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Initial Back-to-Back Fission Chamber Testing in ATRC

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ABSTRACT

Development and testing of in-pile, real-time neutron sensors for use in Materials Test Reactor experiments is an ongoing project at Idaho National Laboratory. The Advanced Test Reactor National Scientific User Facility has sponsored a series of projects to evaluate neutron detector options in the Advanced Test Reactor Critical Facility (ATRC). Special hardware was designed and fabricated to enable testing of the detectors in the ATRC. Initial testing of Self-Powered Neutron Detectors and miniature fission chambers produced promising results. Follow-on testing required more experiment hardware to be developed. The follow-on testing used a Back-to-Back fission chamber with the intent to provide calibration data, and a means of measuring spectral indices. As indicated within this document, this is the first time in decades that BTB fission chambers have been used in INL facilities. Results from these fission chamber measurements provide a baseline reference for future measurements with Back-to-Back fission chambers.

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ACRONYMS

ANL	Argonne National Laboratory
ATR	Advanced Test Reactor
ATRC	Advanced Test Reactor Critical Facility
ATR-LEP	Advanced Test Reactor Life Extension Project
ATR-NSUF	Advanced Test Reactor National Scientific User Facility
BTB	Back-to-Back
CEA	French Alternative Energies and Atomic Energy Commission
CNEA	National Atomic Energy Commission of Argentina
EGTs	Experiment Guide Tubes
HVPS	High Voltage Power Supply
INL	Idaho National Laboratory
ISU	Idaho State University
LIPT	Large In-Pile Tube
LLD	Lower Level Discriminator
MCA	Multi-Channel Analyzer
MTR	Materials Test Reactor
NI	Nuclear Instrumentation
NRAD	Neutron RADiography
OSCCs	Outer Shim Control Cylinders
ROI	Region of Interest
SIPT	Standard In-Pile Tube
SPND	Self-Powered Neutron Detectors
TREAT	Transient REActor Test Facility
ZPPR	Zero Power Physics Reactor

1. INTRODUCTION

The Advanced Test Reactor (ATR) and the ATR Critical Facility (ATRC) at Idaho National Laboratory (INL) lack real-time methods for detecting neutron flux and fission reaction rate for irradiation experiments. An ATR National Scientific User Facility (ATR-NSUF) project was initiated to evaluate options for measuring neutron flux and fission reaction rates for irradiation experiments in real-time.[1] This project was completed in FY13.[2] Follow-on funding from the ATR-NSUF was provided for further evaluation of neutron detectors in the ATRC.

The purpose of this project is to compare the response of back-to-back (BTB) fission chambers, developed by Argonne National Laboratory (ANL), with other neutron detectors in the ATRC. The BTB fission chambers used in this project are legacy detectors that were developed in the Zero Power Physics Reactor (ZPPR) program.[3] BTB fission chambers have not been used for decades at INL. BTB fission chambers have the capability to measure the fission reaction rate with a high degree of accuracy. Using the BTB fission chambers, the fission reaction rate can be compared to signals from other detectors in the same location to characterize the sensitivity of those detectors. In this project, data were obtained as the BTB fission chambers were operating in the ATRC with miniature fission chambers also operating in close proximity to the BTB fission chambers. These tests are an important step in regaining the capability to characterize neutron detectors using BTB fission chambers.

This report summarizes prior ATR-NSUF neutron detector tests in ATRC and the development of new equipment required to perform tests with the BTB fission chamber. A brief description of the ATRC and the experimental setup used for testing with the BTB fission chambers is also provided. Results from the tests with the BTB fission chamber in the ATRC are presented along with conclusions derived from the results.

2. BACKGROUND

2.1. Facility Overview

2.1.1. 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. 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.

There are several design features of the ATR and ATRC that optimize experimental capabilities for a wide range of experiments.[4] These features include: a serpentine fuel arrangement, nine flux traps, and rotating outer shim control cylinders (OSCCs) with hafnium plates for neutron absorption. The OSCCs were designed to maintain axial flux symmetry in the fuel and experiments. These features allow the ATR to provide high thermal-neutron fluxes for irradiation of experiments. The serpentine fuel arrangement and rotational capability of the OSCCs allow the ATR to provide different irradiation conditions for experiments in different core locations within the same cycle. This ability to provide regional power control is what makes the ATR such a versatile reactor.

There is no regional online power measurement in the ATRC core as there is in the ATR. Prior neutron detector testing has primarily occurred in the N-16 positions of the ATRC.[2,5] These positions are not typically considered experiment positions. The ATR uses the N-16 system to measure power in real-time and to determine the power imbalance in different regions (lobes) of the core. The ATRC does not use an N-16 system. Instead, the N-16 positions in the ATRC reflector have surrogate hardware to represent the flow tubes that are in ATR. The surrogate hardware can easily be removed from the ATRC core and detectors can be inserted in these locations with specialized hardware developed for this purpose. There are ten N-16 positions. Eight of these positions are located in the reflector outside of the fuel annulus. The other two N-16 positions are located in the H-positions within the Center Flux Trap. The H-positions form a ring around the Small Irradiation Housing Assembly within the center flux trap. The H-positions that have N-16 hardware are the H-3 and H-11 positions. The N-16 positions are highlighted and labeled in Figure 2-1.

The NW lobe of the ATRC has a Large In-pile Tube (LIPT) experiment facility. This allows larger diameter (less than 10.16 cm) experiments to be inserted in this location than the Standard In-Pile Tube (SIPT) locations can handle (less than 5.08 cm dia.). A diagram of the ATRC is provided in Figure 2-1.

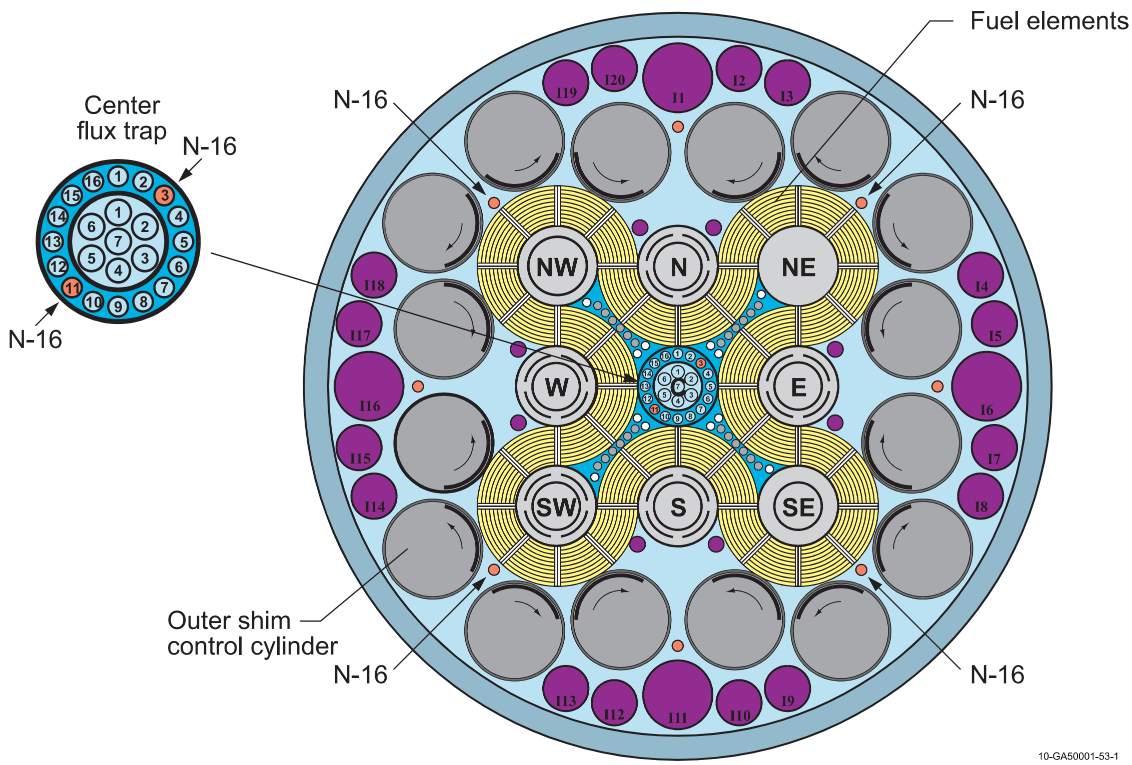

Figure 2-1. Advance Test Reactor Critical Facility core cross section

2.2. Description of Detectors

As part of an on-going ATR NSUF international cooperation, a selection of unique flux detectors were investigated.[1-3] The French Alternative Energies and Atomic Energy Commission (CEA) provided INL three miniature fission chambers (one for detecting fast flux and two for detecting thermal flux) with associated electronics for assessment. In addition, INL has access to an inventory of specialized Self-Powered Neutron Detectors (SPNDs) with a range of response times and BTB fission chambers from prior research conducted at the Transient REActor Test Facility (TREAT) and Neutron RADiography (NRAD) reactors. Also, SPNDs from the National Atomic Energy Commission of Argentina (CNEA) were provided in connection with the INL effort to upgrade ATR computational methods and V&V protocols that are underway as part of the ATR Life Extension Project (LEP). The SPNDs, CEA fission chambers, and CNEA SPNDs were all used extensively in the testing described in section 2.3.1. Table 2-1 contains a list of the detectors and their properties.

2.2.1. CEA Fission Chambers

Fission chambers, which are ion chambers with a fissionable material deposit on the inner anode, offer a method for real-time flux measurement. When the neutrons interact with the fissionable deposit, the fission fragments are emitted in the electric field within the chamber (see Figure 2-2). The fission fragments provide a very large pulse from the neutron-induced reaction. Highly-enriched ^{235}U or ^{239}Pu are commonly used for the fissionable deposit, which will make the detector sensitive to thermal neutrons. However, other deposits, such as ^{238}U, ^{242}Pu, or ^{232}Th, can be used to provide a higher neutron energy cutoff.

Table 2-1. Characteristics of Evaluated Neutron Detectors

Detector	**Composition, Geometry, and Mass**			
CEA Miniature Fission Chambers	Fissile Deposit	Anode/Fill Gas	Cathode / Fill Gas	Extension Cable
Miniature Thermal Fission Chamber	Mass 30µg (deposit on anode) U-235 98.5 % U-234 0.063% U-236 0.038% U-238 1.409%	Material: SS304L (impurities of Co 0.02%) ID: 1.6 mm OD: 2 mm Length: 14 mm Fill Gas: Argon+ 4% N_2 Pressure : 5 bars	Material: SS347(impuritiess of Co 0.2%) ID: 2.5 mm OD: 3 mm Length: 33 mm except cable Fill Gas: Argon+ 4% N_2	Mineral cable (1CCAc22Si50 Ohms) OD: 2.2 mm Length: 10 mm Materials Sheath: SS304L Insulation: SiO2 (>99.5%) Wires: Copper (impurities of Zirconium 0.19%) Shield: Copper
Miniature Fast Fission Chamber	Mass: 1000 µg (deposit on cathode) U-238 : 99.964% U-235 : 0.0354% U-234 : 0.0003%	Material: SS316L ID : / OD: 1 mm Length: 51.5 mm Fill Gas: Argon Pressure: 9 bars	Material: SS316L ID: 6.3 mm OD: 8 mm Length: 33.5 mm Fill Gas: Argon Pressure: 9 bars	Organic cable RG58BU OD: 6.15 mm ; length 10 m Materials Sheath: Polyvinyl Chloride Insulation: polyethylene (PE) Wires: copper clad steel (CCS)
Back-to-Back Fission Chamber	Main Foil Isotope: Mass (µg) U-235 : 119.7 µg U-238: 130.27 µg Pu-239: 106.77 µg	Material: SS316 OD: 3.56 cm Fill Gas: P-10	Material: SS316 OD: 3.56 cm Fill Gas: P-10	Rg-174U Coax Cable Materials Sheath: Polyvinyl Chloride Insulation: polyethylene (PE) Wires: copper /steel
SPNDs	Emitter	Lead Wire(s)	Insulation	Sheath (Collector)
Hafnium Manufacturer: B&W Fuel Sensitivity 4.7e-21 A/nv	Hafnium (minimum 97.5% with up to 2.5% Zr) – fast response Diameter: 0.4572 mm Length: ~ 400 mm (coiled to reduce length) Mass: 0.873 g	Number: Two Material: Inconel 600 Diameter: 0.203 mm	Al_2O_3 Purity: 99.65% Compaction: ~70%	Inconel 600 ID: 0.904 mm OD: 1.372 mm
Gadolinium Manufacturer: B&W Fuel Sensitivity 5.0e-22A/nv	Gadolinium (99.7%) – fast response Diameter: 0.559 mm Length: ~25 mm Mass: 0.0508 g	Number: Two Material: Inconel 600 Diameter: 0.229 mm	Al_2O_3 Purity: 99.65% Compaction: ~70% ID: 0.559 mm	Inconel 600 ID: 1.017 mm OD: 1.575mm
Rhodium	Rhodium Diameter – 1 mm Length – 20 mm	Cu	Acrylic ID: 1.0 mm OD: 1.5 mm Length: 20 mm	SS-304 ID: 1.5 mm OD: 1.9 mm Length: 100 mm

Miniature fission chambers are typically operated in pulse mode using current preamplifier electronics. The mass of the Uranium coatings were chosen in order to provide a high fission rate in ATRC flux (from 10^3 to 10^5 cps). To protect these fission chambers and to preclude any leakage from fission chamber com-

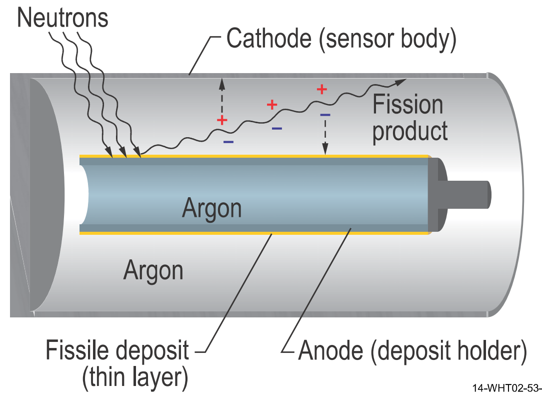

Figure 2-2. Miniature fission chamber and schematic showing operation

ponents into the ATRC coolant, chambers are inserted into the core in Lucite tubes and specialized positioning hardware (see section 2.3.2).

2.2.2. SPNDs

SPNDs have been used effectively as in-core flux monitors for decades in commercial nuclear power reactors and materials test reactors (MTRs) world-wide. SPNDs rely on interactions between neutrons and atomic nuclei to produce a current which is proportional to the neutron flux.

A typical SPND consists of a coaxial cable containing an inner electrode (the emitter), which is surrounded by insulation and an outer electrode (the collector). In an integral SPND, the lead cable and detector are mated directly to each other, the insulation of both sections are identical, and the collector of the detector section is also the outer sheath of the lead cable section (see Figure 2-3). Modular SPND assemblies are made from separate detector and lead cable sections. Typically, SPND characteristics of interest include size, material compatibility at high temperatures, sensitivity, response time, and burn-up rate.

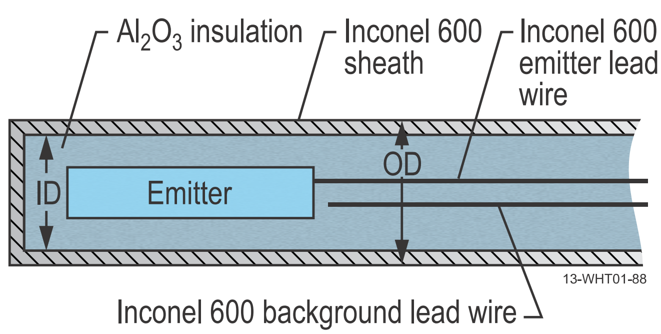

Figure 2-3. Typical SPND design

Characteristics of SPNDs evaluated in this project are listed in Table 2-1. SPNDs were also placed in Lucite tubes to prevent any unwanted leakage of component materials (if they are not leak-tight) and to reduce unwanted noise from the SPND cables being in contact with metal surfaces. SPNDs were inserted into the ATRC N-16 positions using specialized positioning hardware (see Section 2.3.2).

2.2.3. BTB Fission Chambers

BTB fission chambers, which are often called 2π fission chambers, provide an accurate measure of fission reaction rates. For the ATRC evaluations, BTB chambers, developed in the Zero Power Physics Reactor (ZPPR) programs were used.[3] As shown in Figure 2-4, the ZPPR chambers are bisected hollow aluminum spheres, with stainless steel collector plates attached to the inside spherical surface of each half of the detector. Two stainless steel foils, with fissionable material deposits, are positioned such that the uncoated sides are in contact. These foils act as the center divider inside the BTB chamber volume, and are kept at electrical circuit common.

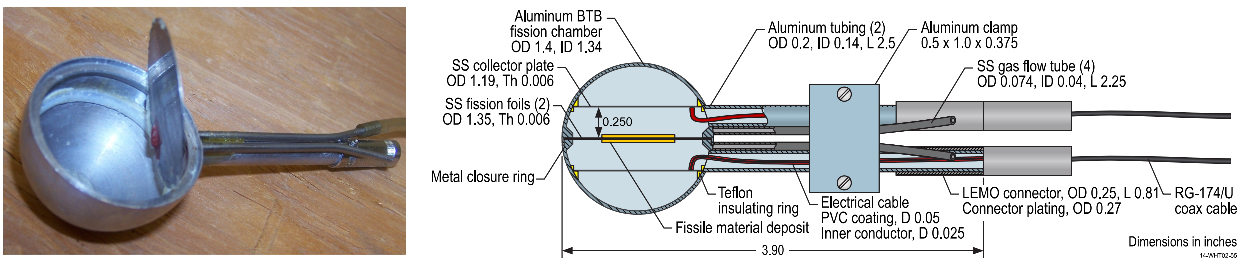

Figure 2-4. BTB fission chamber

Each spherical half has its own purge gas (P-10, a mixture of argon and methane) supply and exhaust lines, and coaxial cable signal leads. These chambers are used for accurate measurements of absolute fission reaction rates. Chambers of this type are called 2π because they are designed to count almost all fission fragments emitting from a thin deposit in a 2π solid angle.

The counting gas continuously flows through these fission chambers. This allows a chamber to be built that can be easily opened and deposits changed without worrying about impurities due to poor seals. There are two obvious uses for this capability. First, one can cross-calibrated an unknown deposit to a known deposit. Second, measured reaction rate ratios (spectral indices) are very accurate since the measurements of BTB deposits are made at precisely the same time. The disadvantage of this type of chamber is that it is limited in the miniaturization possible. It is necessary to register all of the energy deposited by the fission fragments in order to ensure a good spectrum; and at atmospheric pressure, the range of the fission fragments is relatively long. This requires a certain volume in the counting gas, which translates into a minimum fission chamber radius.

2.3. Project Overview

2.3.1. Summary of Prior Tests

An ATR-NSUF project was initiated in FY10 to evaluate neutron detectors in the ATRC.[1] The project was awarded to Idaho State University (ISU) in collaboration with CEA and INL. This project originally had two objectives. The first objective of the project was to investigate the feasibility of using neutron sensors to provide real-time flux and fission reaction rate data for experiments in, and operation of, the ATR and ATRC. The second objective was to obtain neutron spectrum and fission rate data for validating improved reactor physics calculation methods under development for the ATR. This second objective was performed as a series of six experiments funded through the ATR-LEP. This set of six experiments are entitled the Activation Foil Measurement (AFM 1-6) tests. The results of these tests have been documented in ATR LEP reports and other publications.[6-9]

The ATR-NSUF detector testing project was initiated in FY10. However, due to reliability issues with ATRC control systems, only a few hours of testing was completed at that time. In FY13, testing was resumed in the ATRC in order to complete the ATR-NSUF ISU project. Testing in FY13 included performing axial measurements of the flux in the ATRC with self-powered neutron detectors (SPNDs) and fission chambers provided by CEA. Data was also obtained for multiple power levels to determine detector sensitivity and the capability to measure power level variations. The results of the testing in FY13 were documented in a report and a journal article.[2,5]

2.3.2. Hardware and Software Development

To complete the ATR-NSUF ISU project objectives, INL designed and fabricated specific hardware and software to insert the experiments and detectors in the ATRC. Experiment Guide Tubes (EGTs) were developed to insert sensors into the ATRC in the N-16 locations. These locations correspond to locations in the ATR that are used for power measurement. The EGTs were fabricated to allow detectors to be inserted into these positions using Lucite tubes.

The EGTs are primarily fabricated from aluminum to minimize their weight. However, selected components, such as the guide tube shown in Figure 2-5 are made from stainless steel 304 for additional robustness. As illustrated in Figure 2-5, the six EGTs mechanically position detectors at a specified vertical location in four of the N-16 exterior positions and two Center Flux Trap N-16 positions. The EGTs are supported above the reactor by attaching to the reactor control bridge.

The EGTs have motors that move the Lucite tubes vertically in and out of the N-16 positions. The EGT motors are controlled by LabView software. This allows the tubes to be moved either individually or simultaneously. The sensors can measure the local neutron flux and provide a three-dimensional measurement of the vertical neutron flux profile in the N-16 positions. The LabView software also reads and records the signals from the SPNDs.

2.4. BTB Test Development

2.4.1. BTB Test Assembly

Hardware was designed and fabricated to allow the BTB fission chambers to be inserted in the NW LIPT of the ATRC. This hardware consists of an outer cylinder that is bisected to allow insertion and removal of an inner detector holder [Figure 2-6]. Two inner detector holders were designed and fabricated. One of the inner-holders will contain the BTB fission chamber, and it also has two positions for other detectors (fission chambers or SPNDs) to be co-located with the BTB fission chamber. The alternative inner-holder (tri-holder) was designed with three positions allowing multiple variations of fission chambers and SPNDs to be co-located in the test assembly.

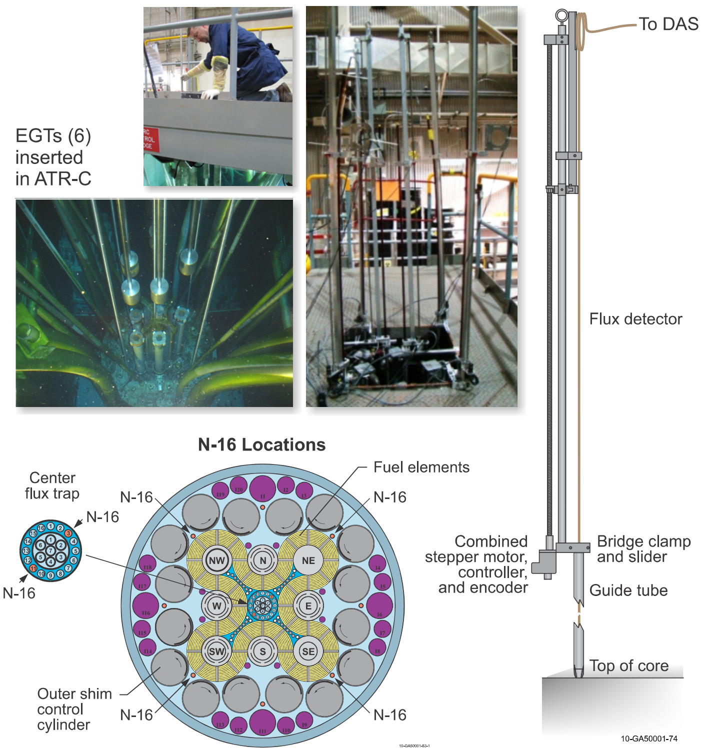

Figure 2-5. Experiment Guide Tubes in ATRC

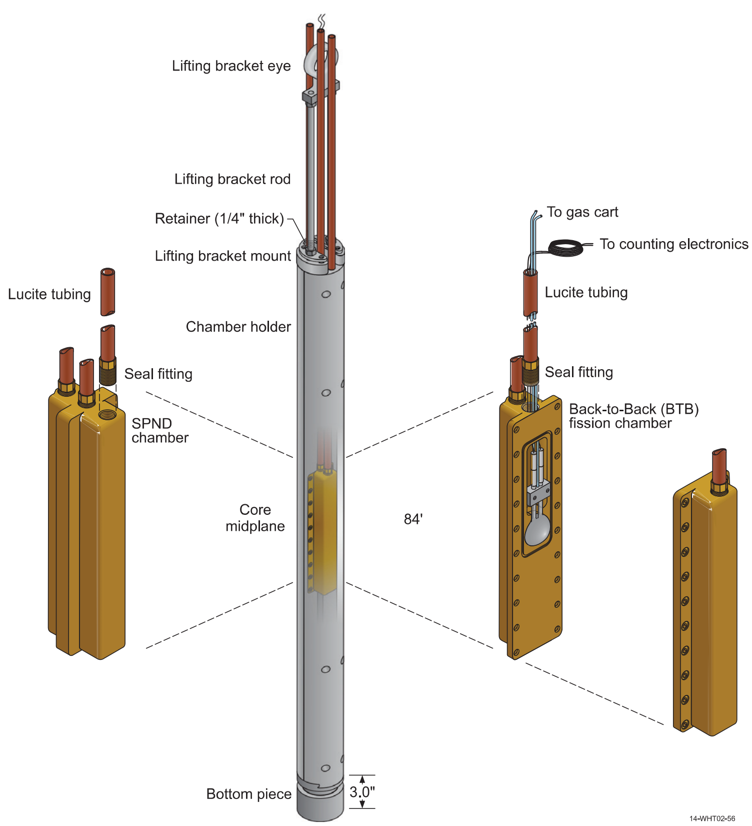

Figure 2-6. BTB test assembly

The detectors are loaded in the inner holder, which is then placed in the outer cylinder holder. The outer cylinder holder is bolted together and inserted into the NW LIPT of the ATRC for testing.

2.4.2. BTB Gas Supply Cart

It was also necessary to develop a gas supply cart to hold the P-10 gas bottle and the associated flow-meters, pressure gauges, relief valves, and piping to monitor the gas flow. A cart and bottle were acquired along with all of the flow-meters, gauges, and relief valves. A particle filter and a carbon filter were included on the cart to provide extra conservatism against a release of radioactive material in the exiting gas. Figure 2-7 contains a diagram of the BTB gas supply cart and associated components.

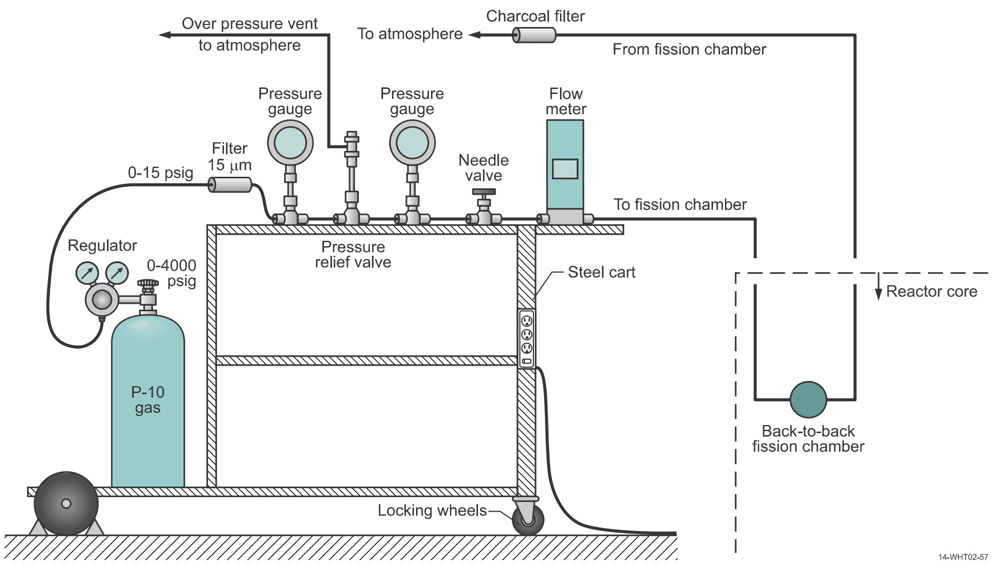

Figure 2-7. BTB gas supply system

3. EXPERIMENTAL SETUP

3.1. ATRC Setup

3.1.1. EGT Setup and BTB Test Assembly and Insertion

Experimental testing and operation of the ATRC are governed by a test plan. Test Plan, TP-2-13 Rev. 2, was written to perform BTB fission chamber testing.[10] This plan provides an outline of the test sequence. It also provides the intermediary steps necessary to perform the desired testing. The outline in the test plan includes steps that dictate when core changes, reactor startup, and reactor shutdowns will occur in the test sequence. Other specific guidance can be found in the test plan regarding core power levels and shim positions. In order to operate the reactor at a given power level, the ATRC console has a Log N channel recorder that is used by the operators to determine the power of the reactor. Calibration curves provide a correlation between the Log N recorder values and the power of the reactor in watts. The power levels are referenced based on the Log N recorder reading due to the ease of attaining and maintaining those levels for the ATRC operators. Table 3-1 is a conversion table of the powers that were used in this series of tests. Table 3-1 contains a list of the powers used in this series of tests, converted from the Log N recorder reading to an approximate value in watts.

Table 3-1. 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

In order to perform the desired tests, the core has to be reconfigured from its standard loading to accommodate insertion of the test hardware. These steps are outlined in the test plan for this experiment.[10] The N-16 surrogate hardware and the NW LIPT Filler were removed by ATRC operators to allow the test hardware to be inserted in the reactor. The EGTs and BTB test assembly were inserted into the ATRC core in the designated test positions.

The EGTs were used in this set of tests in the same manner they were used in prior NSUF detector tests in ATRC. The prior NSUF detector tests are described in Section 2.3.1, and also in more detail in Reference 2. The EGTs were mounted on the control bridge, and the CNEA SPNDs were inserted into the Lucite tubes. The Lucite tubes can be inserted into the reactor core to position the SPNDs at any desired axial location within the N-16 positions. The SPNDs were used to monitor the core power distribution and to perform axial profile measurements.

The BTB fission chamber was loaded in the inner holder, and the gas lines and signal cables were fed through the Lucite tubes. The outer cylinder was secured over the inner holder. Then, the rest of the BTB test assembly hardware was bolted to the outer cylinder. The BTB test assembly was designed to include standard ATRC test shrouding and also the standard bottom piece that is typically used for LIPT tests. The BTB test assembly was loaded in the NW LIPT. Figure 3-1 highlights the position of the detectors in the ATRC core. Once the EGTs and the BTB test assembly were loaded in the reactor, the detectors are connected to the data acquisition system and gas supply system. Figure 3-2 provides some pictures of the assembly process.

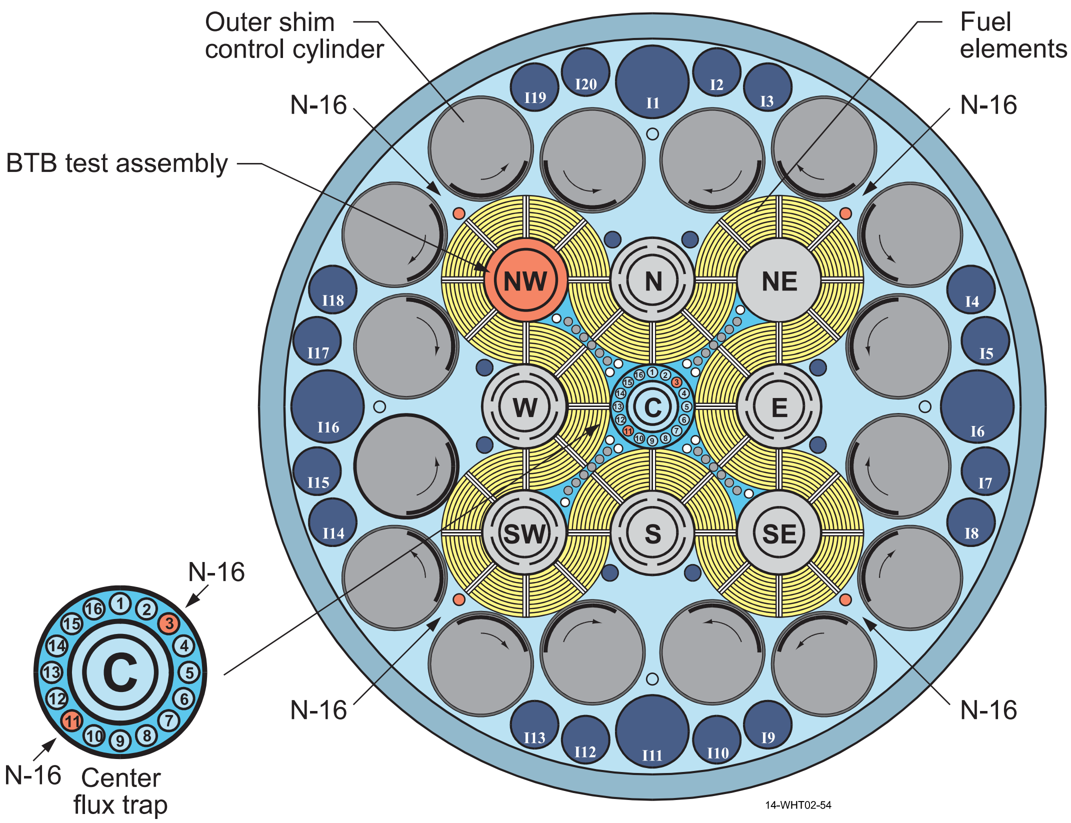

Figure 3-1. ATRC core cross section with experiment locations highlighted in orange

3.2. BTB System Setup

3.2.1. Gas Supply System

The gas supply lines were connected to the BTB fission chamber after the gas supply tubes were fed through the Lucite tubes and prior to insertion of the BTB fission chamber in the inner holder. Once the BTB test assembly was assembled and inserted into the reactor core, the gas supply lines were connected

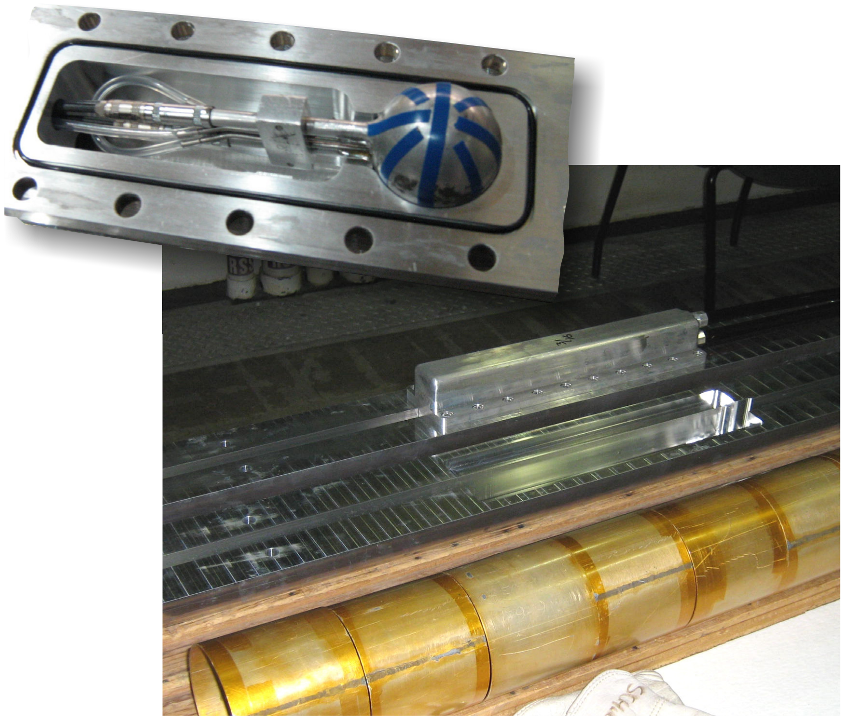

Figure 3-2. Assembly of the BTB fission chamber hardware

to the supply system. A bottle of P-10 gas supplied the necessary purge gas to the BTB fission chamber for proper operation. The gas supply system has valves and flow-meters that enable the user to establish the necessary flow rate for the BTB fission chamber (see Figure 2-7). A low flow rate, 5-10 sccm, is required for operation of the BTB fission chamber. Along with the flow-meter, a bubble test was used to verify flow of the P-10 gas. The end of a gas line was put in water to perform the bubble test. Approximately one bubble per second was used as the criteria to verify the system was providing the proper flow to the detector. This corresponded to an approximately 5 sccm reading on the flow-meter.

3.2.2. Data Acquisition Setup

The data acquisition system for the fission chambers is composed of Ortec Nuclear Instrumentation (NI) hardware. Table 3-2 lists the hardware used for the these tests. The NI hardware includes one high voltage power supply (HVPS), 2 preamplifiers, 2 amplifiers, and 2 Easy Multi-Channel Analyzers (MCAs). The high voltage power supply generates the electrical potential difference between the anode and the cathode of the fission chamber that is necessary to direct the fission fragments in the chamber. The signal generated in the detector first passes through the preamplifier and then the amplifier, which then feeds the Easy MCAs. The output from the Easy MCAs is sent to the data acquisition computer. Figure 3-3 contains an illustration of the data acquisition setup. Maestro software was used to count fission events in the fission chamber. The Maestro software generated channel count files that were used to count fission events in the detector.

Table 3-2. Data Acquisition Components

Component	Model	Input	Output
Pre-amplifier	Ortec 142PC	Detector	Amplifier
Amplifier	Ortec 572A	Pre-Amplifier	MCA
High Voltage Power Supply	Ortec 556	BIN	Detector
Multi-Channel Analyzers	Ortec Easy MCA	Amplifier	CPU
BIN	Ortec 4001C	Building Power	HVPS, Amp
CPU	Dell Optiplex	MCA	NA

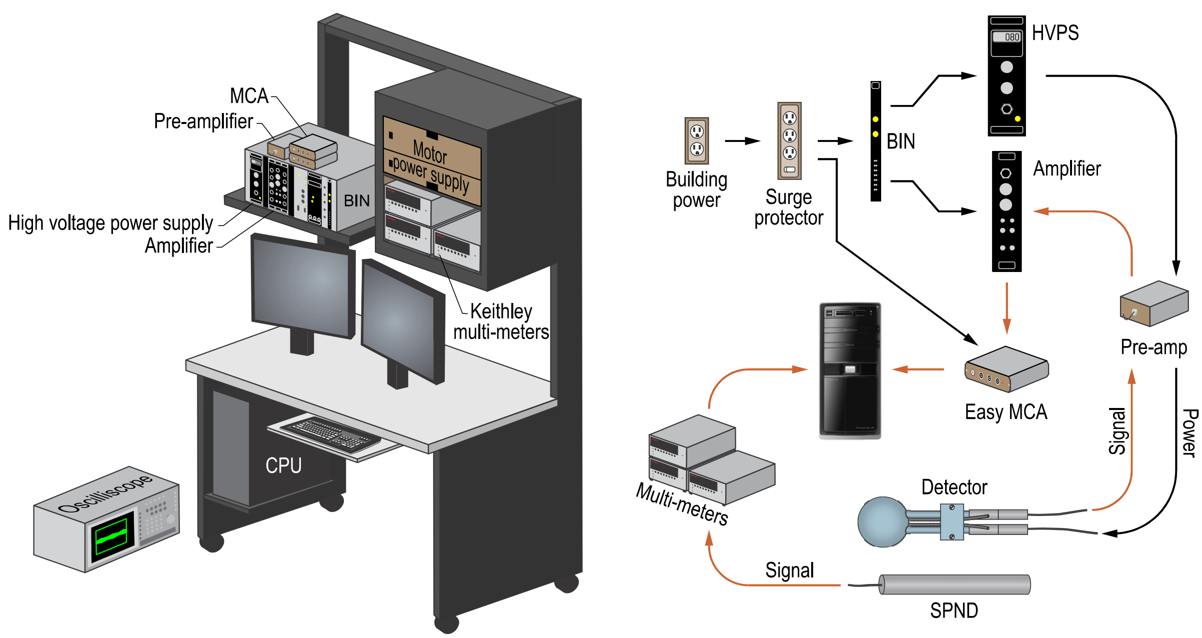

Figure 3-3. Data acquisition setup

Because there was only one high voltage power supply, it was shared between all of the detectors. Therefore, for each measurement state, each detector was disconnected and the next detector connected to the high voltage power supply until the measurements were performed for each of the three detectors.

3.2.3. Initial Detector Evaluation

After the initial experiment setup was completed, detector testing commenced. In order to determine the proper detector settings for consistent measurements, initial testing was performed for each detector. Plateau curves were generated to determine the optimal voltage settings for each detector. The plateau curves are used to ensure that small variations in the applied voltage will not produce inconsistent measurement results. Other settings of the data acquisition equipment were determined through trial and error testing. The results of the tests are used to determine the lower level discriminator (LLD) setting in the Maestro software. The LLD is used to eliminate background noise from the actual detector response. The plateau curves for the detectors are provided in Figures 3-4 through 3-7. The plateau curves for the BTB fission chamber, and the CEA U-235 fission chamber were performed at a reactor power of 185 on the Log N channel recorder. These curves were generated before initiating the first round of tests. The plateau curve for the BTB U-235 detector was repeated at a power of 1.7 on the Log N channel recorder because it was oversaturated at the higher power. The plateau curve and determination of the settings for the CEA U-238 fission chamber were performed after the first round of tests. The CEA U-235 detector was removed from the assembly, and the U-238 detector was inserted in its place. Then the plateau curve was then generated at a reactor power of 10 on the Log N channel recorder.

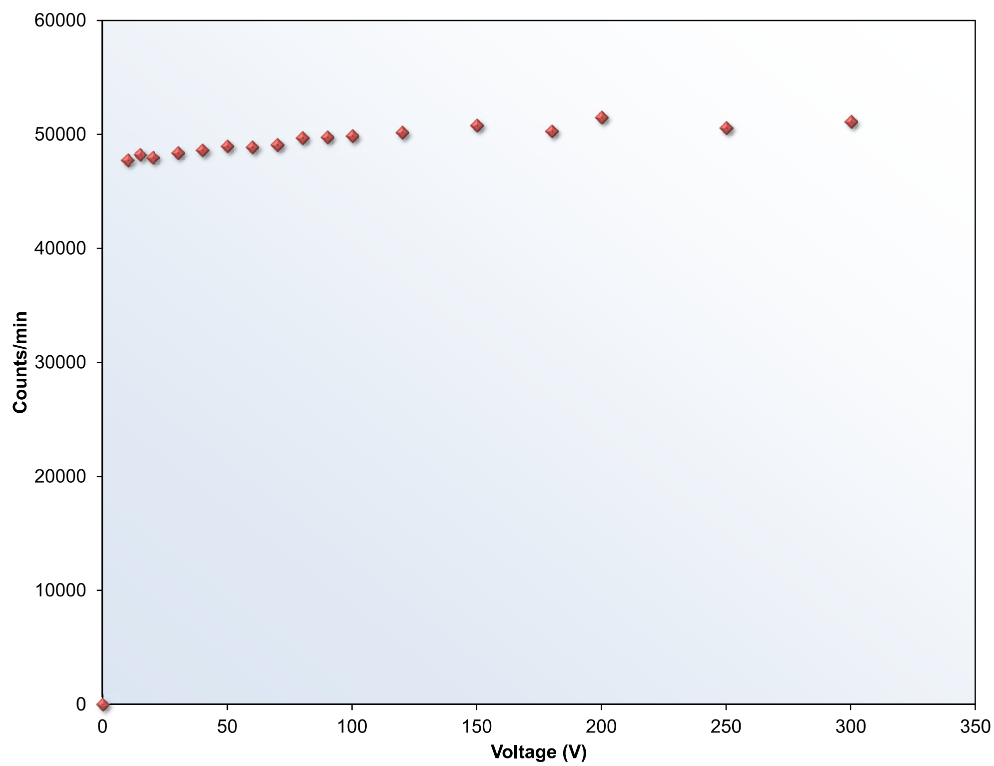

Figure 3-4. BTB U-235 plateau curve

The results from the plateau curves and other data acquisition settings are summarized in Table 3-3. In order to simplify the process, a voltage of 150 V was selected for all the detectors. This corresponded to different points on each plateau curve for a particular detector. However, 150 V was satisfactory for opera-

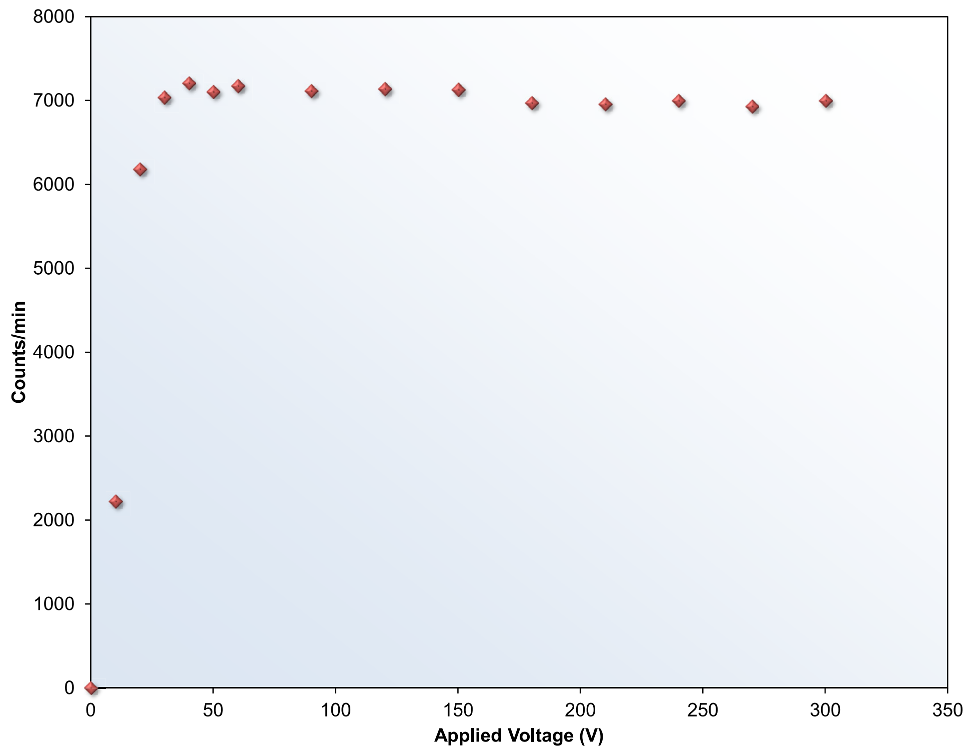

Figure 3-5. BTB U-238 plateau curve

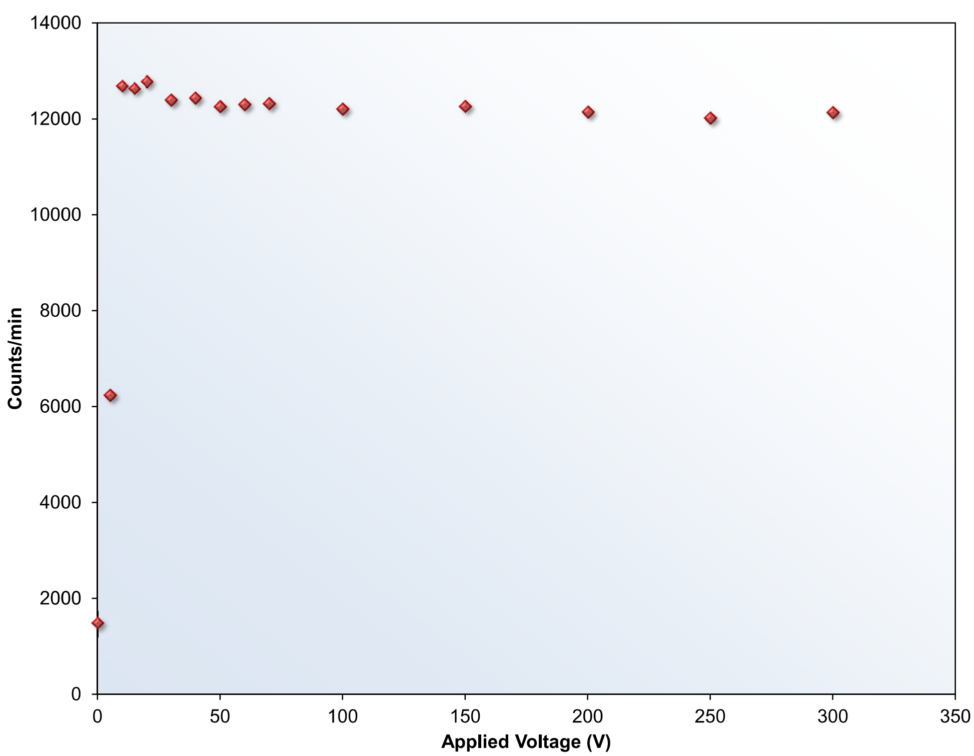

Figure 3-6. CEA U-235 plateau curve

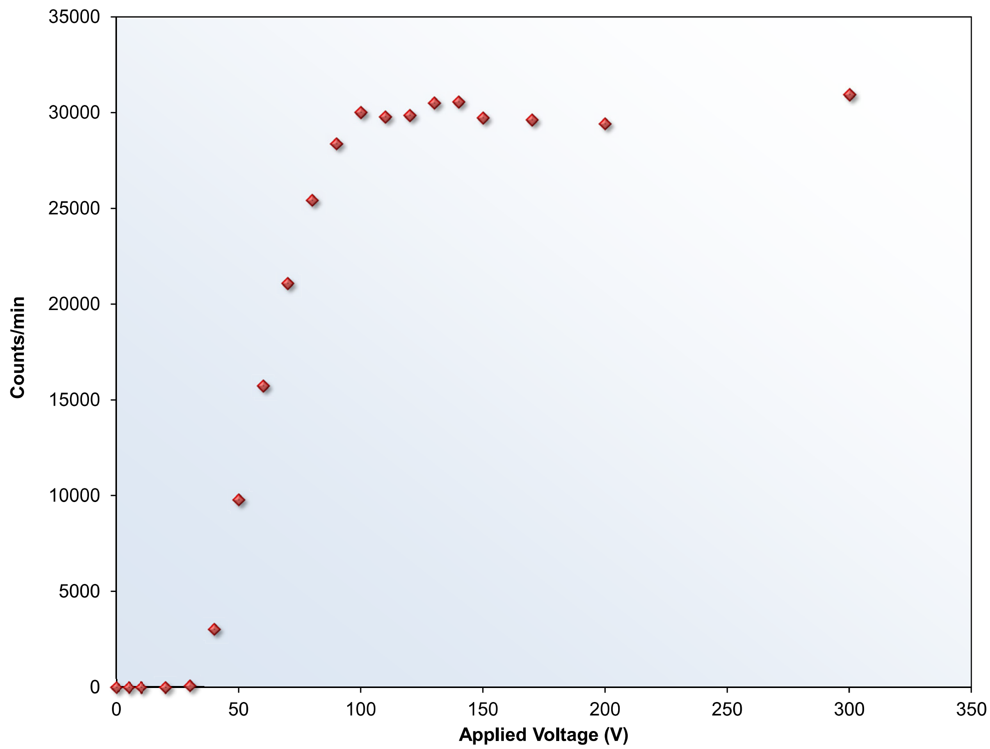

Figure 3-7. CEA U-238 plateau curve

tion of all the detectors. The lower level discriminator setting was based on an initial analysis of the background noise for each detector.

Table 3-3. Detector Settings

Detector	Voltage (V)	Shaping (seconds)	Gain	Polarity	Lower Level Discriminator
BTB U-235	150	$1x10^{-6}$	20	Positive	400
BTB U-238	150	$1x10^{-6}$	20	Positive	200
CEA U-235	150	$1x10^{-6}$	20	Positive	250
CEA U-238	150	$1x10^{-6}$	20	Positive	200

3.2.4. Detector Evaluation

The purpose of this set of tests was to compare the response of the BTB fission chamber with the response of the CEA miniature fission chambers. The BTB fission chamber was loaded with a foil containing a U-235 deposit and a foil with a U-238 deposit. Initially, a CEA U-235 detector was loaded in the test in the adjacent detector port to the BTB fission chamber in the BTB holder. After the first round of tests were completed, the CEA U-235 detector was removed and replaced with the CEA U-238 detector. Testing of the detectors consisted of power escalation measurements and rotational measurements.

Power escalation measurements consisted of taking measurements with the Maestro software at set power levels starting at low powers and increasing to higher powers. Rotational measurements were performed to determine if the orientation of the foils or the location of the detectors in the flux trap affect the detector response.

4. METHOD AND RESULTS

Two sets of tests were performed with the BTB fission chamber in the NW LIPT. Power escalation measurements and detector rotation measurements were both obtained for the CEA U-235 fission chamber and for the CEA U-238 fission chamber. A summary of the test sequence, taken from the test plan (TP-2-13 Rev. 2), is provided in Table 4-1. Only a portion of the test plan contained the test sequence for detector testing. For that reason, the detector testing shown in Table 4-1 begins in Section 9.6 of the test plan.[10]

Table 4-1. Testing Sequence

<table>
<tr><th>Section</th><th>Sub-sections</th><th>Actions</th></tr>
<tr><td rowspan="3">9.6 Setup and signal response checks</td><td>9.6.1-9.6.5</td><td>Core reconfiguration: remove standard/filler hardware and insert test hardware</td></tr>
<tr><td colspan="2">The BTB fission chamber was loaded with the U-235 foil and the U-238 foil. The CEA U-235 fission chamber was inserted into the BTB test assembly next to the BTB fission chamber.</td></tr>
<tr><td>9.6.6-9.6.7</td><td>Startup reactor, vary reactor power to perform measurements to determine detector setttings, shutdown</td></tr>
<tr><td rowspan="2">9.7 Cross calibrations with BTB</td><td>9.7.1-9.7.2</td><td>Startup reactor, vary reactor power to perform power escalation measurements, rotate BTB test assembly to perform measurements, shutdown</td></tr>
<tr><td colspan="2">At this point the CEA U-235 fission chamber was removed and replaced with the CEA U-238 fission chamber</td></tr>
<tr><td>Repeated 9.7 for CEA U-238 detector</td><td>9.7.1-9.7.2</td><td>Startup reactor, vary reactor power to perform power escalation measurements, rotate BTB test assembly to perform measurements, shutdown</td></tr>
<tr><td>Repeated 9.7 for axial measurements</td><td>9.7.1-9.7.2</td><td>Startup reactor, hold power constant while axial measurements are performed, shutdown</td></tr>
<tr><td rowspan="2">9.8 Cross calibrations with tri-holder</td><td>9.8.1-9.8.2</td><td>Core change: remove BTB assembly and replace BTB holder with the tri-holder</td></tr>
<tr><td>9.8.3-9.8.4</td><td>Startup reactor, vary reactor power to perform detector measurements, rotate tri-holder test assembly to perform measurements, shutdown</td></tr>
<tr><td>9.9 Reestablish Core Loading</td><td>9.9.1-9.9.4</td><td>Remove test hardware and EGTs and insert standard/filler hardware</td></tr>
</table>

4.1. Power Escalation Measurements

4.1.1. CEA 235 Fission Chamber and BTB

For the first series of tests, a CEA fission chamber with U-235 deposit was inserted into the detector position adjacent to the BTB fission chamber. Data were taken at incremental points as the ATRC power was increased from 0.1 on the Log N recorder to a peak of 100 on the Log N recorder. Figure 4-1 contains a plot of the normalized power escalation data for the CEA U-235 fission chamber, BTB U-235 foil, and BTB U-238 foil. The data show a difference in the trend of the power for the BTB U-235 detector before a Log N reading of 50 than the trend after this point. This is not consistent with prior measurements which showed a consistent linear relationship between power and counts/min.

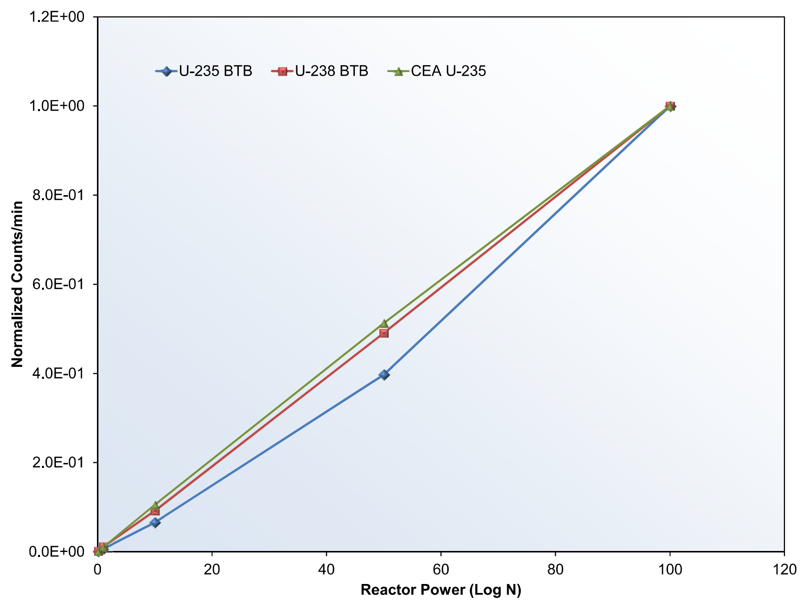

Figure 4-1. Normalized CEA U-235 and BTB power escalation measurements

4.1.2. CEA 238 Fission Chamber and BTB

For the second series of tests, the CEA U-235 fission chamber was replaced by the CEA U-238 fission chamber. Data were again recorded at incremental points as the reactor power was increased from a value of 1 on the Log N recorder to a value of 190 on the Log N recorder. The results of these measurements for the CEA U-238 fission chamber and the BTB foils are presented in Figure 4-2. Again, the data show an irregularity in the power prior to a reading of 50 on the Log N recorder when compared to the data after that point.

4.1.3. Power Escalation Discussion

The BTB fission chamber had some anomalous readings during the power escalation measurements. Rather than having a linear response to the rise in power, the fission chamber measurements showed some

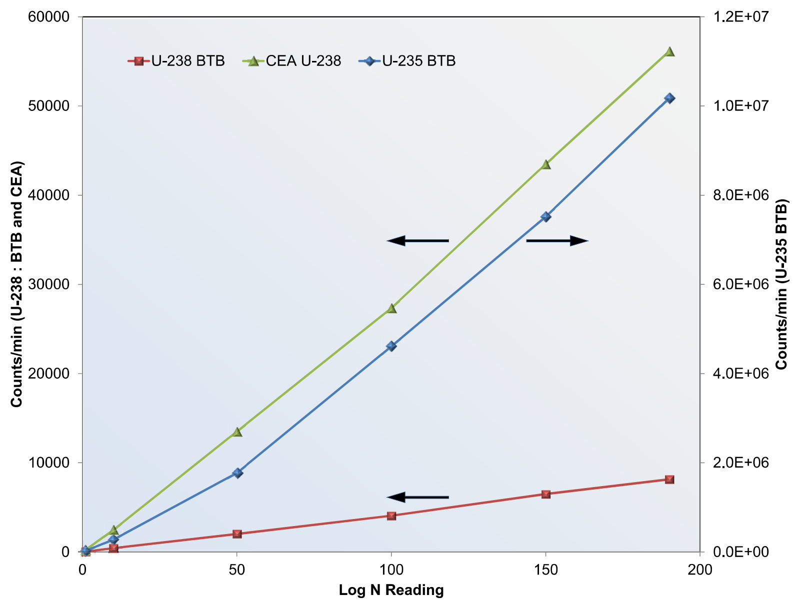

Figure 4-2. CEA 238 and BTB power escalation measurements

distinct variation from linearity. The reason for the discrepancy could be due to slight variations in the region of interest (ROI) selected from the data file. For each measurement, the counts per minute are determined by the selection of a ROI in the Maestro channel file. The ROI is manually selected by the experimenter and is prone to error. Sensitivity analysis should be performed on this process to determine if differences in the selected ROI can cause significant changes to the resulting data.

4.2. Detector Rotation Measurements

4.2.1. CEA 235 Fission Chamber and BTB

For the first series of tests, the BTB test assembly was rotated in the NW LIPT at 90 degree increments in an attempt to quantify any variation in flux based on orientation of the fission chamber foils in the test assembly. The CEA U-235 detector was in the test assembly for these measurements, and data were obtained from this detector as well. The rotational testing was performed with the reactor at a power of 100 on the Log N recorder. Figure 4-3 presents results of the detector rotation measurements for the BTB detector and the CEA U-235 detector.

4.2.2. CEA 238 Fission Chamber and BTB

For the second series of tests rotations of the test assembly were again performed, but with the CEA U-238 detector replacing the CEA U-235 detector. The reactor was held at a power of 100 on the Log N recorder during the rotation of the test assembly. The same procedure was used to obtain the second round of rotational measurements as was used for the first round described in Section 4.2.1. The results of the rotational measurements with the CEA U-238 detector and the BTB fission chamber are provided in Figure 4-4.

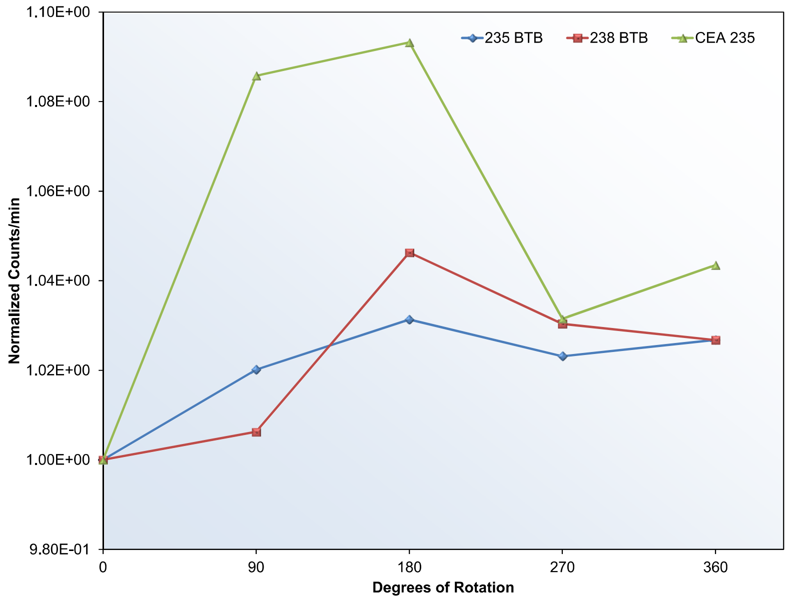

Figure 4-3. BTB and CEA 235 rotation measurements

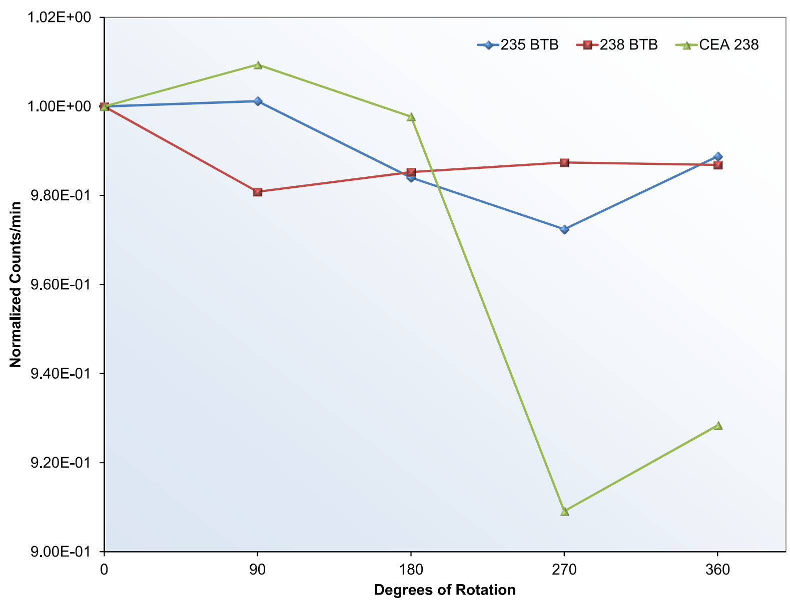

Figure 4-4. BTB and CEA 238 rotation measurements

4.2.3. Detector Rotation Discussion

The results from the rotation of the detectors show similarities in the response of the detectors. This is particularly noticeable in Figure 4-3. All three detectors show the same trend in the response for each rotation. This is true with the exception of the last measurement, where the U-238 BTB fission chamber response decreases while the other two increase. In Figure 4-4, the U-235 BTB fission chamber and CEA U-238 fission chamber again display the same trend in their response, but the U-238 BTB fission chamber does not follow the same trend. These trends seems to imply there is a detectable and predictable difference in the response of the detectors based on their orientation in the in-pile tube. However, there are discrepancies in the trend for the U-238 BTB fission chamber that are disconcerting. Also, there is a difference in the general shape of the curves between the two measurements. This may imply that the measurements are highly sensitive to the orientation of the foils and the location of the detectors in the flux trap. Therefore, small differences in the orientation result in a measurable response in the fission chamber. If this is the case, then the comparison of the BTB fission chamber response and the CEA fission chamber response would need to be corrected to account for this gradient. However, it also may be that there isn't a significant dependence on the orientation of the foils and location of the detectors. The variation in the two measurements may be due to random fluctuations or uncertainty in the measurements. Future testing, with a focus on repeatability, should be performed to determine the correlation between the orientation of the detectors and their response.

4.3. SPND Axial Measurements

4.3.1. CNEA SPNDs

Axial measurements were performed using the EGTs to position the CNEA SPNDs in the N-16 positions. Axial measurements were performed to provide data to compare with prior testing results.[2] Figure 4-5 contains the results from axial measurements with the CNEA SPNDs. The DN0 SPND in the H3 position of the center flux trap shows a significant variation from the rest of the data. However, this is attributed to water damage that occurred in previous tests with this SPND. Currently it will only operate properly if it is lifted up to prevent contact with the bottom of the Lucite tube. This detector was approximately 20-26 centimeters (8-10 inches) above the other SPNDs, which accounts for the observed shift in the axial profile.

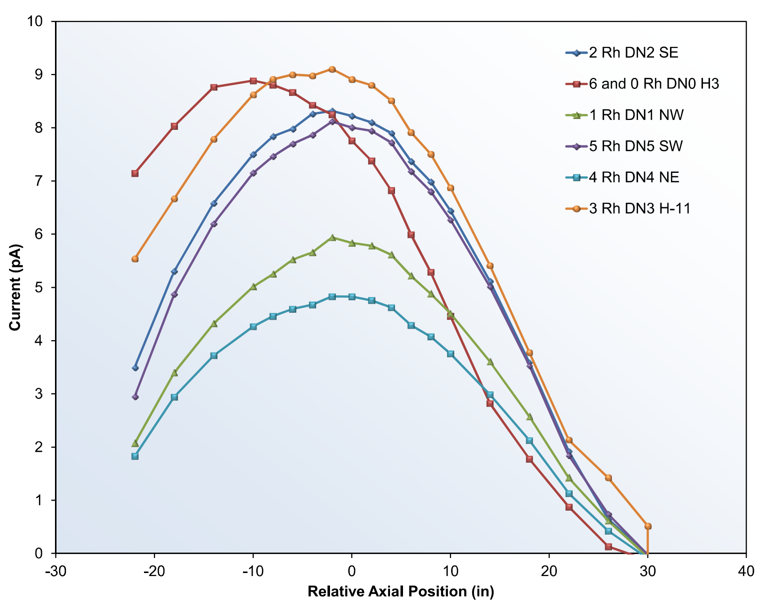

Figure 4-5. CNEA SPND axial measurements

The results from this set of axial profile measurements are consistent with the results from the previous set of measurements performed in the initial detector evaluations.[2]

5. SUMMARY AND CONCLUSIONS

New specialized hardware was designed and fabricated to test BTB fission chambers in the ATRC. This hardware was used to test BTB fission chambers with CEA fission chambers in the ATRC. Power escalation measurements and orientation sensitivity measurements were performed. Observations from these measurements have been documented in this report. The power escalation measurements and the detector rotation measurements have provided preliminary BTB fission chambers data that can be used in future comparisons. This is the first time BTB fission chambers have been used at INL in decades. These detector evaluations have provided INL researchers with experience using BTB fission chambers. This experience is invaluable as further work is performed evaluating neutron sensors for use in MTR experiments.

The results from this round of fission chamber measurements provide a baseline for future measurements. It is apparent that more measurements are necessary to evaluate the accuracy of these results. Anomalies in the linearity of the power escalation measurements should be investigated further. The detector rotation measurements should also be repeated. However, these results also provide important insights. The current results suggest that the detector response depends on its orientation in the LIPT. Also, the data from the U-238 BTB detector are questionable, therefore, the Pu-239 foil should be used in future tests instead.

In summary, results from these tests provide an opportunity to identify needs for future testing. Of particular importance would be a test in which the PU-239 and U-235 foils are collocated in the BTB fission chamber. This would provide data required to calculate a Pu-239 to U-235 fission rate ratio. This ratio is one of several spectral indices that can be used to characterize the energy dependence of the neutron flux in the reactor. The Pu-239 to U-235 spectral index is an indicator of thermal fission effects because both isotopes have high thermal fission cross-sections. This type of measurement will help characterize future fission chamber evaluations. The power escalation and orientation sensitivity measurements should be repeated with the Pu-239 and U-235 foils in the BTB fission chamber.

Also, the use of the tri-holder in the experiment assembly would allow researchers to characterize any desired combination of three detectors. This will provide comparison data for the CEA miniature fission chambers and the SPNDs. Using the tri-holder will also allow the detectors to be characterized concurrently in the NW flux trap of the ATRC.

Future evaluation of real-time, in-pile neutron detectors will be necessary to characterize newly developed sensors. The experiments documented in this report provide a reference baseline and for those future tests.

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