INL/MIS-19-55710-Revision-0

Conceptual Design Report for the I2 Instrumentation Experiment in ATRC

Joe Palmer, Kevin Tsai, Troy Unruh, Michael A Reichenberger

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Prepared for the
U.S. Department of Energy

Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

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Approved by:

Joe Palmer Design Engineer/Lead Author	Date
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ABSTRACT

The US Department of Energy In-Pile Instrumentation (I2) program is tasked with developing advanced sensors for in-pile service as well as supporting the engineering required to implement existing nuclear sensor technologies in US high-power test reactors. The ATRC instrumentation test has been conceived to address both of these missions, specifically with respect to neutron flux measurements. Space has been allocated in the test for Self-Powered Neutron Detectors (SPNDs), fission chambers, and Micro-Pocket Fission Detectors (MPFDs). The real-time flux readings obtained from these instruments will be compared with time integrated data obtained from passive neutron dosimetry (i.e., "flux" wires).

This work will be complementary to data obtained from the TREAT MIMIC-N experiment. This experiment is expected to support instrumentation efforts related to the proposed Medium-I loop and to instrumenting loop experiments conducted in the ATR center flux trap. While the MIMIC-N experiment was conducted in a dry environment, the ATRC I-19 experiment will be conducted in an aqueous environment, similar to the center flux trap loop experiments, but will take place at ambient temperature and pressure, and at a much lower neutron flux. One of the challenges of the ATRC I-19 experiment will be low amplitude signals produced by the sensors in the low neutron fluxes of ATRC. However, related work conducted several years ago in ATRC was able to reliably detect signals using identical or similar fission chambers and SPNDs. However, it appears that the current generation of MPFDs will require larger fissile material deposits to generate sufficient signal strength to be detectable.

CONTENTS

ACRONYMS

ASI	Advanced Sensor and Instrumentation
ATRC	Advanced Test Reactor Critical facility
CEA	French Atomic Energy Commission
DAS	Digital Acquistion System
DOE	Department of Energy
FC	Fission Chamber
MIMIC-N	Materials and Instruments Modular Irradiation Capability (N)
MITR	Massachusetts Institute of Technology Reactor
MPFD	Micro-Pocket Fission Detector
NE	Nuclear Energy
NEET	Nuclear Energy Enabling Technology
SPND	Self-Powered Neutron Detector
TREAT	Transient Reactor Test Facility

Conceptual Design Report for the I2 Instrumentation Experiment in ATRC

1. INTRODUCTION

The Advanced Test Reactor (ATR) at Idaho National Laboratory conducts a variety of instrumented fuels and materials experiments that are essential to the Department of Energy (DOE) Nuclear Energy (NE) mission. However, these experiments are not equipped with real-time neutron flux sensors. The unique fuel arrangement of ATR provides great flexibility in operating the reactor – power may be “tilted” to one of four lobes, but this flexibility also results in a measure of uncertainty in the neutron flux at any one experiment location. To remedy this situation an effort to develop and deploy reliable neutron flux sensors has been initiated as part of the Nuclear Energy Enabling Technology (NEET) Advanced Sensor and Instrumentation (ASI) In-Pile Instrumentation (I2) program.

The ATRC I2 flux instrumentation experiment has a second complimentary mission, and that is to confirm neutronics modelling associated with the Medium I-loop project. The objective of the Medium I-loop project is to replace some of the irradiation capabilities lost when the Halden reactor shut down. Plans include installing a booster fuel element in a Large I position adjacent to the Medium I position that will house the Medium I-loop. The I2 flux instrumentation experiment package will be in a corresponding Medium I position in ATRC, and thus can be used to confirm the neutronics modelling performed in support of the Medium I-loop.

Figure 1. The Advanced Test Reactor.

The ATRC I2 flux instrumentation experiment will be designed for temporary operation in ATRC. The experiment will be inserted in the I-19 position using standard ATRC handling tools. Cabling from the in-core portion of the experiment will routed over the parapet surrounding ATRC and connected to a portable instrumentation rack located on the beach surrounding the parapet. All cabling supports will be temporary. The experiment will incorporate a flux wire dosimetry package that can be removed with standard handling tools while the balance of the experiment remains in place.

Simplified neutronics analyses conducted in support of this experiment indicate that the flux will be a factor of approximately 2 E+05 less than the equivalent I-19 position in ATR. Preliminary calculations are performed herein to determine whether the sensors selected will be able to provide sufficient signal strength to be measured by existing techniques.

2. BACKGROUND AND REQUIREMENTS

2.1 Description of ATRC

The ATRC is a full-scale nuclear mock-up of the ATR core, but the ATRC is only licensed to operate at a thermal power of 5 kW. For most applications, the ATRC is operated at approximately 600 watts. The ATRC does not have an active cooling system. The ATRC relies on natural convection for cooling. The ATRC is typically used to characterize expected changes in core reactivity of prototypic experiments to be irradiated in the ATR. The ATRC is often used to measure core flux distribution based on experiment loading and axial flux distribution of experiments. The ATRC is a pool-type reactor and so accessibility to irradiation positions is much easier than in the ATR. There are differences between the core configuration of ATR and ATRC. The differences are due to upgrades made to the ATR reflector, and other components, that have not been made in the ATRC. These differences between the ATR and ATRC are not considered to be significant, and the ATRC is still considered a neutronically equivalent low power mock-up of the ATR.

2.2 Experiment Objectives

This experiment is intended to serve as the second in a three step process to full deployment of real-time neutron flux sensors in ATR. The first step was the MIMIC-N experiment conducted in TREAT in June 2019 [1]. This ATRC experiment is intended to further that work by moving the sensors to an aqueous environment, with a similar spectrum to ATR. The third step is to irradiate a similar sensor package in the Massachusetts Institute of Technology's MTIR reactor, which provides flux prototypical to many ATR positions, and can produce temperatures of 250°C or more in an aqueous (but low pressure) environment [2].

The second primary objective of this experiment is to confirm the neutronics modelling performed for the booster fuel installed in the adjacent large I position is accurate, i.e., to confirm (two group) spectrum and flux magnitude.

2.3 Experiment Requirements

1. Install in a Medium I position, I-19, or similar.
2. Provide equivalent water to metal ratio as the Medium I-loop in-core assembly.
3. Tubes for Med I loops are expected to be zircaloy, but aluminum tubes are acceptable for the ATRC test if demonstrated to be neutronically equivalent.
4. Test space shall be flooded with water. If some instruments are water sensitive, they will need to be enclosed in a sealed, miniature sub capsule.
5. The experiment shall be located in a fixed azimuthal orientation during operation.
6. The flux wire holder shall be separable from the rest of the experiment so that it can be retrieved quickly and sent for analysis.

7. Total operating time in ATRC is to be <20 hrs, over a period of roughly two weeks.
8. Real-time flux measurements to be taken a ATRC half-power (~300 W) and full-power (~600 W). A separate flux wire dosimetry package shall be used for each of the two runs.
9. Data Acquisition System (DAS) shall be rack mounted and portable (with locking wheels).
10. DAS shall be stand alone with no network connections while installed at ATRC
11. DAS power input to be 120 VAC.
12. Instruments are to be as shown in Table 1 below:

Table 1. Instrument list for I2 experiment in ATRC

Position	Sensor	Comments	Diameter
A	Flux Wire Passive Dosimetry Package	Accessible by hook-tool	8 mm
B	U-235 fission chamber from CEA (thermal **n** detector)	On hand @ ATRC. Sealed (water proof)	3 mm
C	U-238 fission chamber from CEA (fast **n** detector)	On hand @ATR but not water proof	8 mm
D	SPND, Rh large diameter	To be mfg by ILC	2.4 mm
E	SPND, Rh small diameter	To be Mfg by ILC	1.6 mm
F	MPFD, Th Type	Mfg by Kansas State and INL	4-6 mm
G	MPFD, NU Type, Mesytec Electronics	Mfg by Kansas State and INL	4-6 mm
H	MPFD, NU Type, MONACO Electronics	Mfg by Kansas State and INL	4-6 mm

3. CONCEPTUAL DESIGN

3.1 Test Train Overview

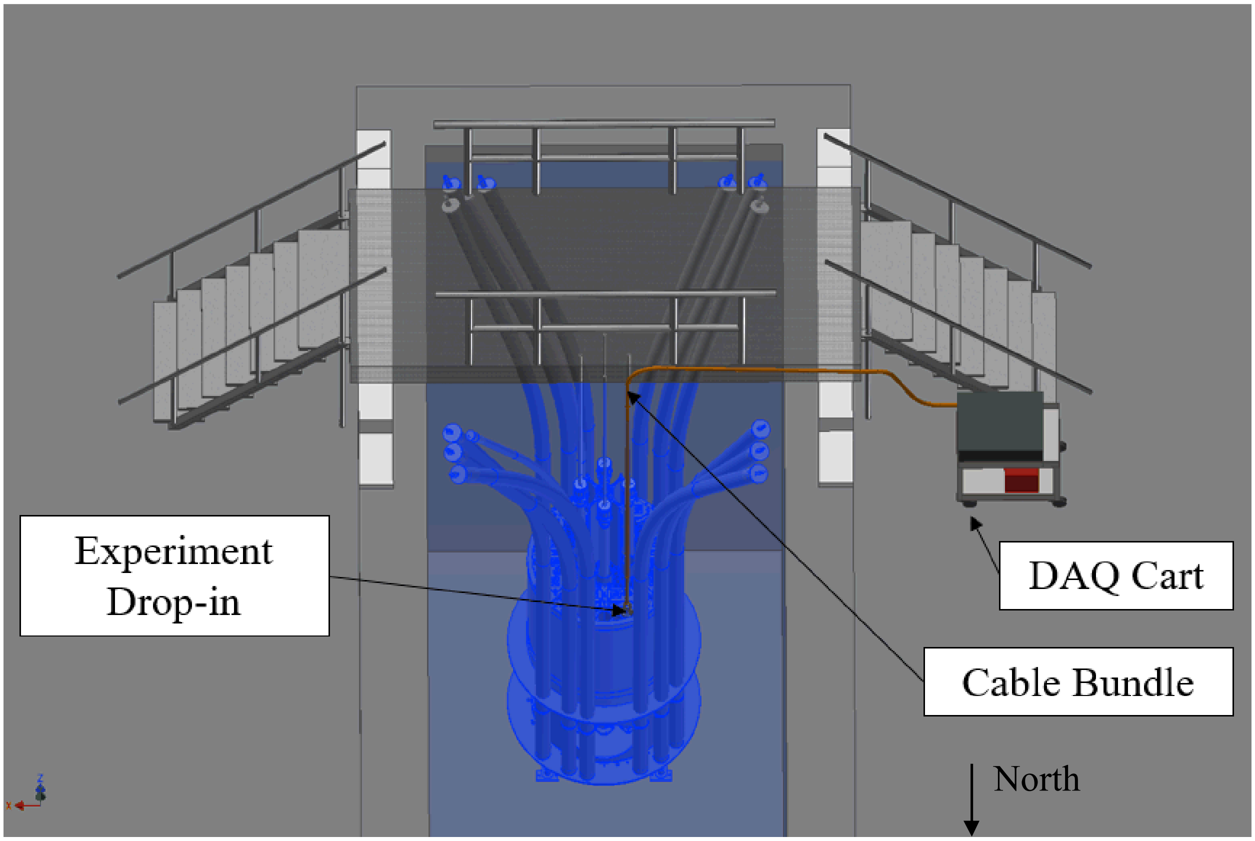


Figure 2. Overall Experiment Installation.

Fig. 2 shows an overall view of the layout of the ATRC I2 experiment. The experiment test assembly is to be placed in the I-19 position of the reactor which is on the northwest side of the reactor. The cable bundle is routed to the surface of the pool and supported from the ATRC walk-over platform. The cable bundle is then routed to the west and connected to the Data Acquisition System (DAS) cart, which is located within a few feet of the canal parapet.

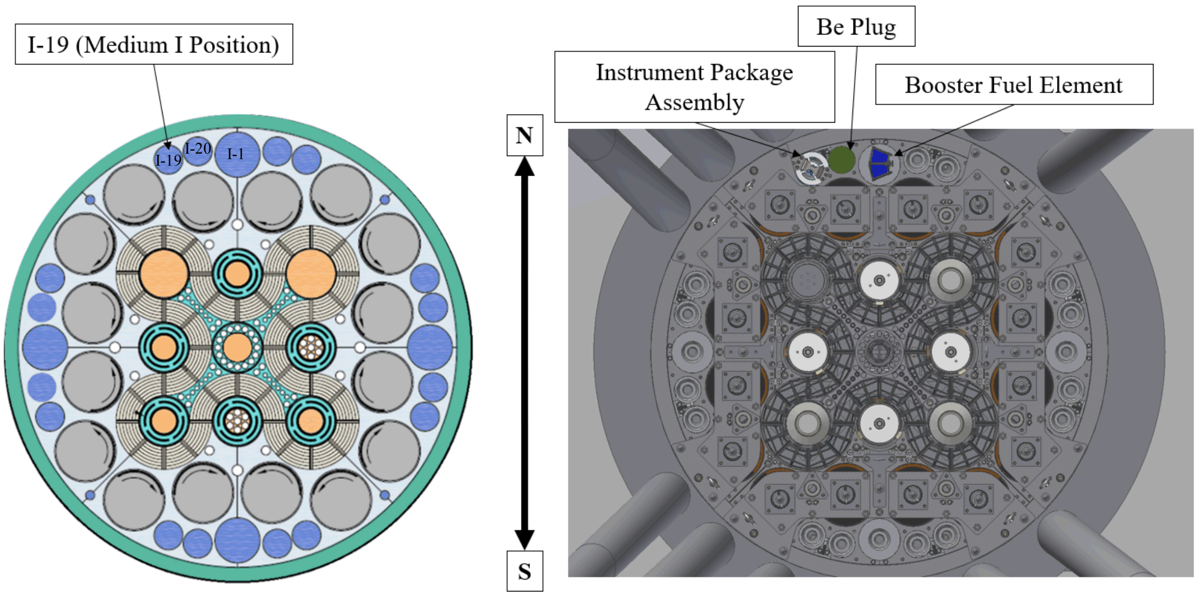


Figure 3. Experiment Plan Views.

Fig. 3 shows plan views of the ATRC I2 experiment installation. A standard ATR fuel element will be installed as booster fuel in the northern large I position (I-1) to provide a local increase of thermal flux. Between the I-1 and I-19 position is another medium I position designated I-20. A beryllium filler plug will be placed in this position in an effort to increase the thermal flux in I-19. The ATRC I2 experiment can also be conducted without the booster fuel or beryllium plug.

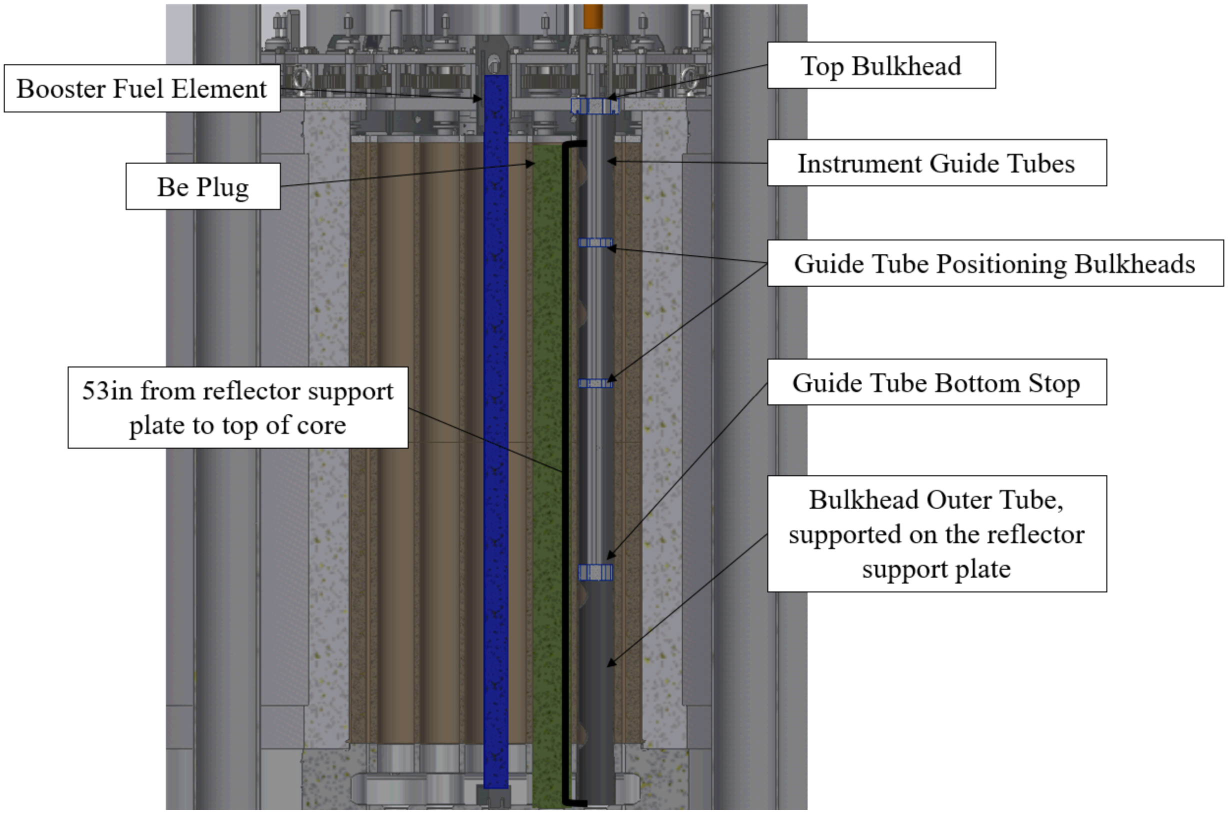


Figure 4. Elevation View.

Fig. 4 is an elevation view showing the entire ATRC core height. The in-core section of the experiment consists of a bundle of tubes housed within a larger aluminum tube. The tubes in the bundle locate and support each neutron flux sensor. This core section is bottom supported from the reflector support plate. The experiment is designed to be irradiated at a given azimuthal orientation, however no locking features are provided. An alignment mark will be provided at the top of the in-core assembly, and its weight is sufficient to maintain azimuthal orientation.

Figure 5. Upper Section of In-Core Assembly and Lifting Bail.

Fig. 5 provides view of the upper section of the in-core assembly and the lifting bail. As can be seen in the figure, the tube surrounding the tube bundle has holes along its length so that it will flood when immersed in ATRC and drain as it is retrieved. The aluminum tubes making up the interior bundle also have holes along their lengths so that they will flood and drain in a similar manner.

The bail at the top of the assembly is stainless steel (for strength) rather than aluminum and is mechanically attached to the top bulkhead.

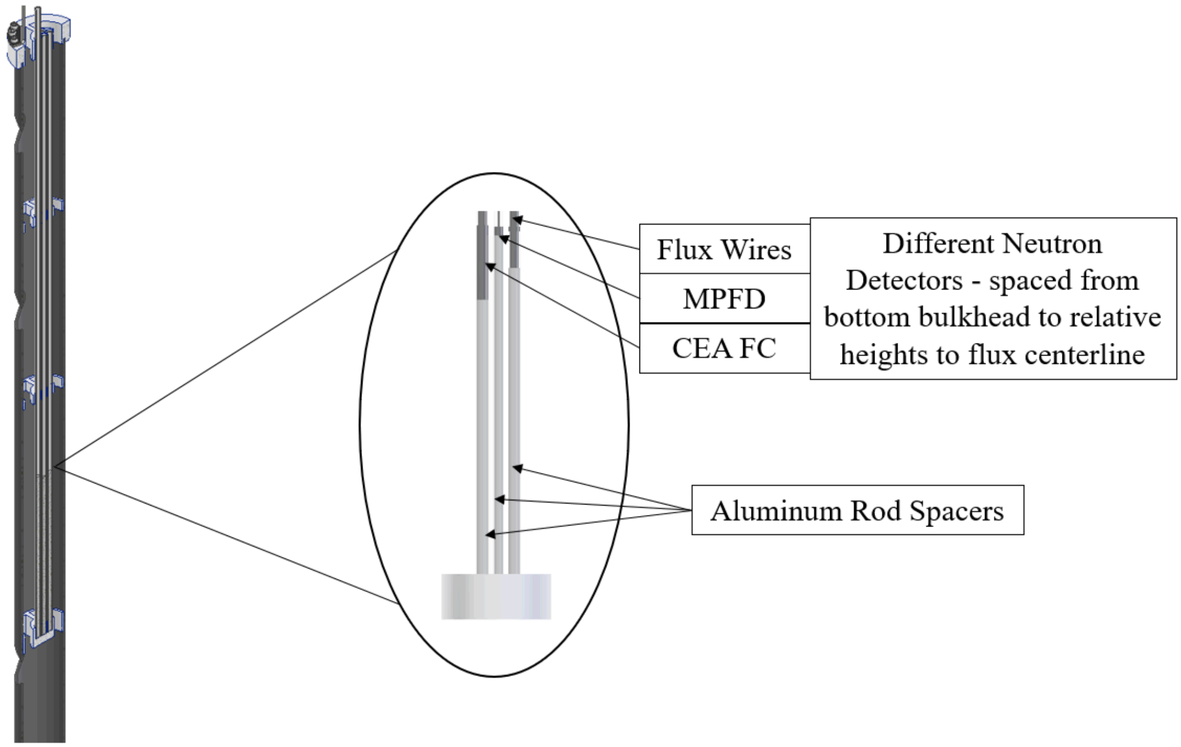


Figure 6. Positioning of Sensors within the Aluminum Tubes.

Fig. 6 shows details of the in-core assembly at a location near core mid-plane. Rather than spacing the flux sensors axially throughout the core, it has been decided that the sensors (and passive dosimetry) will be placed near core mid-plane so that all sensors and flux wires will see the same flux. Fig. 6 shows the internals of three different guide tubes with three different instruments. Because the sensors have different active lengths, the sensors will sit on aluminum spacers of specific custom heights to place the center of the sensor at, or near, core mid-plane. There may be some slight staggering of sensors to avoid one sensor shielding some of the neutron flux from another.

3.2 In-Core Configuration

Detector Layout		
#	Detector	Guide Tube ID (in)
1	MPFD, Th Type	0.240
2	MPFD, NU Type Mesytec	0.240
3	MPFD, NU Type MONACO	0.240
4	U238 CEA FC	0.315
5	Flux Wire Package	0.315
6	SPND, Rh Type Large	0.100
7	SPND, Rh Type Small	0.065
8	U235 CEA FC	0.118

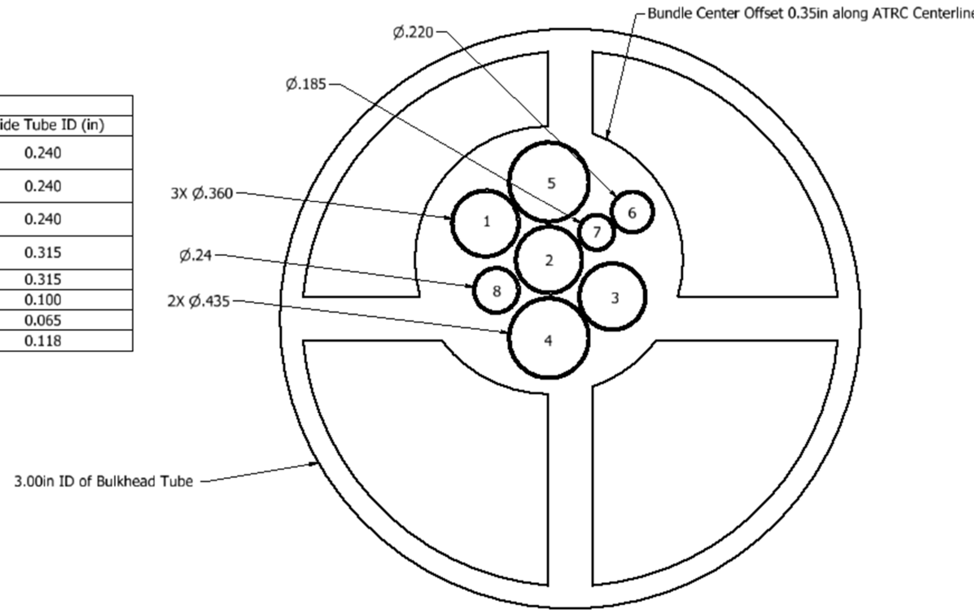


Figure7. Cross-Section of In-Core Assembly.

Fig. 7 shows a cross section of the instrumentation layout for the experiment. The center of the instrument bundle is offset 0.35in from the center of the I-position in order to mimic the future proposed position of the I-Loop in ATR. This offset is designed to maximize thermal flux when the pressurized water loop is installed in a medium I position. The water to metal ratio of this in-core arrangement is designed to match the future high pressure water loop installation.

3.3 Neutronics Evaluation

The ATRC I2 flux instrumentation experiment is slated for irradiation in the I-19 position of ATRC. This is a “Medium I” position. As shown in Table 2, the peak flux available in a medium I position with the ATR reactor operating at 110 MWth is 3.4 E13 n/cm^2-sec. The standard operating power of ATRC is 600 W. By simply scaling the flux by the ratio of the reactors’ thermal powers, a rough estimate of the peak flux available in ATRC’s I-19 position may be obtained.

$$\Phi_{th\ ATRC-I19} = \frac{600\ W}{110{,}000{,}000\ W} * 3.4E13 \frac{n}{cm * \sec^2} = 1.85E8 \frac{n}{cm * \sec^2}$$

As discussed in Section 3.1, a booster fuel element is planned to be installed in the I-1 position to boost the flux in I-19. Preliminary calculations indicate that this booster fuel will increase the thermal flux 20% – 30%. However, for conservatism, no credit is taken for this additional flux in the calculations that follow, or in the Section 3.5 signal strength estimates.

Positions		Diameter (in.)[a]	Thermal Flux (n/cm^2-s)[b]	Fast Flux (E>1 MeV) (n/cm^2-s)	Typical Gamma Heating W/g (SS)[c]
Northwest and Northeast Flux Traps		5.250	$4.4x10^{14}$	$2.2x10^{14}$	
Other Flux Traps		3.000[d]	$4.4x10^{14}$	$9.7x10^{13}$	
A-Positions					
	(A-1 - A-8)	1.590	$1.9x10^{14}$	$1.7x10^{14}$	8.8
	(A-9 - A-12)	0.659	$2.0x10^{14}$	$2.3x10^{14}$	8.8
*	**(A-13 - A-16)**	**0.500**	**$2.0x10^{14}$**	**$2.3x10^{14}$**	8.8
B-Positions					
*	**(B-1 - B-8)**[f]	**0.875**	**$2.5x10^{14}$**	**$8.1x10^{13}$**	6.4
*	**(B-9 - B-12)**	**1.500**	**$1.1x10^{14}$**	**$1.6x10^{13}$**	5.5
H-Positions					
	(H-1 - H-16)	0.625	$1.9x10^{14}$	$1.7x10^{14}$	8.4
I-Positions					
*	**Large (4)**	**5.000**	**$1.7x10^{13}$**	**$1.3x10^{12}$**	0.66
*	**Medium (16)**	**3.500**	**$3.4x10^{13}$**	**$1.3x10^{12}$**	
*	**Small (4)**	**1.500**	**$8.4x10^{13}$**	**$3.2x10^{12}$**	

Table 2. Approximate peak flux values for ATR capsule positions at 110 M_{th} reactor power [3]

Another way of expressing the relative power between the two reactors is that ATR typically runs at more than five orders of magnitude greater power than ATRC.

$$Log_{10}\left(\frac{110{,}000{,}000}{600}\right) = 5.26$$

Previous work conducted with similar neutron flux sensors utilized the flux traps [4], while the ATRC I2 experiment will be irradiated in a lower flux position. In order to estimate sensor response from this lower flux position, the ratio of the thermal flux between the medium I positions and the flux traps used previously is calculated below (fluxes taken from Table 2). Note that the fluxes used are for ATR rather than ATRC, however the ratio should be the same for both reactors, since ATRC is just a lower powered version of ATR.

$$\frac{\Phi_{th\,Med-I}}{\Phi_{th\,Flux\,Trap}} = \frac{3.4\,E+13}{4.4\,E+14} = .0773$$

For fast flux the ratio is

$$\frac{\Phi_{f\,Med-I}}{\Phi_{f\,Flux\,Trap}} = \frac{1.3\,E+12}{9.7\,E+13} = .0134.$$

3.4 Instrumentation Description

3.4.1 Fission Chambers

Fission chambers are a type of real-time neutron detector which function similar to ion chamber dosimeters. On the inside of a fission chamber is a fissile material deposited on the surface of an anode, typically surrounded with a noble gas, with the main chamber or sensor body acting as the cathode. Fission fragments from a neutron-induced reaction provide good signal in either pulsed, or direct current mode. Often, highly-enriched, over 90%, U235 is used for the coating on the anode in order to have high signal sensitivity for thermal neutrons. However, other deposits can be used, such as U238, Pu242, or Th232, providing data on varying neutron energy cutoffs - for instance using U238 for fast neutron flux.

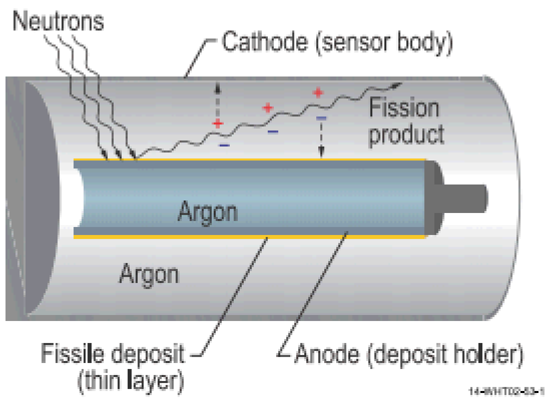


Figure 8. The design of a fission chamber (left) and a photo of a typical fission chamber (right).

Signal from fission chambers can be controlled via the material deposit - what isotope, at what refinement, with what mass of deposit, what surface area of deposit. However, fission chamber deposits are fundamentally sensitivity limited, especially in a volume limited space, because at greater deposit mass there is more self-shielding. For previous flux measurements in ATRC [6] fissile deposit masses were chosen for high sensitivity (from 10^3 to 10^5 cps). For the I2 ATRC instrumentation experiment these deposit masses will be the same - ~20µg 98.5% U235 for thermal flux CEA fission chamber and 1mg 99.96% for the U238 fast flux CEA chamber.

3.4.2 Self Powered Neutron Detectors

Self-Powered Neutron Detectors (SPNDs) function fundamentally different from fission chambers in that they are reliant on interactions of neutrons and atomic nuclei to produce a current which is proportional to the neutron flux. A typical SPND consists of an emitter which is a neutron absorbing material which undergoes beta decay, an insulator surrounding the emitter, an outer sheath, and a lead wire which the current travels down through a coaxial cable.

SPND characteristics of interest include size, material compatibility at high temperatures, sensitivity, response time, and burn-up rate. The emitter material must be a material with a respectively high neutron absorption cross-section which is stable at high temperatures. Response time depends on the average rate of decay, or the average time between absorption and the release of a beta particle. Emitter materials with low response time would be required for an experiment with short irradiation time. The SPND sensitivity and burnup relate to the cross section of the material - a material with a high neutron absorption cross-section will be highly sensitive, but will burn up faster than a material with a lower cross-section.

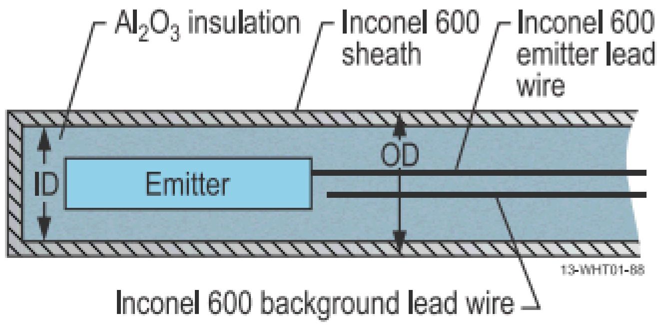


Figure 9. The design of a typical SPND (left) and an SPND with attached cable (right).

For the ATRC I2 flux instrumentation experiment, both sensitivity and burnup were considered in relation to the future uses of this instrumentation in ATR. Three material options were analyzed: vanadium, rhodium, and gadolinium. Vanadium is commonly used in SPNDs to detect PWR neutron flux due to its low burnup - but the sensitivity it low. Due to the low neutron flux in the medium I positions in ATRC, vanadium would not give enough sensitivity to collect reasonable signal, so rhodium and gadolinium were better candidates in terms of sensitivity. Rhodium was chosen as the emitter material due to its higher sensitivity with low burnup compared to gadolinium, with rhodium's response time being a delayed 4.34 minutes (See Figure). Gadolinium emitters wouldn't be used in future ATR experiments due to high burnup, so there was no experimental reason to use it in this ATRC experiment.

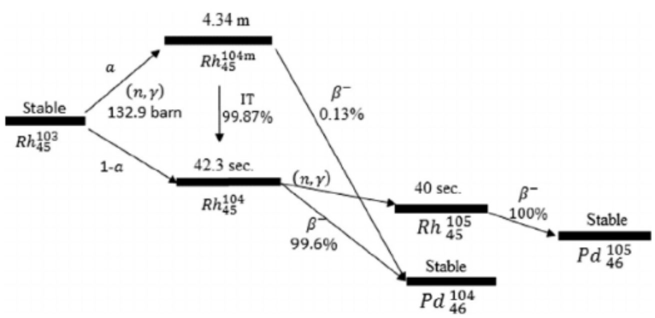


Figure 10. The decay scheme of rhodium with the response time before the first beta decay being 4.34 minutes.

3.4.3 MicroPocket Fission Detectors

Micro-Pocket Fission Detectors (MPFDs) were initially developed by the Kansas State University (KSU) and INL as extremely compact coaxial fission chambers capable of simultaneously measuring neutron flux in real-time at variable energy cutoffs. Similarly to fission chambers, MPFDs produce signal from the ionizing gas as a result of the interaction with a fission fragment created from the neutron induced fission of the deposit. MFPD's can also measure both fast and thermal flux based on the fissile deposit that it uses, and the sensitivity is also variable based on the mass of deposit present. The MPFD design developed at KSU has excellent sensitivity because the energy deposited by the fission products is much greater than background radiation interactions in the detector, allowing for better signal discrimination - this allows for the MPFD deposit to be smaller, and as a result the total size of the detector to be much smaller.

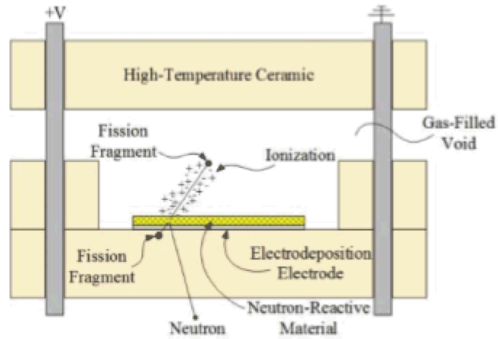


Figure 11. The internal wafer stack of an MPFD (left), and an internal view (right).

3.4.4 Flux Wires

Flux wires are the most commonly used passive dosimetry for local neutron flux. A flux wire is simply a material of known isotope and purity placed in a neutron field and activated for a known irradiation time. After irradiation, the induced activity of the material is measured and used to calculate the neutron flux that the material experienced. This measurement can only be performed after the irradiation is complete and the flux wire is removed from the reactor. This is done usually through the use of a calibrated gamma ray detector, commonly germanium semiconductor detectors.

The size of flux wires and foils are optimal for small materials test reactor (MTR) applications where there is no requirement for real-time in-situ neutron flux data. The wire package in the ATRC experiment will be used primarily as a control against the real-time detectors to be able to characterize their accuracy and for calibration. The materials used will be U235-aluminum for thermal neutron flux data and copper-1.55% gold for information on the ratio between thermal and fast neutron flux. In some experiments a cadmium cover is placed over the foils in order to further increase fast flux detection, but this will not be done for the I2 ATRC experiment.

3.5 Instrument Signal Strength Estimates

As discussed in Section 3.3, the power (and hence flux) of the ATR reactor is more than five orders of magnitude greater than ATRC. A natural question arises as to whether instruments selected for measurement of neutron flux in ATR will be sensitive enough for operation in ATRC. A previous flux measurement program conducted in ATRC [4], is helpful in addressing this question.

The previous real-time neutron flux measurement efforts encompassed a large range of ATRC reactor power levels. The objective of the ATRC I2 experiment is to measure neutron flux at only two power levels: approximately half power (300 W), and full power (600 W). Table 3 provides the approximate conversion between reactor power and Log N recorder values used to operate the reactor. In the figures that follow in subsequent sections the detector outputs are provided in terms of Log N recorder readings due to the ease of attaining and maintaining those levels for the ATRC operators.

Table 3. Power Conversion: Log N Recorder to Watts

Log N recorder reading	Approximate power (watts)
0.1	0.3
1	3
10	35
50	160
100	330
185	600
190	620

3.5.1 Fission Chambers

The two fission chambers slated for incorporation into the experiment are the same instruments as those used previously in ATRC. Both were supplied by CEA (see Table 1) [4]. One is a thermal neutron detector based on a U-235 deposit. The second is a fast neutron detector based on a U-238 deposit.

Fig. 12 is a normalized plot of the response of several fission chambers during the previous ATRC flux measurements. The response of the U-235 based fission chamber (labeled CEA U-235) was about 2,500,000 counts/min (see Table A-6 of [6]) with the reactor at half power (Log N reading of 100)[a]. Since the I-19 position has only about 7.7% of the thermal flux of the flux trap used for the previous work, we would expect a count rate of roughly 192,000 counts/minute, and so the instrument should function adequately in the I-19 position with its lower flux.

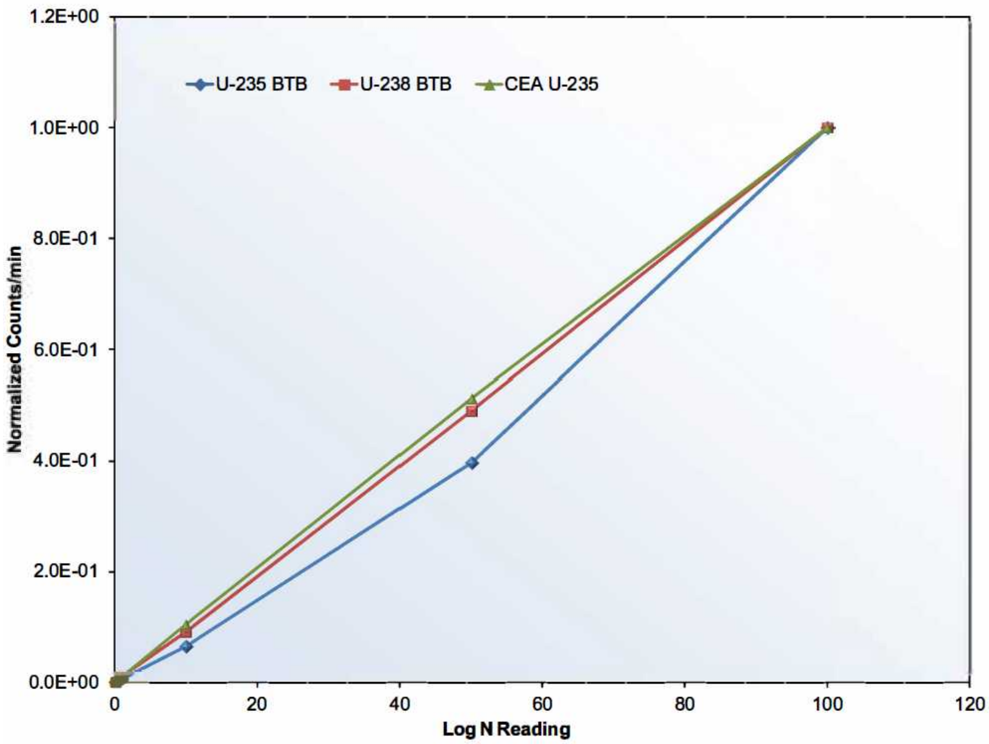


Figure 12. U-235 Fission Chamber Response During ATRC Testing Conducted in 2014.

[a] All figures in Section 3.5.1 and 3.5.2 were taken from [4].

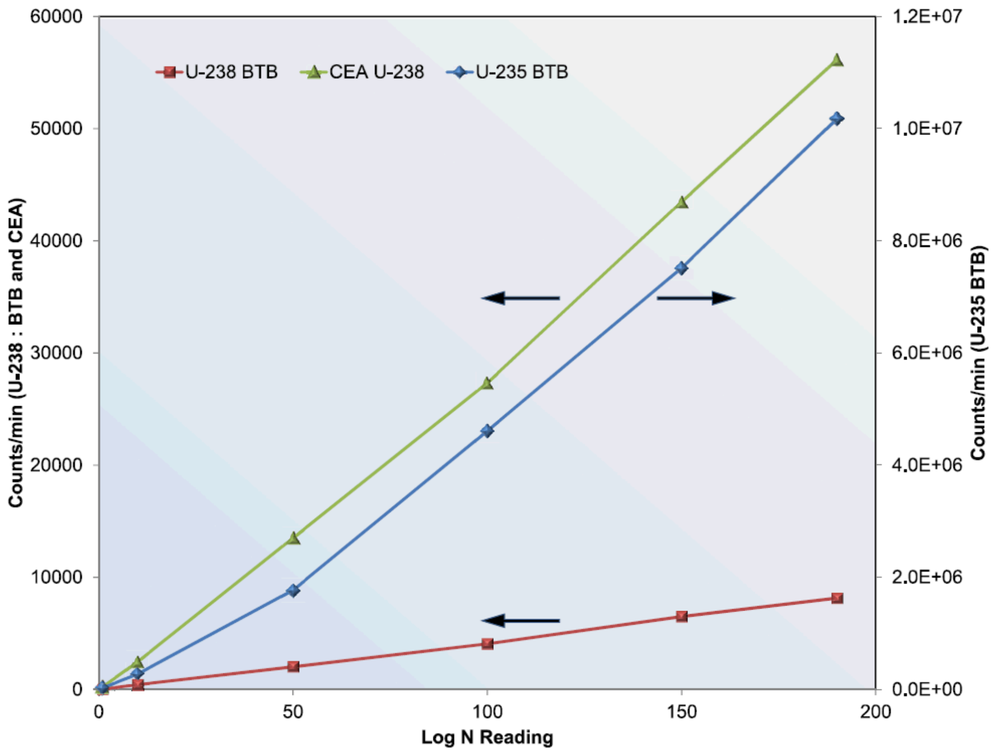
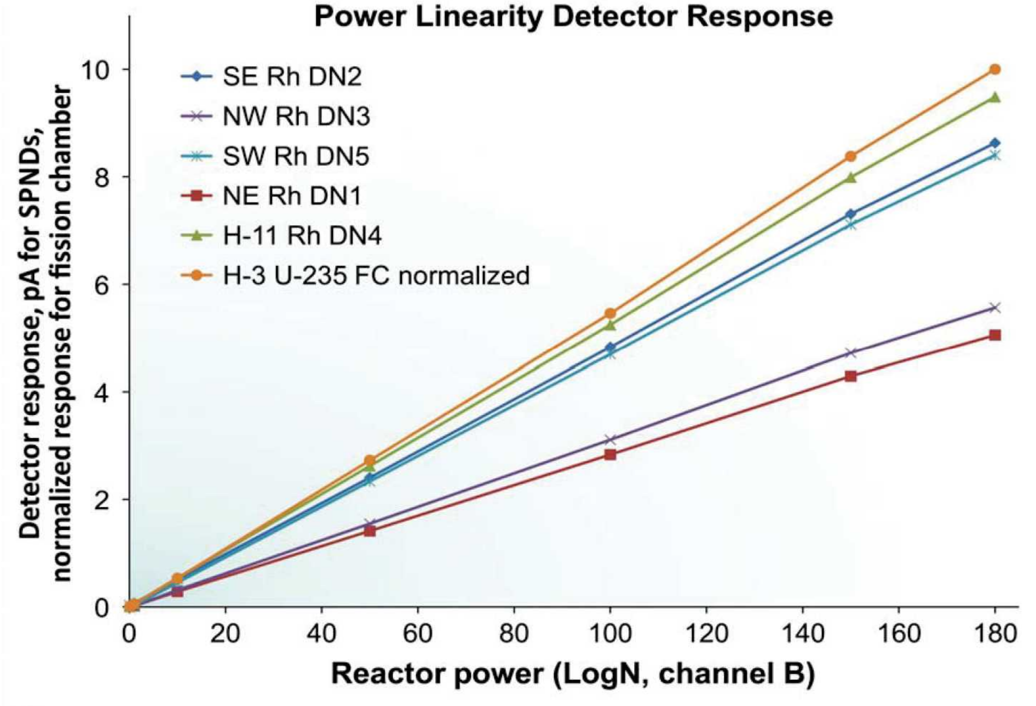


Figure 13. U-238 Fission Chamber Response During ATRC Testing Conducted in 2014.

Fig. 13 shows the response for the U-238 based fission chamber (labeled CEA U-238). Its response is several orders of magnitude greater than the U-235 based fission chamber. The count rate at half power (100 Log N Reading) was approximately 28,000 counts/minute. Using the fast flux ratio calculated in Section 3.3, we would expect a count rate of 28,000 x .0134 = 375 counts/minute with this instrument in the I-19 position, which should provide a good measurable signal.

3.5.2 Self Powered Neutron Detectors

Unlike the fission chambers, the SPNDs will be newly constructed instruments. However, these



instruments will be very similar to the Rh based SPNDs irradiated previously in ATRC.

Figure 14. Rh Based SPND Responses During ATRC Testing Conducted in 2014.

The signal strength of an SPND is generally proportional to the volume of the emitter. However, for high cross-section elements like Rh, some self-shielding is expected when the diameter exceeds 0.5 mm[b]. Table 4 compares the volumes of the old Rh based SPNDs, to the new Rh based SPNDs, and provides estimated currents for the two new Rh based SPNDs at half reactor power (300 watts, ~100 LogN).

Table 4. Estimated current of new SPND designs

Instrument	Emitter Dia (mm)	Emitter Length (mm)	Vol Ratio Compared to Old	Ratio of Thermal Flux Between I-19 and Flux Trap (see Section 3.3)	Estimated Current at 300 W ATRC Power (pA)
SPND Old	1.0	20	1.0	NA	4.7 (SW flux trap)
SPND New (large)	0.78	89	2.71	0.0773	0.98
SPND New (small)	0.48	89	1.03	0.0773	0.38

The current estimates provided in Table 4 were calculated by multiplying the current from the old SPND by the emitter volume ratio and the flux ratio. According to the estimate provided in Table 4, the new large SPND is expected to provide a current signal of about 1 pA with the reactor at 300 W, and the

[b] Based on a conversation between the author and Ludo Vermeeren, June 2019. Dr. Vermeeren works for SCK*CEN and has considerable experience with Rh SPNDs. He typically uses 0.5 mm emitter diameter Rh SPNDs to avoid self-shielding.

small SPND a signal less than half of that. Because the old SPND was of fairly large diameter, it may have experienced significant self-shielding. If this was the case, the new (smaller diameter) SPNDs may provide larger currents than estimated by Table 4, because they will experience less self-shielding. Even if the signals are marginally higher because of less self-shielding, the current levels will still be very low, and will be challenging to detect. The previous effort was able to detect signals of this magnitude, e.g., Fig. 14 shows data points at LogN 10, with associated current readings of <0.4 pA; so this offers a degree of encouragement that the signals from the new SPNDs will be detectable.

3.5.3 MicroPocket Fission Detectors

MFPDs were not part of the previous flux measurement effort that is referenced extensively herein. This instrument type has been under development at INL for about five years, and recent testing at the TREAT reactor [5] offers some insight into the signal strength that might be expected in ATRC I-19 at a reactor power of 600 W.

Fig. 15 is a plot of a reactor power transient conducted in the TREAT reactor in 2018. An estimate of the thermal flux is provided on the left-side Y-axis. Fig. 16 is a plot of the same TREAT reactor transient with an MFPD signal response on the left-side Y-axis

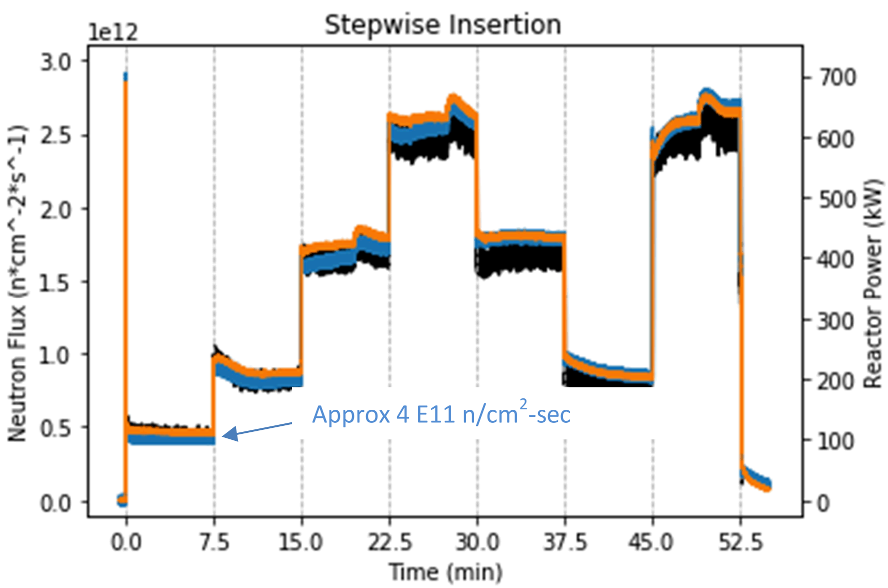


Figure 15. Neutron Flux Profile During TREAT Testing Conducted in 2018.

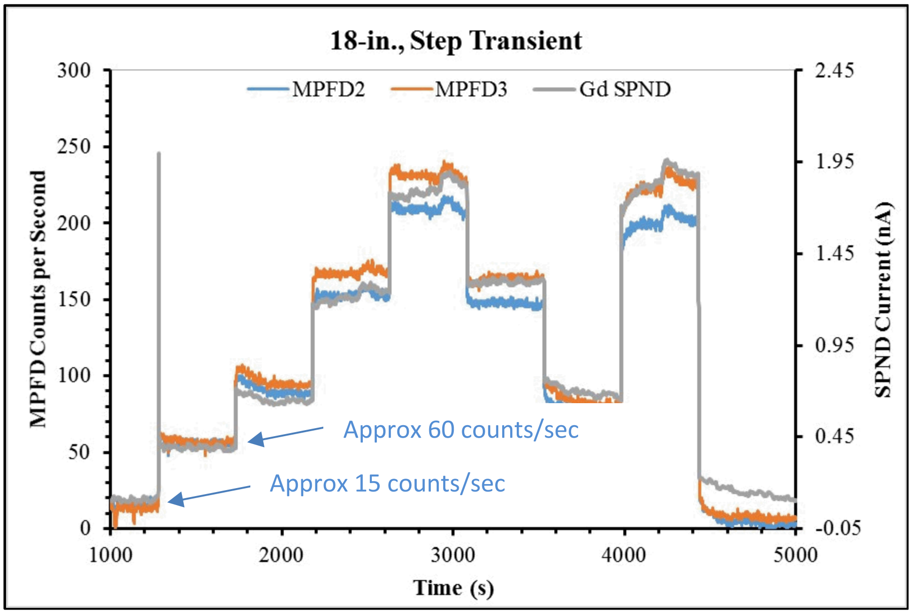


Figure 16. MPFD Response During TREAT Testing Conducted in 2018.

An estimate for MFPD signal response in ATRC can be made by multiplying the flux ratio by the MFPD signal response at one of the plateaus on this TREAT transient curve. We will use the second plateau (60 counts/sec) as shown in Fig. 16. (This corresponds to the left-most plateau in Fig. 15.) The expected flux in the ATRC I-19 position with the reactor at full power (600 W) is approximately 1.8 E8 n/cm^2-sec (see Section 3.3). The flux ratio is therefore

$$\frac{3.4\ E{+}08}{4.0\ E{+}11} = .00085$$

Multiplying this flux ratio by the MPFD signal obtained during the TREAT transient we obtain

.00085*60 counts/sec = .051 counts/sec

The counts/sec measure of the MPFD signal was not actually a digital signal. The MPFD data processor was in current mode during these measurements, but the scale read in counts/sec. A reading of 15 counts/sec was near bottom of the range of the data processor, i.e., currents much below this value would likely not be distinguishable from background noise. Therefore, it appears that an MPFD configured similarly to that used in the TREAT experiments would not produce sufficient signal for the ATRC I2 experiment. To obtain signals comparable to the bottom end of the readable range of the TREAT experiments, the fissile deposit mass would need to be increased or the counting time could be extended by a factor of about

$$\frac{15\ counts/sec}{0.051\ counts/sec} = 294$$

Note that this calculation was performed for an ATRC reactor power of 600 W. To obtain a meaningful signal at 300 W, the fissile deposit would need to be about twice as large or the integration time should be twice as long.

4. SUMMARY

1. The I2 ATRC Instrumentation Experiment is the second in a planned three-part series of experiments, whose aim is to develop and demonstrate a set of real-time neutron flux sensors suitable for deployment in ATR experiments.
2. A conceptual design has been prepared, which consists of an in-core instrumentation set connected via a cable bundle to a data acquisition system. The data acquisition system consists of several signal processors mounted on a mobile cart located a few feet from the canal parapet on the west side of ATRC
3. The real-time neutron flux detection set consists of: fission chambers, self-powered neutron detectors, and micro-pocket fission detectors. This active set of instrumentation is complemented by a passive set of flux wires, which will be used to confirm the (integrated) measurements of the active sensors.
4. Calculations performed in support of this conceptual design indicate that the expected signals from the fission chambers and self-powered neutron detectors will be weak, but within the range of previous ATRC measurements using such instruments. However, signals from the current generation of micro-pocket fission detectors will likely be too small to detect. Larger deposits of fissile material can likely overcome this deficiency in the MPFDs.

5. REFERENCES

1. DP-150, "Materials and Instruments Modular Irradiation Capability (MIMIC)-N in TREAT Data Package", Rev. 1, June 2019.
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3. INL/EXT-08-14709, "ATR Advanced Test Reactor National Scientific User Facility Users' Guide", 2009.
4. INL/EXT-14-31830, "Initial Back-to-Back Fission Chamber Testing in ATRC", June 2014.
5. INL/EXT-18-51613, "FY18 Report for Instrumentation Development for the Transient Testing Program", September 2018.
6. INL/EXT-13-29896, "ATRC Neutron Detector Testing Quick Look Report", August 2013.

Appendix A – Underwater High Pressure Connector

In tandem with the ATRC neutron flux characterization experiment will be the development of an underwater high pressure electrical connector. From a design sourced from the Halden test reactor, this electrical connector would provide a dry pin-socket connection under PWR conditions. This will allow for the easier creation of sensor cabling due to the ability to connect just 4 ft of cable to the remaining 20ft cable length to get out of water and into a data acquisition system. This is especially important when the manufacturing of long lengths of sensors may be difficult.

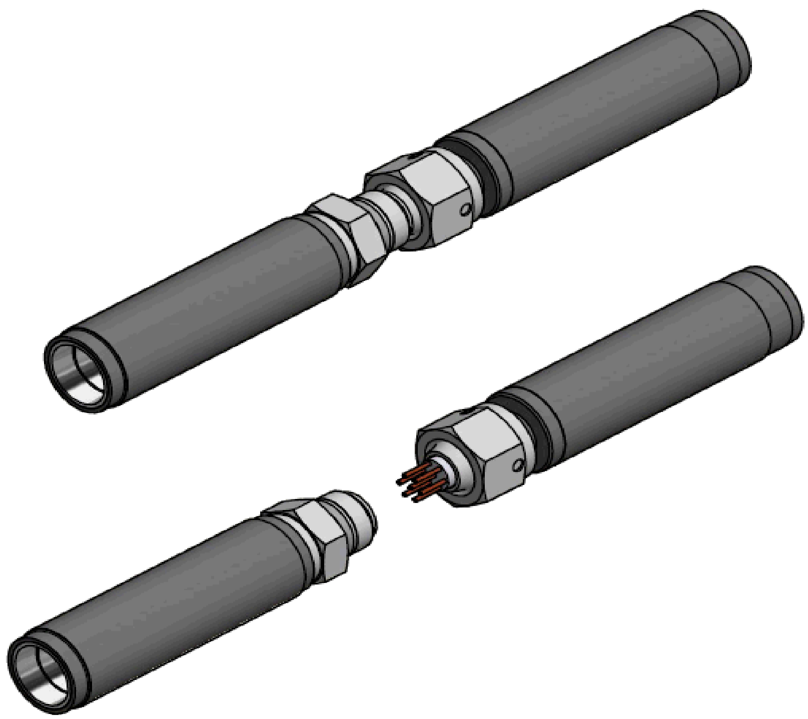

Figure A.1. High-pressure underwater connector