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Revision 0

Characterizing the Performance of Fission Chambers for Local Neutron Flux and Spectrum Measurement

November 2022

Milestone Report—M2CT-22IN0702013

Kevin Tsai
Idaho National Laboratory

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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ABSTRACT

Three fission chambers were tested at The Ohio State University Research Reactor (OSURR) to evaluate fission chambers for neutron flux and spectrum measurements. Two of the fission chambers are commercial Photonis CFUR43 fission chambers—one utilizing highly enriched uranium-235 fissile deposits for thermal neutron detection and the other with highly depleted uranium-238 for fast neutron detection. This experiment was also performed in collaboration with French Alternative Energies and Atomic Energy Commission (CEA) with CEA suppling a uranium-235 loaded fission chamber built from the Photonis CFPR-CE8/9 kit.

The fission chambers were irradiated in a movable 6.5 inch dry tube at reactor powers of 50 kW, 200 kW, and 450 kW at ambient temperature and at 350°C. While all sensors demonstrated good linear sensitivity to reactor power, a leakage current of 6 nA was measured for the CFUR43 detectors. Additionally, the measured signal ratios of the two CFUR43 detectors did not match the theoretical values and are subject to further investigation on individual signal contributors.

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ACRONYMS

CEA	French Alternative Energies and Atomic Energy Commission
OSURR	The Ohio State University Research Reactor

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Characterizing the Performance of Fission Chambers for Local Neutron Flux and Spectrum Measurement

1. INTRODUCTION

This report documents the testing and evaluation of commercial fission chambers for measuring local neutron flux and energy spectrum. The experiment was carried out in collaboration with the French Alternative Energies and Atomic Energy Commission (CEA). The experiment presented here was conducted at the Ohio State University Research Reactor (OSURR).

In-core neutron flux is a crucial parameter needed to characterize fuel performance and validate models in support of advanced fuel cycle research and advanced reactor demonstrations. However, the operational environments of current advanced reactor designs necessitate the inclusion of neutron spectral measurements—specifically measurements of fast neutron flux. To demonstrate neutron spectral measurement capabilities, commercial fission chambers utilizing U-235 for thermal neutron measurements and U-238 for fast neutron measurements were procured from Photonis. Additionally, CEA supplied a U-235 fission chamber built with a Photonis fission chamber kit.

This experiment currently evaluates sensor responses to reactor power in ambient temperatures and at 350°C. Irradiations with higher temperatures above 350°C and additional neutron flux sensors are planned for fiscal year 2023 (FY-23).

1.1 Photonis Fission Chamber Overview

The two commercial fission chambers used in this experiment are procured from Photonis Technologies—model CFUR43. One of the CFUR43 fission chambers uses U-235 for thermal neutron detection and the other with U-238 for fast neutron detection. The fission chamber supplied by CEA uses a Photonis fission chamber kit—model CFPR-CE8/9. Both fission chamber models are cylindrical, gas-filled fission chambers with a maximum outer diameter of 3 mm. The fissile deposition and fill-gas specifications at 20°C are given in Table 1.

The low amount of fissile material in the CFPR fission chamber allows it to be operated in pulse mode. The advantage of pulse mode operation is the inherent capability to discriminate gamma-generated ionization events from neutron-induced fission events due to the difference in signal pulse heights [2]. The disadvantage of operating in pulse mode, however, is the detection range limitation to pulse rates of approximately 10^6 Hz depending on applicable electronics. Additionally, background electronic noise is a concern during sensor deployment into a nuclear facility; especially if the noise-generated pulses are equivalent or higher than the pulse from a fission fragment ionization event. The CFPR fission chamber therefore uses a full-length mineral-insulated cable terminated into an HN connector alongside power supply filters and grounding wires to reduce background noise.

The CFUR43 fission chambers use significantly more fissile deposits and were designed to be operated in current mode—an operational mode where signal pulse rates from fission events are sufficiently high to be integrated as a steady electrical current. The advantage of operating in current mode is the increased detection range as electronic systems are more adaptable to a wider range of electric current detection. Additionally, the background noises are less concerning since they can be integrated into the overall signal and can be expressed as a current baseline offset. Therefore, in the fabrication of the CFUR43 models, it is acceptable to have a transition between mineral-insulated cabling to soft-coaxial cabling that terminates in a BNC connector for better flexibility in sensor deployment. The disadvantage of current mode, however, is that since the electric current is the integration of all contributing components, it is not possible to discriminate between each contributor—neutron, gamma, electronic noise, or leakage currents—without prior characterization and calibration.

Table 1. Photonis fission chamber fissile and fill-gas specifications.

Detector Identification	Fissile Deposit	Fissile Location from Sensor Tip	Fill-Gas
CFUR43/ID1/U5 No. 204	140 µg 93.09% U-235	14 – 24 mm	Argon at 110 kPa
CFUR43/ID1/U8 No. 206	140 µg 99.80% U-238	14 – 24 mm	Argon at 110 kPa
CFPR CE8/9 No. 2349	0.96 µg 97.66% U-235	21.7 – 25.7 mm	Argon + 4 % Nitrogen at 500 kPa

1.2 The Ohio State University Research Reactor Experiment Overview

The experiment at the OSURR was performed in the 6.5-inch external dry-tube positioned east of the reactor core (Figure 1). As shown in Figure 2, the neutron spectrum within the 6.5-inch dry-tube is roughly 75% thermal (1.4E + 12 nv) and 25% epithermal per the cadmium cutoff (4.9E + 11nv). The experimental rig is comprised of an alumina sensor guide-tube cluster surrounded by a silicon carbide heater (Figure 3). The estimated vertical neutron flux and temperature profile are given in Figure 4. The sensors that are positioned within the guide tube cluster are shown in Figure 5; the specific positioning of each sensor was made to optimize neutron flux and temperature uniformity.

The experiment was performed with reactor power steps at 50 kW, 200 kW, and 450 kW—first at ambient temperature and then repeating the power steps at 350°C.

The CFPR fission chamber (pulse mode) signal was measured by a specialized CEA fission chamber acquisition system. The CFUR43 fission chambers (current mode) signal was measured with the Keithley 6517B. The initial planned electronic system for the CFUR43 fission chambers were the Instrumentation Technologies Libera Current Meter instead of the Keithley 6517B. However, the external high-voltage power supply to be operated in concurrence with the Libera Current Meter was not functional. Since the Keithley 6517B was used as a backup system, only the stabilized current from the CFUR43 fission chambers were recorded manually at each power step.

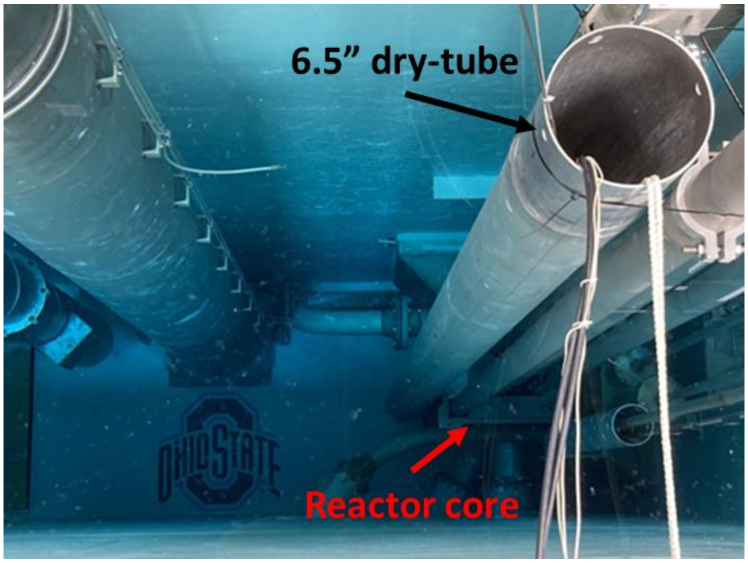

Figure 1. Image of 6.5-inch dry-tube located to the east of the reactor core.

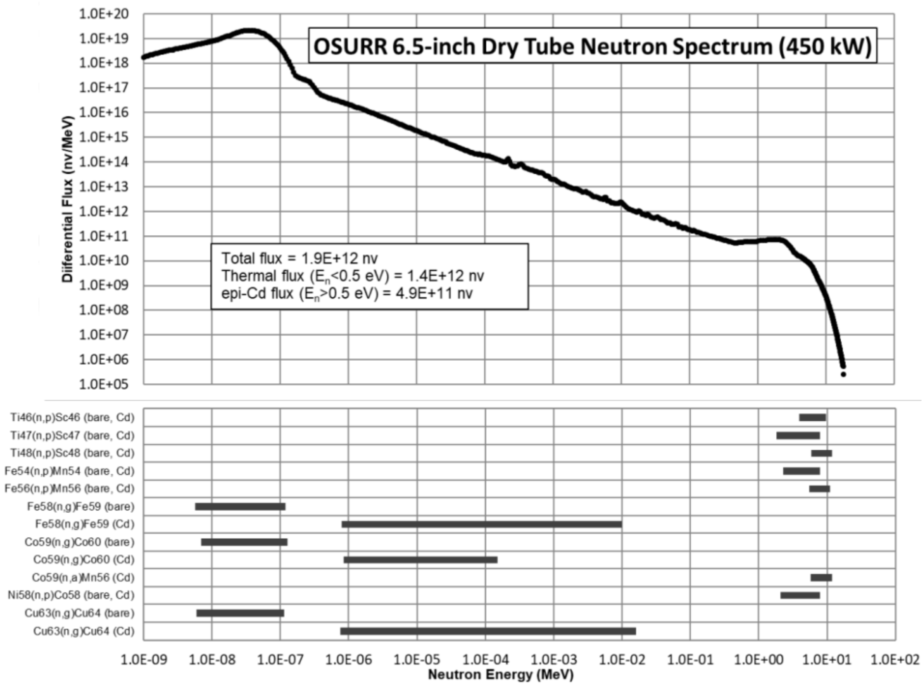

Figure 2. OSURR 6.5-inch dry-tube neutron flux spectrum distribution at 450 kW [3].

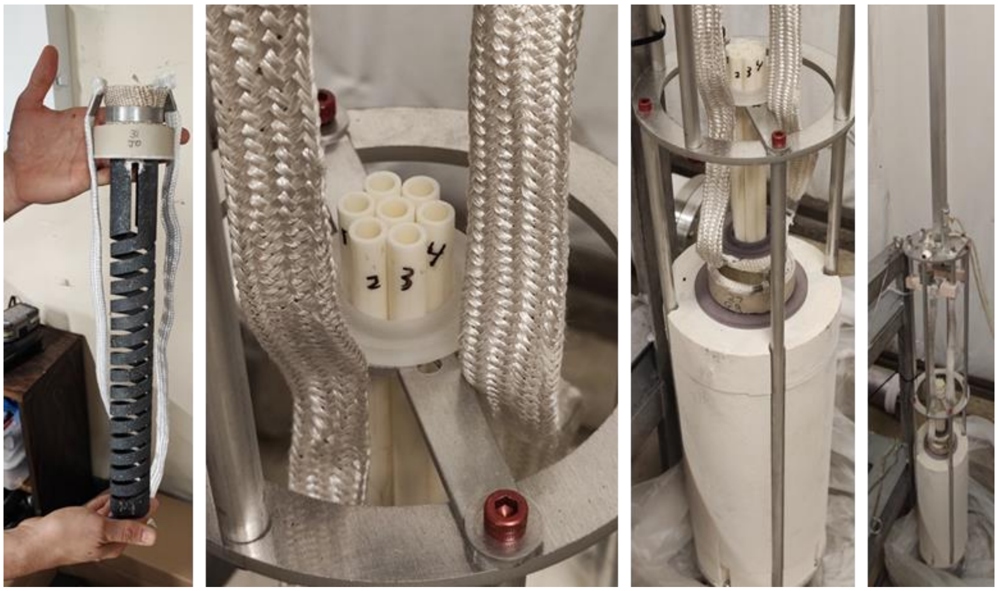

Figure 3. Image of silicon carbide heater assembly.

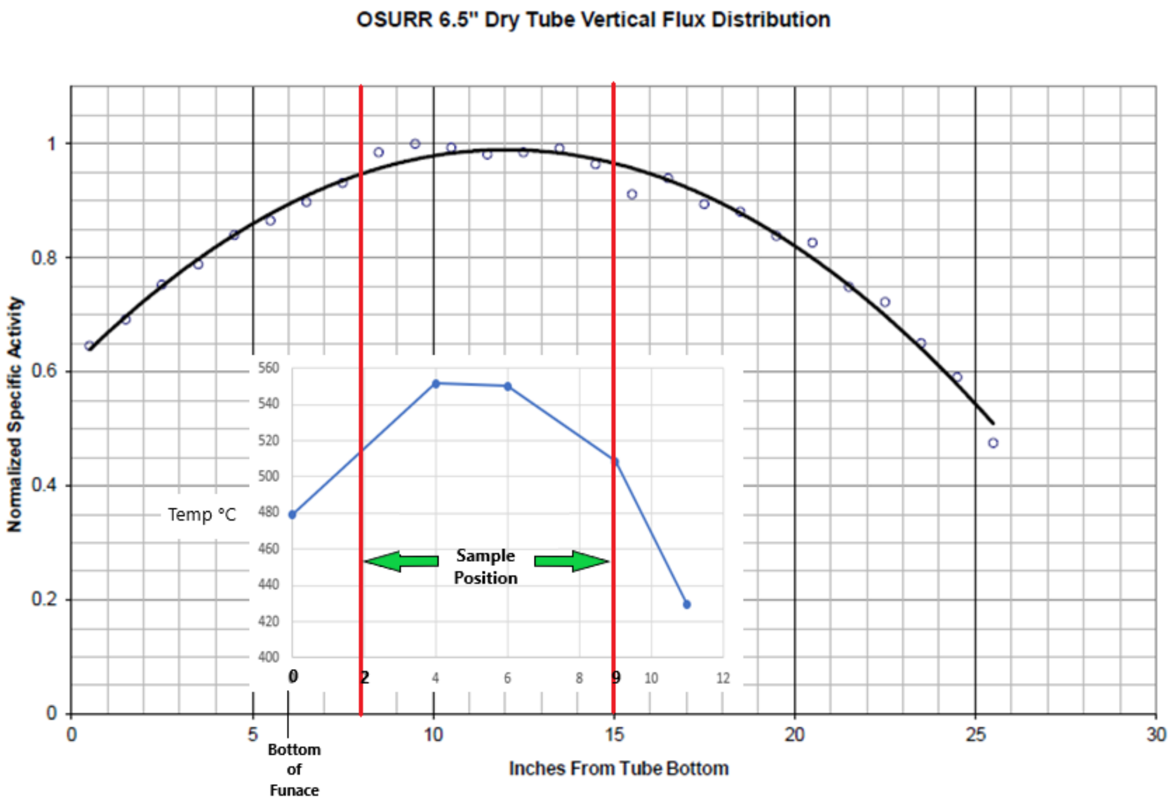

Figure 4. Experiment vertical flux distribution overlayed with heater temperature distribution.

Sensor	Sensitive Region in tube height (in.)	Tube position
CFPR-CE8/9 U5 FC	13 – 13.4	4
CFUR43 U8 FC	11.6 – 12	2
CFUR43 U5 FC	12.4 – 12.6	3
CEA Rh-SPND	9.2 – 11.2	1

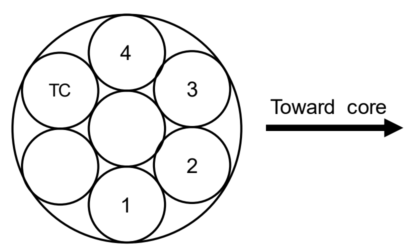

Figure 5. Sensor positioning in the guide-tube cluster.

1.3 Neutron Spectral Measurements Overview

Due to their differences in fission cross sections, U-235 and U-238 can be used for thermal and fast neutron measurements. Figure 6 presents the fission cross-section data provided by the ENDF/B-VIII.0 library [1]. As observed, the fission cross section of U-235 is primarily in the thermal neutron region while the U-238 fission cross section is in the fast region. In the context of the OSURR experiment, given the flux spectrum presented in Figure 2 and the fission cross section in Figure 6, the relative fission rates from U-235 and U-238 is calculated and presented in Figure 7. In consideration of an isotopically pure fission chamber, the expected fast neutron signal contribution from a U-238 fission chamber is 99.98%. Similarly, the thermal neutron signal contribution from a U-235 fission chamber is 99.996%. However, it should also be noted that the total signal between an isotopically pure U-238 fission chamber to the equivalent U-235 fission chamber of equal mass is 1.32E-4; hence, the uranium enrichment of the fission chambers plays a significant role in calculating the overall signal ratio of the fission chambers.

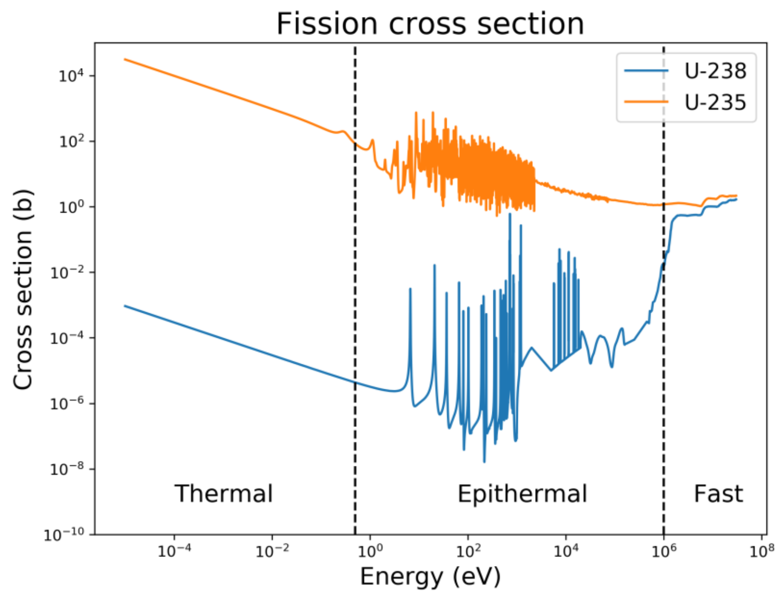

Figure 6. U-235 and U-238 fission cross sections as a function of energy.

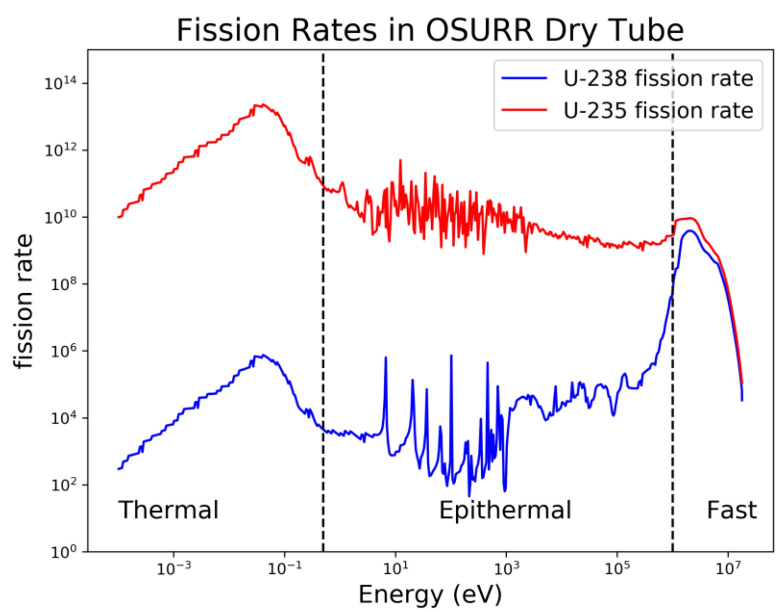

Figure 7. U-235 and U-238 fission rates in the OSURR 6.5 inch dry-tube.

2. RESULTS

Plots of sensor signals as a function of power at ambient temperature and at 350°C are presented in Figure 8. All three fission chambers showed a linear proportionality to reactor power for both temperatures.

The CFPR-CE8/9 U-235 fission chamber demonstrated the best performance compared to the other sensors with a measured detector sensitivity of 2,354 cps/kW and an averaged count-rate difference of −2.25% between ambient temperature and 350°C for all power levels. This result is expected since the advantage of pulse mode operation is the inherent discrimination of background contributors, resulting in an unperturbed neutron sensitivity even at 350°C.

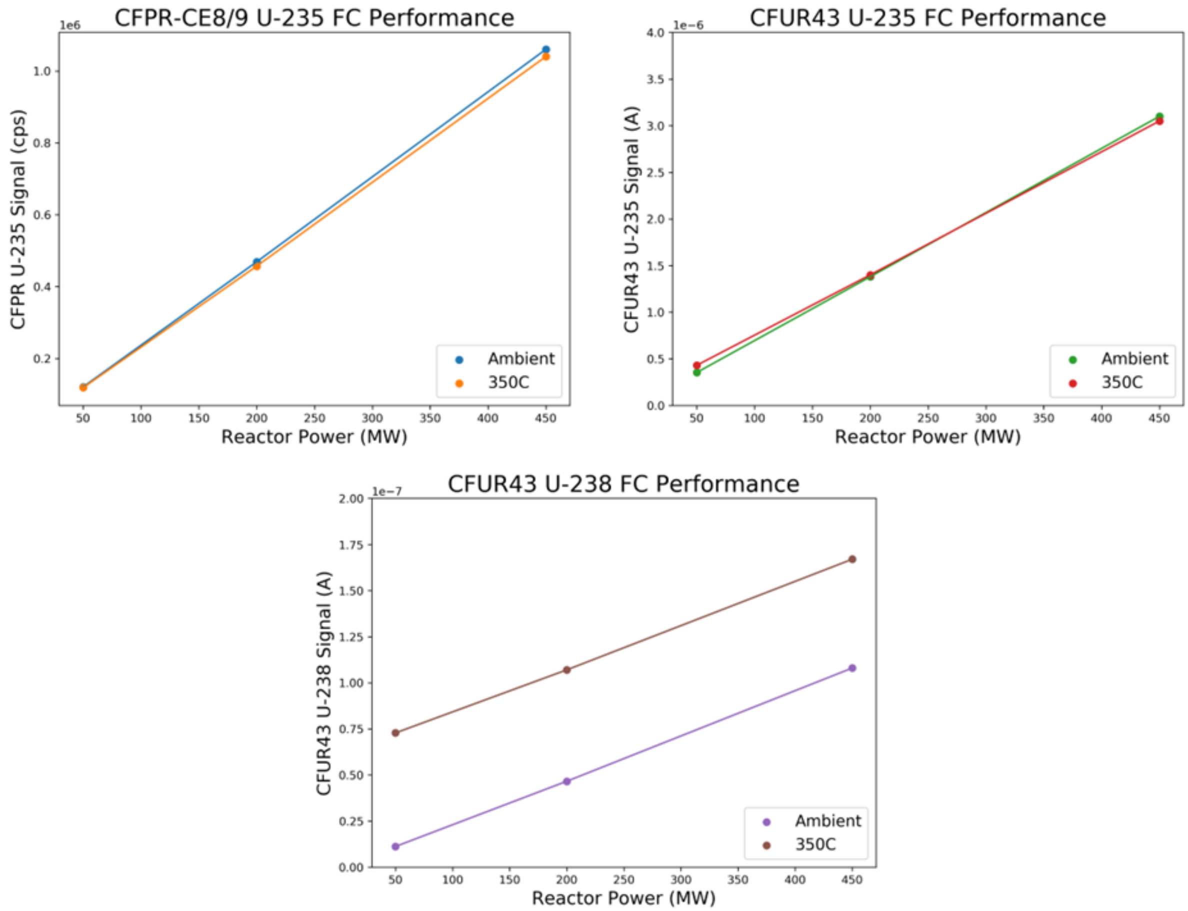

Figure 8. Sensor signal as a function of reactor power for ambient temperature and 350°C.

Unlike the pulse mode operation from the CFPR fission chamber, the CFUR43 fission chamber operating in current mode demonstrated a DC current offset as the temperature changes between ambient to 350°C. This is more readily observed by the U-238 fission chamber—given its low current output at power—with an averaged measured direct-current offset of 6.0 nA across all three power steps. This is also the same offset measured by the U-235 fission chamber at 50 kW reactor power—a power level sufficiently low for the leakage current to contribute to approximately 20% of the overall signal.

Comparing the two CFUR43 fission chambers, the U-238 fission chamber to U-235 fission chamber signal ratio averaged across the three power steps was 3.3E-2 at ambient temperature. Similarly, after subtracting the measured 6.0 nA leakage current contribution from both detector signals, the averaged signal ratio was calculated to be 3.5E-2 at 350°C. This ratio should also theoretically be same the ratio of fission events between the two CFUR43 fission chambers; however, the calculated ratio—factoring in the isotope enrichment and assuming identical gamma contribution and fission detection efficiency—was determined to be 2.35E-3.

Upon investigation of the theoretical contribution of U-235 and U-238 isotopes within both fission chambers, it was calculated that the 0.28 µg of U-235 (accounts for 0.20% enrichment) in the CFUR43 U-238 fission chamber contributed to 93.9% of the overall signal when factoring in the difference in the U-235 thermal fission cross section along with the largely thermalized neutron spectrum in the 6.5-in. dry tube. Separately, further investigation is needed to determine the discrepancy between the measured ratios and the theoretical ratios.

3. REFERENCES

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