3.83%	33.037	0.0008
Ce-141	5.840%	0.0547%	1.90%	780.096	0.264
Zr-95	6.457%	0.0441%	0.53%	1,536.77	0.144

ATR-C Dosimetry

- Radioactivation of materials per ASTM standards.
- Southeast Flux Trap (SE) presents a broader neutron spectrum.
- Instrument Thimble (IT) neutron fields are mostly thermalized.

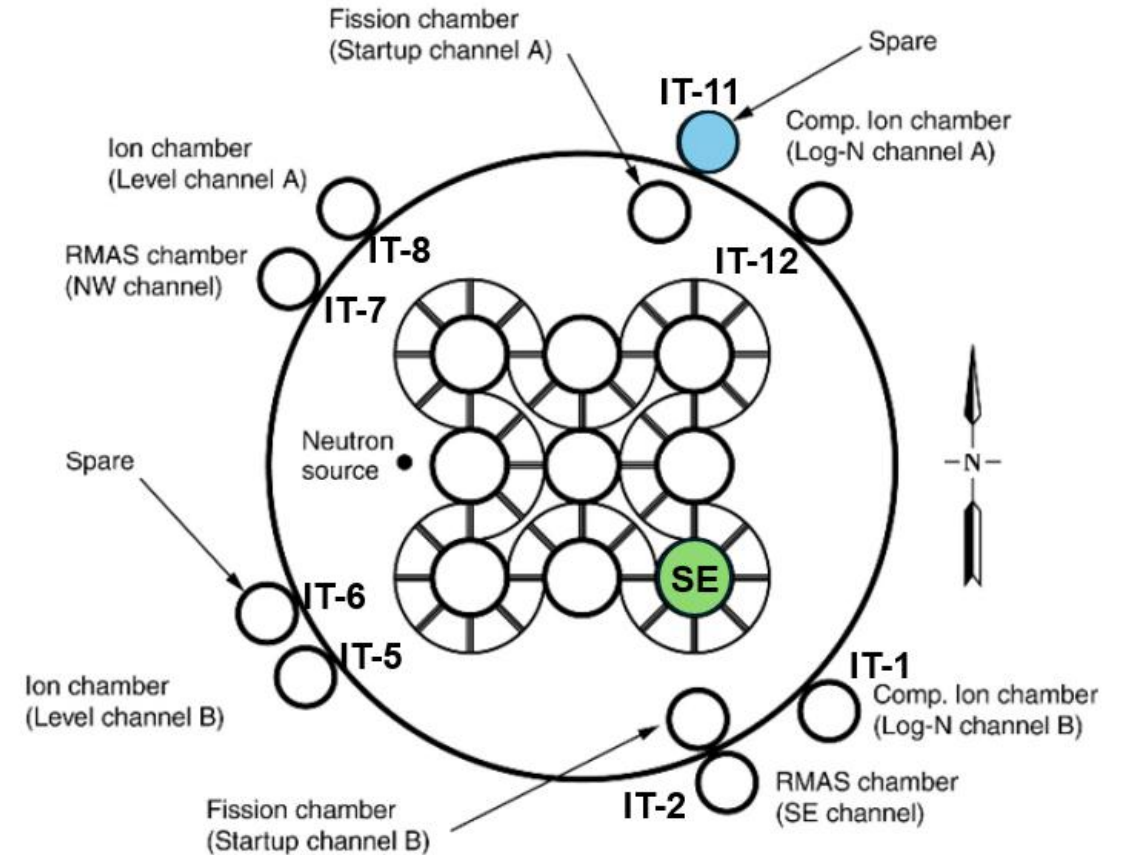


Image adapted from the Safety Analysis Report for the ATRC Facility, SAR-192, Idaho National Laboratory, United States: N. p., 2024.

Instrument Thimble-11 (IT-11)

- Radioactivation of gold and indium foil
- Radioactivation of gold, silver, cobalt and nickel wires
- Characterization of the neutron field within IT-11

Ottaway, D.G, McCary, K.M., Reichenberger, M.A., "Measurement of the Thermal Neutron Fluence Rate in the Instrument Thimble 11 Position in the Advanced Test Reactor Critical," EPJ Web Conf. 338 04034 (2025), DOI: 10.1051/epjconf/202533804034



Dosimeters prepared in sample vials.

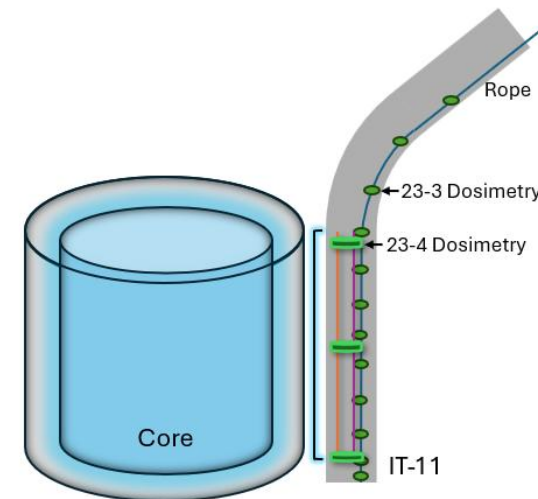
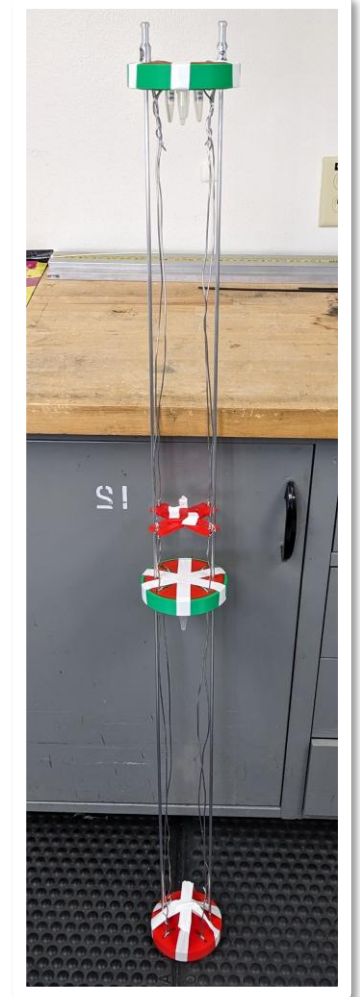


Illustration of dosimetry positioning.

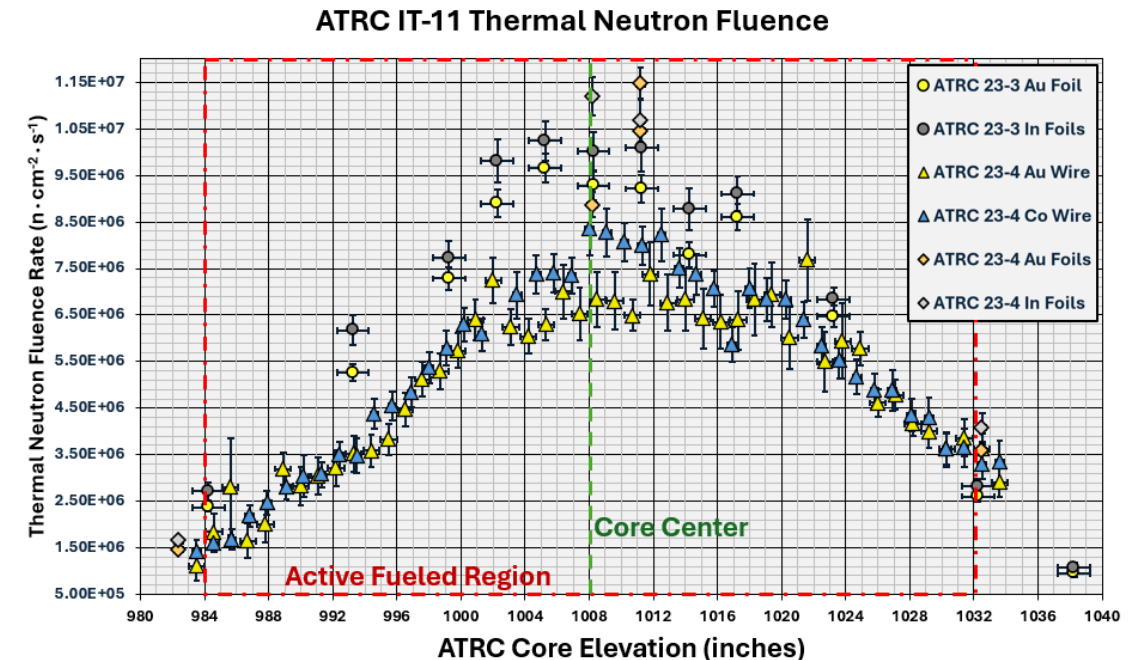


Long wire dosimetry test assembly.

Calculated Thermal Neutron Fluence Rates (TNFR) from activated dosimetry measured within ATR-C IT-11*

- TNFR using comparative wire measurements are similar.
- TNFR using comparative foil measurements are similar.
- A bias exists towards higher fluence rates being reported from measurements of foils.
- Dosimeters of like materials but different matrices disagree.
- Possible factors?

Ottaway, D.G, McCary, K.M., Reichenberger, M.A., "Measurement of the Thermal Neutron Fluence Rate in the Instrument Thimble 11 Position in the Advanced Test Reactor Critical," EPJ Web Conf. 338 04034 (2025), DOI: 10.1051/epjconf/202533804034



*Calculations performed utilizing methods outlined in ASTM International standards E261, E262, E264 and E481.

Questions/Contacts

Please send any follow up questions or comments to Dani Ottaway: dani.ottaway@inl.gov

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