INL/CON-24-81586-Revision-0

Qualifying the Instrument Thimble 11 Test Position in the Advanced Test Reactor Critical

November 2024

Changing the World's Energy Future

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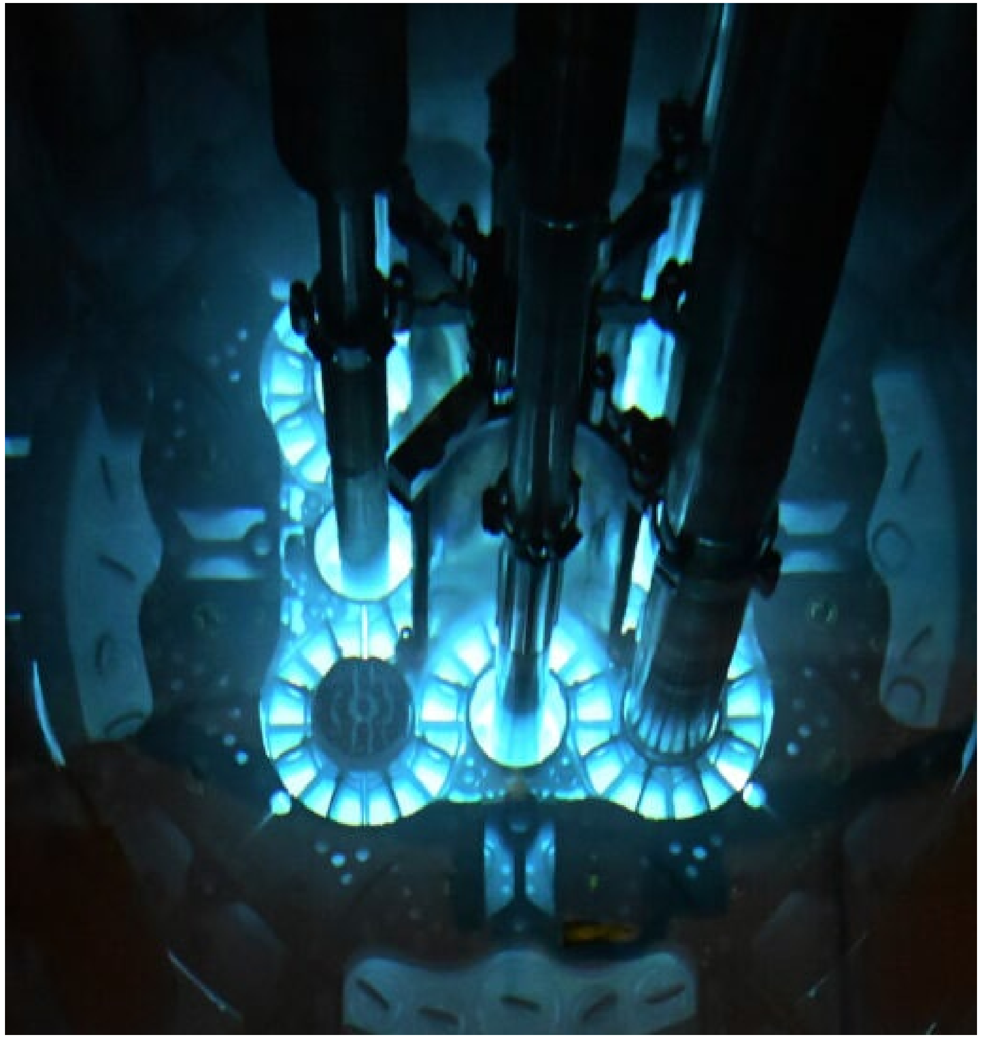
Qualifying the IT-11 Position in the Advanced Test Reactor Critical

Idaho National Laboratory's Advanced Test Reactor (ATR)

- Light Water Cooled, Beryllium Moderated
- Nominal thermal power capacity: 250 MW
- Max Thermal Neutron Flux: 1.0×10^{15} n•cm^{-2}•s^{-1}
- Max Fast Neutron Flux: 5.0×10^{14} n•cm^{-2}•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 (ATRC)

Find a photo of ATRC

- 1:1 Scale replica of ATR's core
- In pool in lieu of a pressure vessel
- Operates at ≤ 600 watts
- Typical Uses:
  - Physics testing
  - Instrumentation testing
  - Experiment testing prior to ATR insertion
  - Research
- Measurements in ATRC are scaled up to ascertain performance in ATR.

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

ATR & ATRC Instrument Thimbles (IT)

- The core was designed with 12 dry-tube instrument thimble locations placed just outside the main reactor tank.
- 6 of the ITs are used for operations instrumentation in both reactors.
- 2 stand empty as reserves should one of the other ITs be compromised.
- Neither reserve has been needed in ATR or ATR-C except for special projects or measurements.
- This is an underutilized resource for the research community.

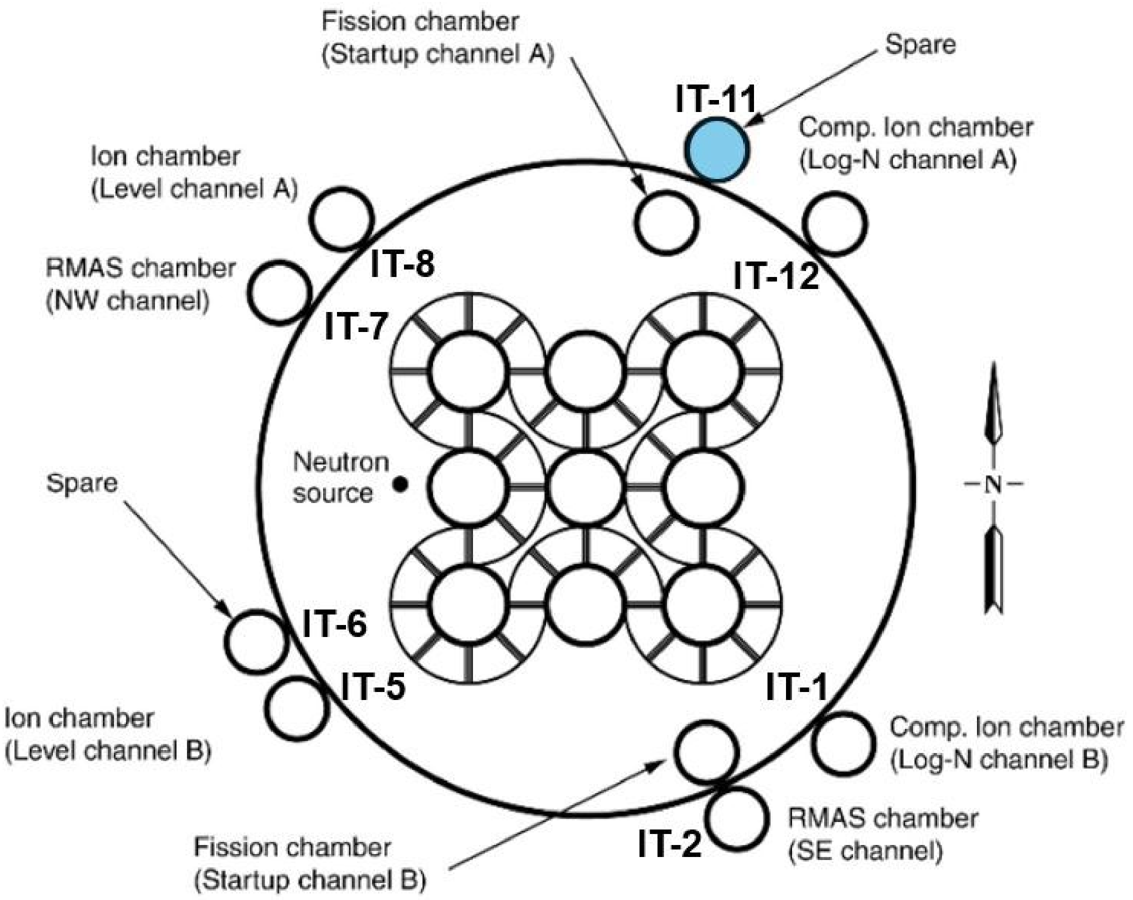


Image adapted from the Safety Analysis Report for the ATRC Facility, SAR-192, Idaho National Laboratory, United States: N. p., 2024.

Why ATRC and not ATR?

- Scheduling:
  - ATR is usually scheduled 2-3 years out, making it harder to access for shorter term projects.
- Cost:
  - As fewer personnel are required for operations and test handling, it is substantially cheaper to perform experiments in ATRC.
- Access:
  - ATRC ITs can be accessed while the reactor is in operation. This is not presently an option for ATR.
- Materials:
  - As ATRC isn't pressurized nor reaching high temperatures, the guidelines for experiment design materials are more flexible.
- Time Sensitivity:
  - As materials are not irradiated for nearly as long in ATRC, PIE can be performed without the need for extensive processing facilities.
  - The Radiation Measurement Laboratory has been measuring dosimetry on HPGe detectors within 1 hour of ATRC scram.

Nuclear Interactions for Dosimetry

- ASTM E262 "Standard Test Method for Determining Thermal Neutron Reaction Rates and Thermal Neutron Fluence Rates by Radioactivation Techniques"
- Indium
  - $^{115}In(n,\gamma)^{116}In$
    - ^{116}In has a 14.1 sec half life but decays to ^{116m}In in 79% of interactions which has a 54.29 min half life.
    - As RML is within walking distance, indium dosimeters can be measured before much activity is lost.
  - $^{197}Au(n,\gamma)^{198}Au$
    - ^{198}Au has a half life of 2.695 days. This allows measurements of gold dosimeters to be performed without the same time crunch as indium.
    - Gold dosimeters don't have to be corrected for reaction incidence rate or isotopic abundance.

ASTM International Standard E262, "Standard Test Method for Determining Thermal Neutron Reaction Rates and Thermal Neutron Fluence Rates by Radioactivation Techniques," 2017.

Test Set Up

- Pure indium and gold dosimeters were compiled, cleaned, weighed and placed in individual sample vials with a number assignment.
- 1 gold and 1 indium dosimeter were secured to a rope at measured increments and then lowered into the IT.
- A metal plate was affixed to the end of the rope to notify when the bottom of the IT was hit.
- The dosimeters were lowered during the 23-3 ATRC irradiation and irradiated for 10 minutes before being withdrawn.
- The vials were extracted and, after being cleared for contamination, brought to RML for measuring.

Gold and indium dosimeters prepared in sample vials.

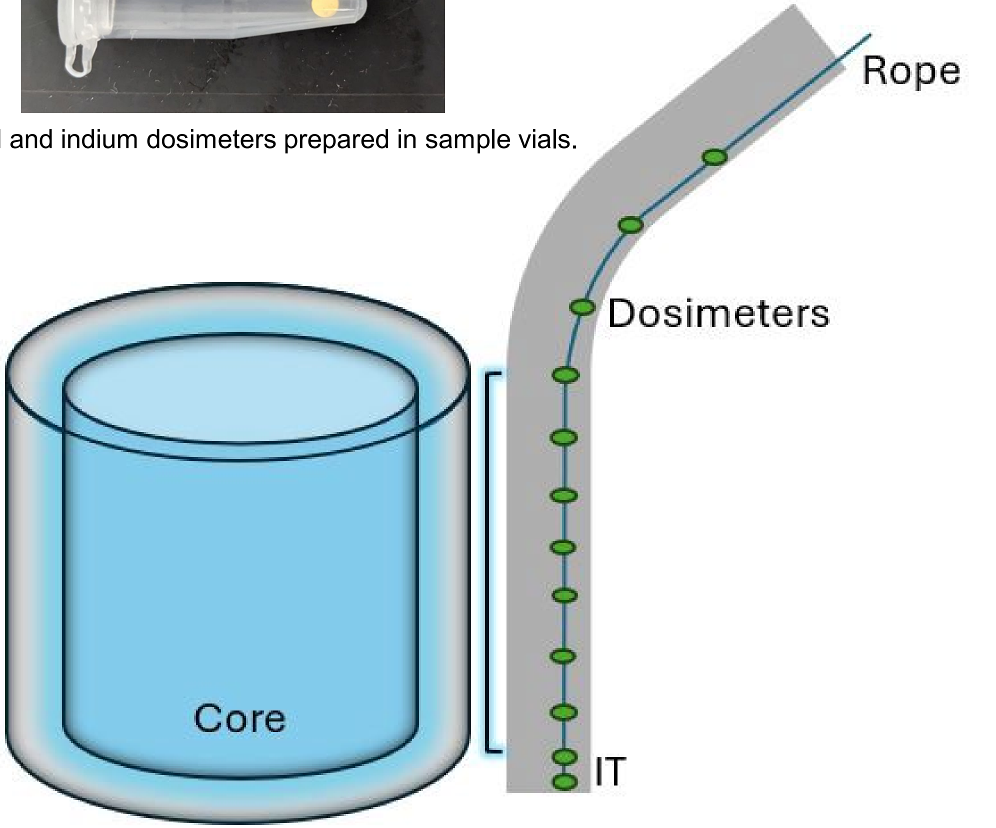


Illustration of the experiment configuration.

PIE - Gamma Spectroscopy

From E262, Eq. 15 & 16:

$$\varphi_0(t) = \frac{Ce^{\lambda t_w}}{g\sigma_0 \varepsilon N_0\left(1-e^{-\lambda t_i}\right)} \quad \text{(Eq. 1)}$$

Given $N_0 = \frac{m_{dos} N_{Avg}}{M_{mol}}$, and $A_{sp} = \frac{Ce^{\lambda t_w}}{\varepsilon m_{dos}}$

$$\varphi_0(t) = \frac{A_{sp} M_{mol}}{G_{th} g \sigma_0 N_{Avg}\left(1 - e^{-\lambda t_i}\right)} \quad \text{(Eq. 2)}$$

$\varphi_0(t)$ = TNFR for bare dosimeters
C = counts
λ = decay constant
t_w = time between irradiation and measurement
g = wescott g factor
σ_0 = thermal neutron cross section
ε = detector efficiency
N_0 = number of atoms in dosimeter
t_i = irradiation time
m_{dos} = mass of dosimeter
N_{Avg} = Avogadro's Number
M_{mol} = dosimeter molar mass
A_{sp} = decay corrected, measured specific activity
G_{th} = self shielding factor

- The dosimetry was measured on several HPGe detectors at RML per industry standard practices.
- The specific activity of individual samples was obtained and then, for the indium, corrected to account for the natural abundance of ^{115}In in the dosimeters.
- Following the methods outlined in ASTM E262, the Thermal Neutron Fluence Rate (TNFR) was calculated

Results

TABLE II. Gold Data

Gold Foil	Sp. Act. $\mu Ci \cdot mg^{-1}$	φ_0 $n \cdot cm^{-2} \cdot s^{-1}$	φ_0 Unc. $n \cdot cm^{-2} \cdot s^{-1}$	IT Elev. in
1	4.26E-06	3.21E+05	2.91E+04	3
2	3.18E-05	2.38E+06	1.33E+04	15
3	7.02E-05	5.28E+06	1.12E+04	24
4	9.82E-05	7.31E+06	1.09E+04	30
5	1.18E-04	8.93E+06	1.04E+04	33
6	1.29E-04	9.70E+06	1.04E+04	36
7	1.24E-04	9.31E+06	1.05E+04	39
8	1.23E-04	9.24E+06	1.05E+04	42
9	1.04E-04	7.83E+06	1.08E+04	45
10	1.15E-04	8.64E+06	1.07E+04	48
11	8.62E-05	6.49E+06	1.11E+04	54
12	3.48E-05	2.62E+06	1.37E+04	63
13	1.28E-05	9.62E+05	2.59E+04	69
14	3.60E-06	2.71E+05	6.00E+04	75
15	2.09E-06	1.57E+05	9.31E+04	81

TABLE III. Indium Data

In Foil	Sp. Act. $\mu Ci \cdot mg^{-1}$	φ_0 $n \cdot cm^{-2} \cdot s^{-1}$	φ_0 Unc. $n \cdot cm^{-2} \cdot s^{-1}$	IT Elev. in
1	9.92E-04	4.19E+05	6.56E+04	3
2	6.47E-03	2.74E+06	1.86E+05	15
3	1.47E-02	6.24E+06	3.21E+05	24
4	1.84E-02	7.81E+06	3.63E+05	30
5	2.33E-02	9.91E+06	4.60E+05	33
6	2.44E-02	1.03E+07	4.28E+05	36
7	2.38E-02	1.01E+07	4.03E+05	39
8	2.41E-02	1.02E+07	5.16E+05	42
9	2.09E-02	8.87E+06	4.57E+05	45
10	2.19E-02	9.20E+06	3.77E+05	48
11	1.62E-02	6.91E+06	2.56E+05	54
12	6.76E-03	2.85E+06	1.72E+05	63
13	2.56E-03	1.08E+06	1.01E+05	69
14	5.82E-04	2.44E+05	4.19E+04	75
15	2.64E-04	1.12E+05	3.31E+04	81

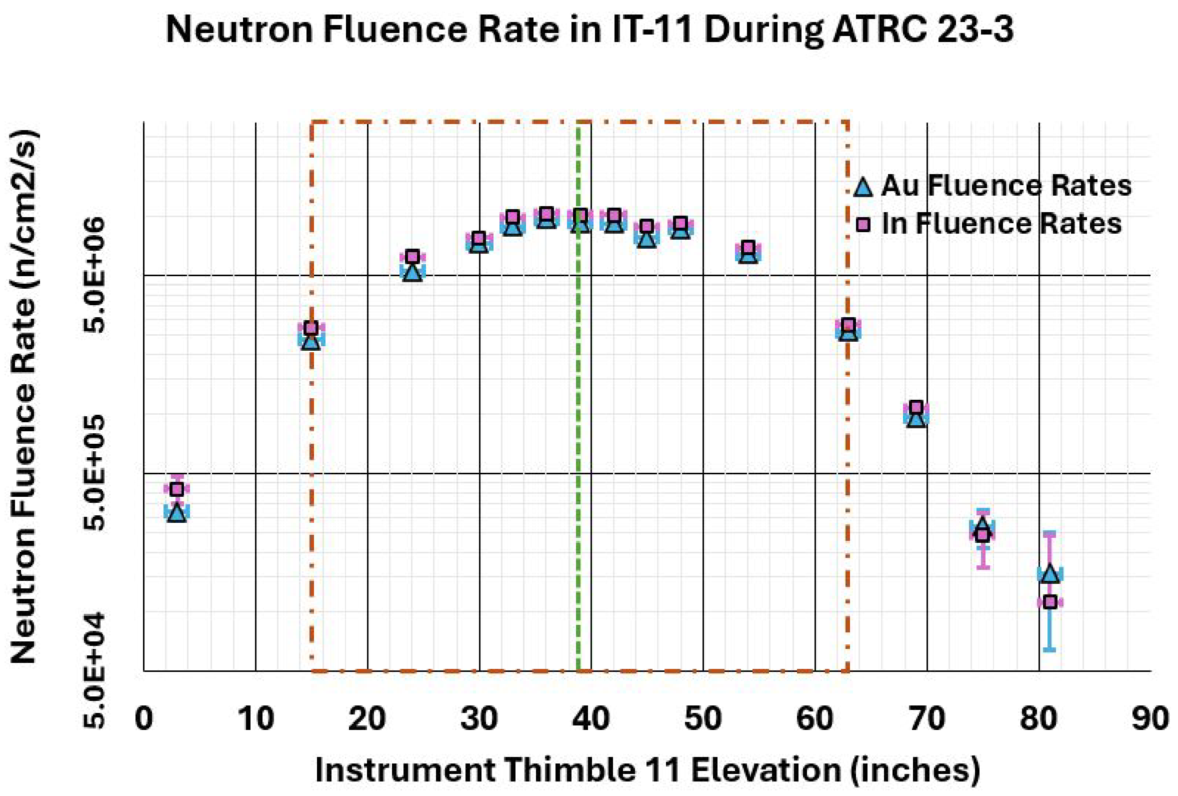
TABLE IV. Comparison Data

Foil	Au φ_0 $n \cdot cm^{-2} \cdot s^{-1}$	In φ_0 $n \cdot cm^{-2} \cdot s^{-1}$	Diff. %	IT Elev. in
1	3.21E+05	4.19E+05	23%	3
2	2.38E+06	2.74E+06	13%	15
3	5.28E+06	6.24E+06	15%	24
4	7.31E+06	7.81E+06	6%	30
5	8.93E+06	9.91E+06	10%	33
6	9.70E+06	1.03E+07	6%	36
7	9.31E+06	1.01E+07	8%	39
8	9.24E+06	1.02E+07	9%	42
9	7.83E+06	8.87E+06	12%	45
10	8.64E+06	9.20E+06	6%	48
11	6.49E+06	6.91E+06	6%	54
12	2.62E+06	2.85E+06	8%	63
13	9.62E+05	1.08E+06	11%	69
14	2.71E+05	2.44E+05	-11% *	75
15	1.57E+05	1.12E+05	-40% *	81

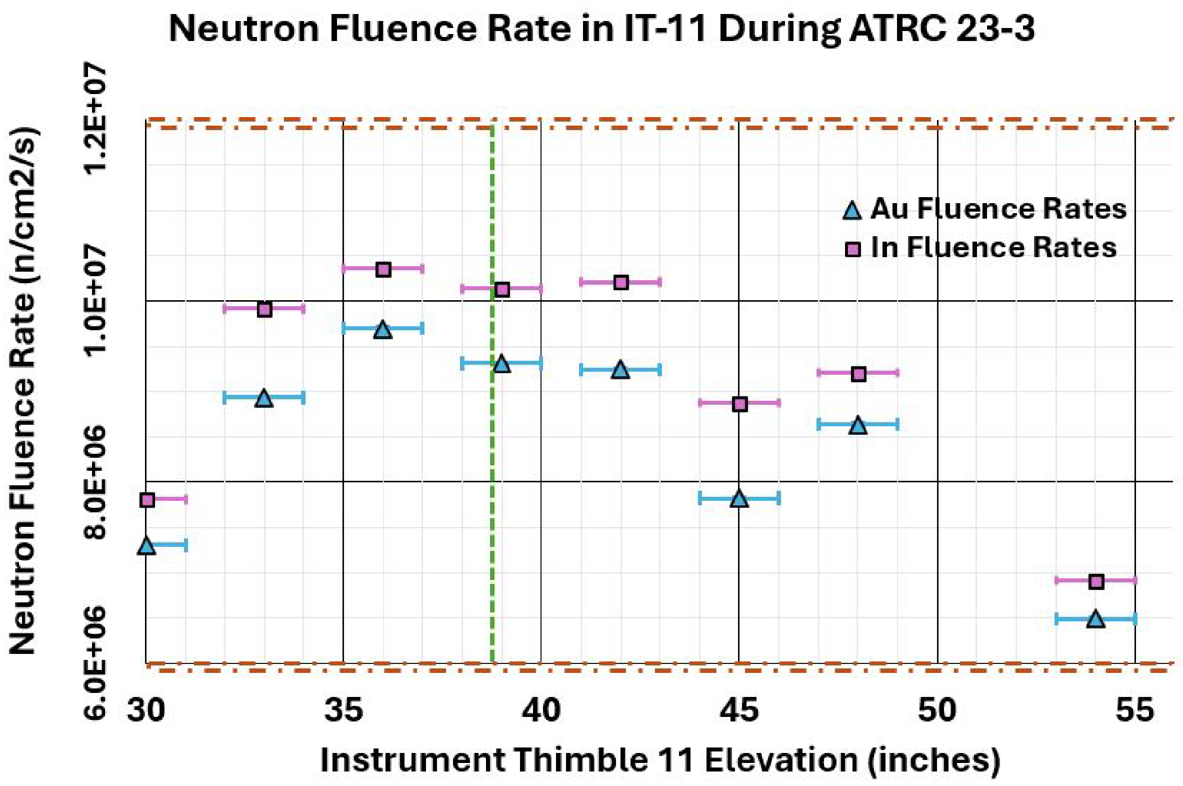
* Reported values for the TNFR from indium dosimeters 14 and 15 are likely lower than actual values due to the rapid decay of ^{116m}In. These two dosimeters had experienced 3.5 and 4.5 half-lives respectively and the counting statistics were poor.

Tables are from and included in ANS Summary.

Results



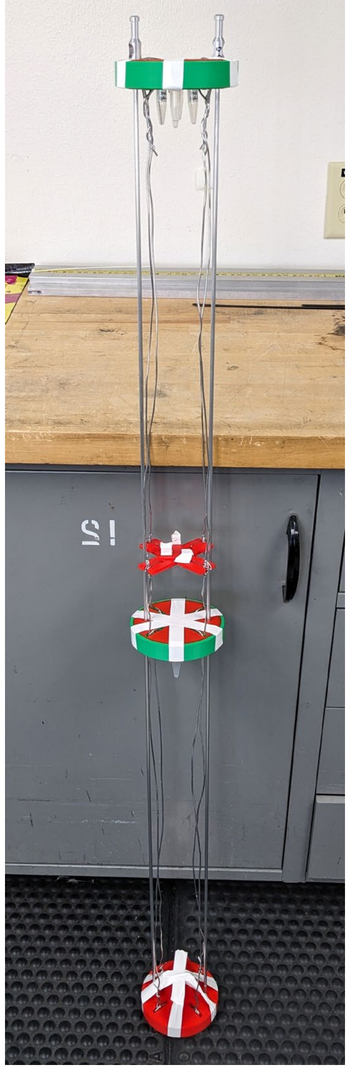
Neutron Fluence Rate in IT-11 During ATRC 23-3
Neutron Fluence Rate (n/cm2/s)
5.0E+04
5.0E+05
5.0E+06
0
10
20
30
40
50
60
70
80
90
Instrument Thimble 11 Elevation (inches)
Au Fluence Rates
In Fluence Rates



Neutron Fluence Rate in IT-11 During ATRC 23-3
Neutron Fluence Rate (n/cm2/s)
6.0E+06
8.0E+06
1.0E+07
1.2E+07
30
35
40
45
50
55
Instrument Thimble 11 Elevation (inches)
Au Fluence Rates
In Fluence Rates

Future Work

- Obtain data from several irradiations to determine the behavior of the TNFR within IT-11.
- Develop a more reliable test platform to decrease the vertical positional uncertainty.
- Develop a model from the data to predict behavior within IT-11.
- Perform measurements to verify the integrity of the model.
- Establish IT-11 as qualified thermal neutron test platform for nuclear instrumentation and research.



Questions/Contacts

- Questions?

- Please send any follow up questions or comments to:

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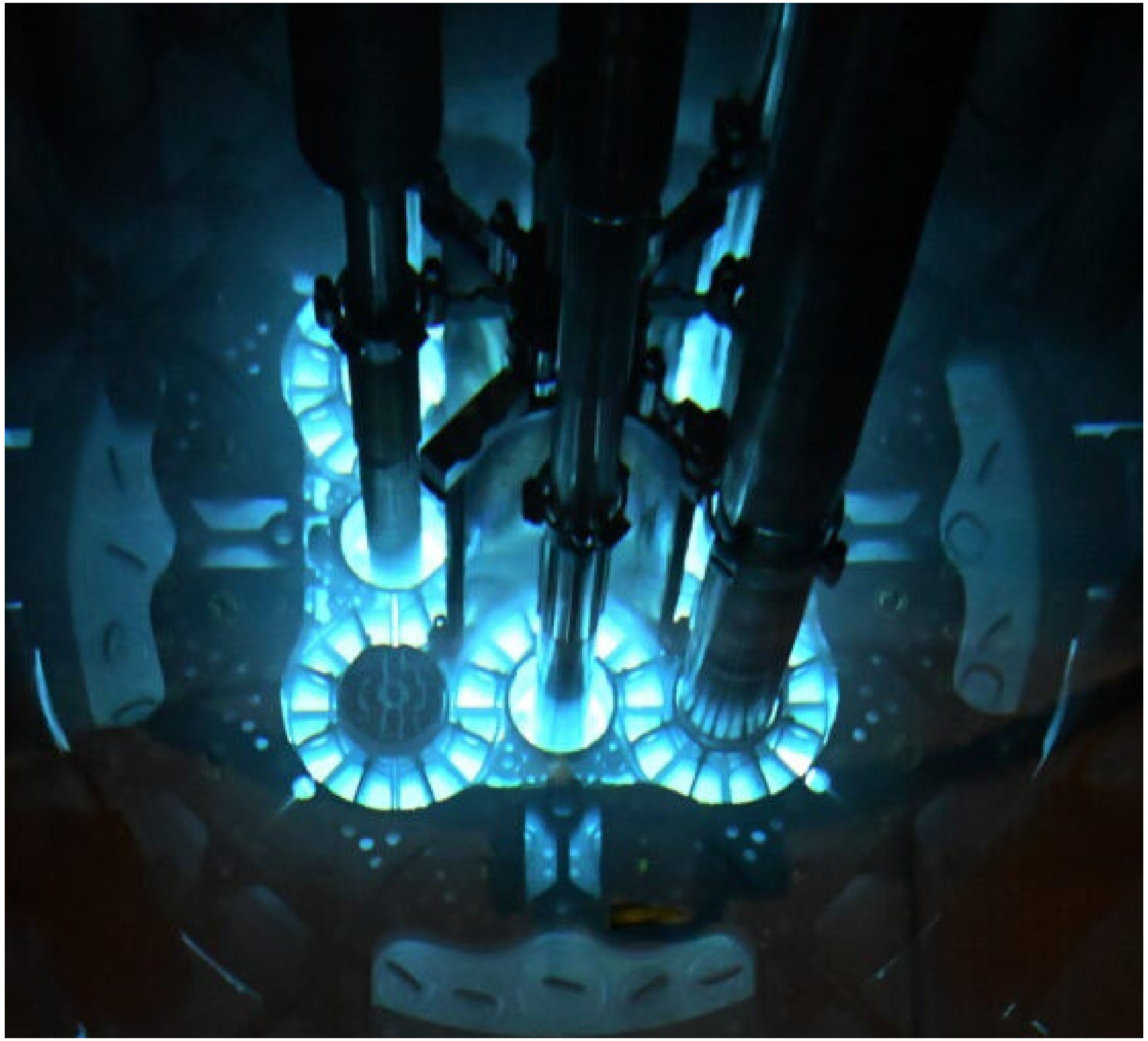
- Special thank you to INL Photography for use of images, and RML Personnel: M. A. Reichenberger, K.M. McCary, B.J. Walker, and C.D. Jones.



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