

THE SLOWPOKE-2 NUCLEAR REACTOR AT THE ROYAL MILITARY COLLEGE OF CANADA: APPLICATIONS FOR THE CANADIAN ARMED FORCES

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ABSTRACT – The Royal Military College of Canada (RMCC) has a 20 kW SLOWPOKE-2 nuclear research reactor which is used for teaching and research. Since its commissioning, the reactor facility and instruments have been continuously upgraded to develop and enhance nuclear capabilities for the Canadian Armed Forces (CAF). Specific applications of neutron activation analysis (NAA), delayed neutron counting (DNC) and neutron imaging relevant to the CAF are discussed.

Introduction

Safe Low Power C(K)ritical Experiment (SLOWPOKE) nuclear research reactors were designed by Atomic Energy of Canada Limited (AECL) as a simple, safe, and affordable neutron source for universities and hospitals for application of neutron activation analysis (NAA) and radioisotope production. In 1985, the Royal Military College of Canada (RMCC) commissioned a 20 kW SLOWPOKE-2 reactor into its new engineering building in support of the proposed Canadian nuclear submarine program. The nuclear submarine program never materialized but the SLOWPOKE-2 has proven to be an extremely versatile and valuable asset for RMCC and the Canadian Armed Forces (CAF). In addition to continuing to successfully conduct NAA as per its original design intent, RMCC has significantly upgraded the facility and instruments to develop capabilities such as delayed neutron counting (DNC) and neutron imaging, including 2D thermal neutron radiography and 3D thermal neutron tomography. These unique nuclear capabilities have been applied to relevant issues in the CAF. NAA at RMCC is used to investigate the elemental content of soil from small arms ranges (SARs). DNC is used to enhance the nuclear forensics capabilities of the CAF, through the identification of special nuclear materials (SNMs). Neutron imaging is used to inspect flight control surfaces (FCS) of the CF188 Hornet for water ingress and structural degradation.

1. Design and Construction

The aluminum container for the SLOWPOKE 2 reactor core is suspended in a water filled pool, which has a diameter of 2.46 m and a depth of 5.87 m. Both the reactor container and the pool are filled with light de-ionized water. This water provides cooling, radiation protection and acts as a moderator for the critical assembly. The core has a total of 198 fuel pins with Low Enriched Uranium (LEU) fuel (19.89% U-235). The fuel pins are arranged vertically inside a beryllium assembly. The beryllium acts as a neutron reflector and the annulus contains five inner radiation sites. Any of the four inner irradiation sites or the three appropriate outer sites may be used to irradiate samples for the DNC.

In order to provide a higher neutron flux for neutron imaging, an outer irradiation site was replaced (before reactor commissioning) by a thermal column containing heavy water between the beryllium annulus and the reactor container as shown in Figure 1. At half power, the thermal neutron flux measured at the location adjacent to the heavy water column is 2.7 times greater, [1] $1.4 \times 10^{11} \text{ n cm}^{-2} \text{ s}^{-1}$ compared to $5.1 \times 10^{10} \text{ n cm}^{-2} \text{ s}^{-1}$ measured at the reactor container wall at a different radial location [2].

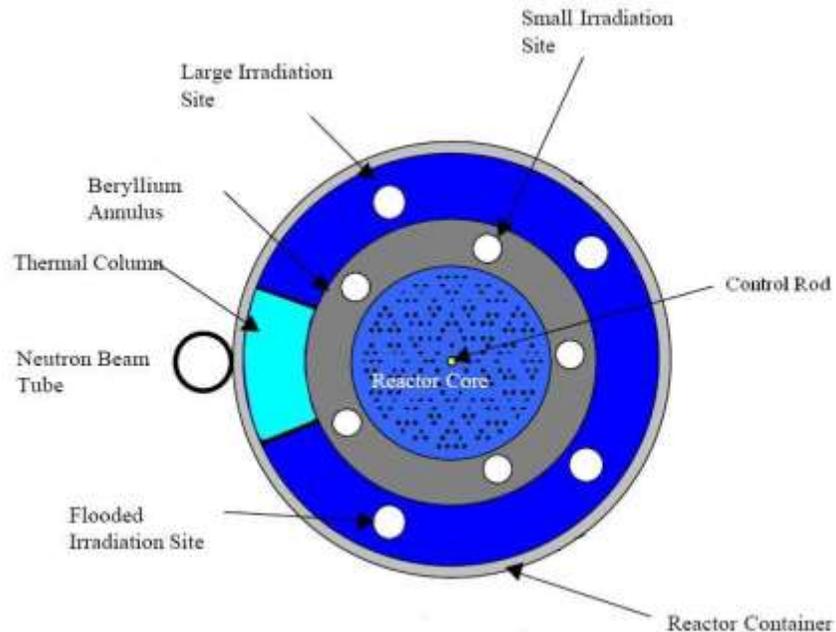


Figure 1: Cross Section View of RMCCs SLOWPOKE-2 Reactor Core

A Neutron Beam Tube (NBT) was installed in the reactor pool to permit neutron imaging. When neutron imaging is not being conducted, the NBT is positioned vertically in the reactor pool away from the core. To initiate imaging, the NBT is moved towards the reactor core by a hydraulic jack until the bottom of the NBT contacts the reactor container and forms an 8.5° angle from vertical. The bottom of the NBT is called the illuminator and is made from a graphite block. When the NBT is coupled to the reactor container, neutrons travel through the beryllium reflector and the heavy water thermal column to the graphite block. The graphite block redirects the neutron beam upwards through the divergent beam tube. The beam tube and peripheral equipment required for neutron imaging are shown in Figure 2.

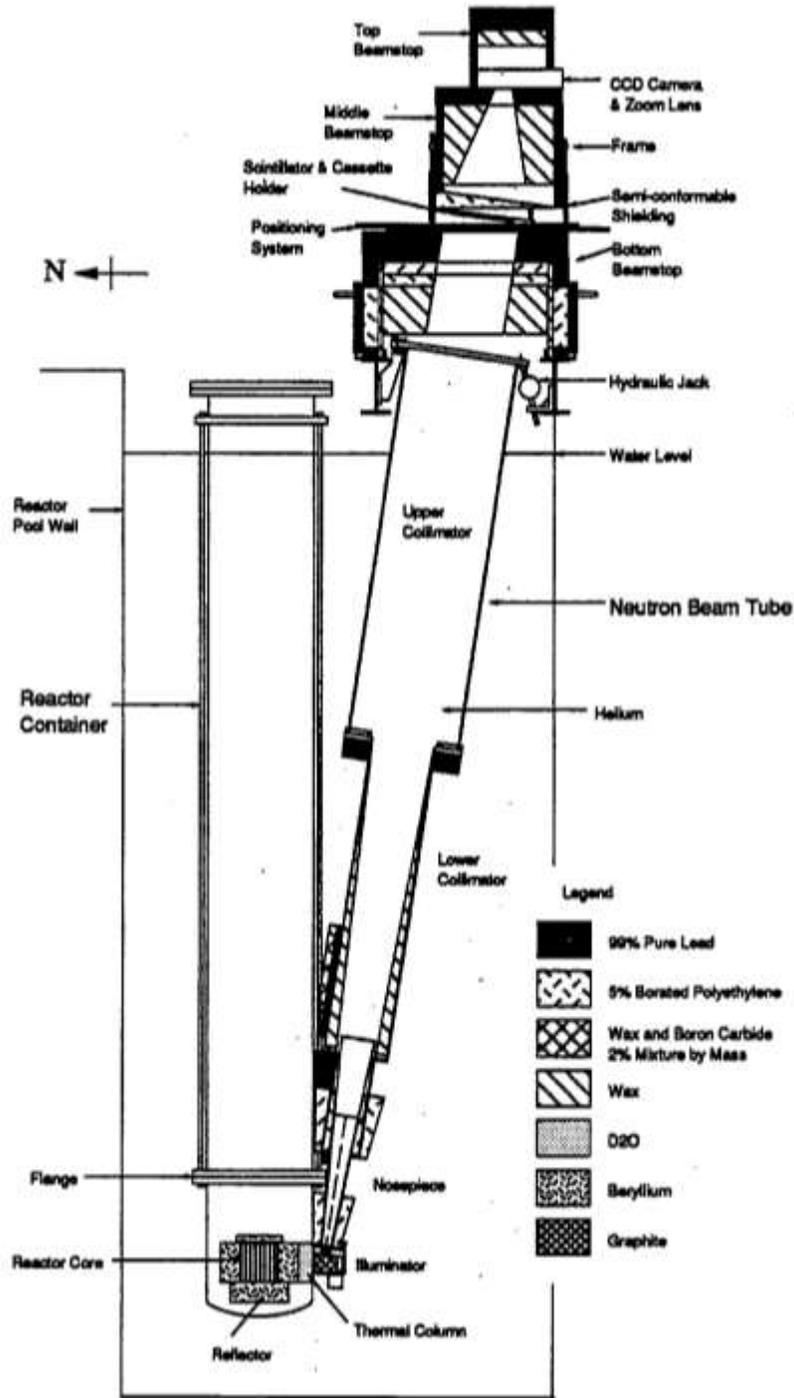


Figure 2 : Side View of RMCC Neutron Imaging System

2. Applications

Three specific applications relevant to the CAF for NAA, DNC and neutron imaging will be briefly examined.

2.1 Neutron Activation Analysis (NAA)

NAA is a nuclear based technique used to identify and determine the concentrations of elements in material samples. The samples under inspection are bombarded with neutrons, producing radioisotopes. The gamma emissions from the isotopes are characteristic of elements and the recorded spectra can be analyzed using well-known decay paths.

As part of its role as an environmental custodian, the CAF is committed to the assessment, control and mitigation of contaminants from SARs. Actions include the assessment of soil contamination, particularly by copper, lead and antimony. The ability of NAA to accurately determine the concentrations of antimony in soil samples was compared to other analytical techniques including nitric acid, *in situ* HF microwave digestions and nitrate ashing. It was concluded that only NAA is capable of providing data which reflect 'true' concentrations [3]. Since antimony represents a significant mass fraction of many munitions and since its toxicity is considered comparable with that of arsenic, the provision of reproducible and accurate laboratory data with respect to antimony in soil is essential. Due to its ability to accurately and easily measure total antimony content in soil, the CAF uses NAA to measure soil samples from its SARs.

2.2 Delayed Neutron Counting (DNC)

A prototype DNC system has been developed within the SLOWPOKE-2 Facility to enhance nuclear forensic instrumentation available to the CAF [4]. An array of ^3He detectors record the temporal behaviour of delayed neutrons produced after the irradiation of special nuclear material (^{233}U , ^{235}U and ^{239}Pu) in one of the irradiation sites of the SLOWPOKE-2 reactor. The DNC allows for the rapid and non-destructive analysis of fissile mixtures. Figure 3 provides a theoretical difference in delayed neutron temporal behavior for various SNMs initialized to the same count rate.

The DNC system has recently been upgraded to simultaneously record delayed neutrons (He-3 detectors) and delayed gammas from via the inclusion of a high purity germanium detector. Delayed measurements from this system are compared to MCNP6 simulations in collaboration with the Monte Carlo Codes group at Los Alamos National Laboratory [5].

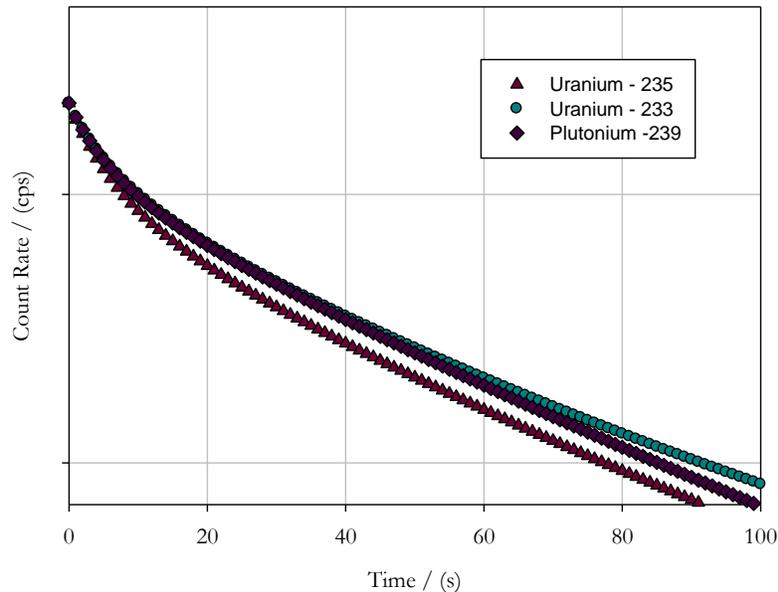


Figure 3: Time Dependant Delayed Neutron Counts for SNMs U-233, U-235 and Pu-239 Normalized to Equal t=0 Counts.

2.3 Neutron Imaging

The honeycomb composite flight control surfaces (FCS) on the CF-188 aircraft are susceptible to water ingress. Water enters these components and can cause structural degradation to the interior honeycomb structure. The degradation can become so severe that numerous rudders have departed the aircraft during flight. The CAF conducted an evaluation of various non-destructive evaluation (NDE) techniques capable of locating water within honeycomb composites. Several NDE techniques proved effective at locating the water, but neutron imaging was determined to be the most sensitive [6]. A neutron radiograph of water inside the honeycomb core of a CF-188 rudder is shown in Figure 4.

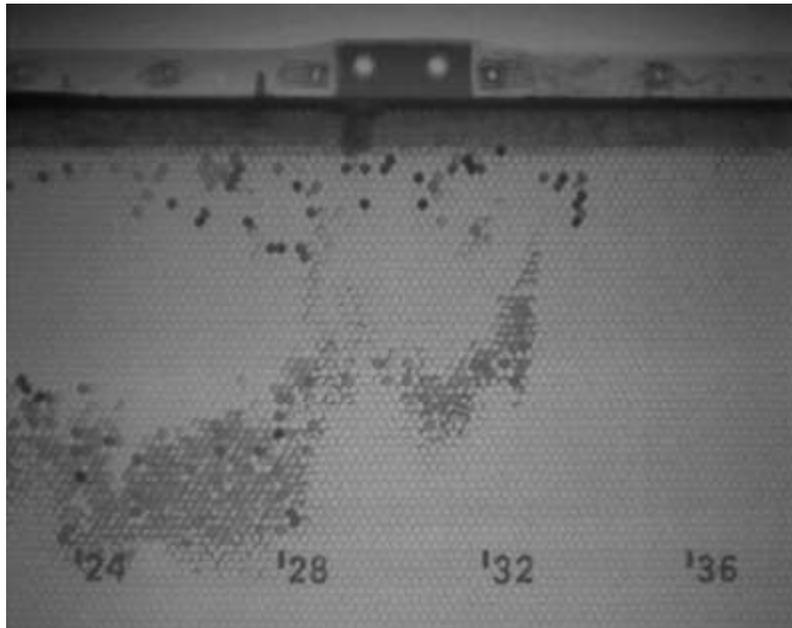


Figure 4: Water Ingress in CF-188 Rudder

Neutron imaging was used as the primary NDE technique in the development of an effective and non-invasive water removal technique for CF-188 flight surfaces. The successful drying method utilizes vacuum pressure and heat to allow water to be removed from the FCS [7]. This process is now performed at CAF fighter bases and has been instrumental in the reintroduction of numerous rudders previously compromised by water ingress. However, not all rudders can be returned to service following the drying procedure. The original designer of the rudders, Northrup Grumman, has developed water ingress limits which restrict the location and degree of water exposure, due to fears of structural degradation [8] [9].

In order to characterize degradation in honeycomb composites and assist in the quantification of degradation, a neutron tomography system was designed and built at RMCC [10]. The tomography system is capable of determining the exact location of water ingress inside honeycomb composites and to identify which structural adhesive bonds potentially are degraded. Figure 5 is a neutron tomographic reconstruction of water ingress in a section of the honeycomb composite core of a CF188 rudder (full and side view).

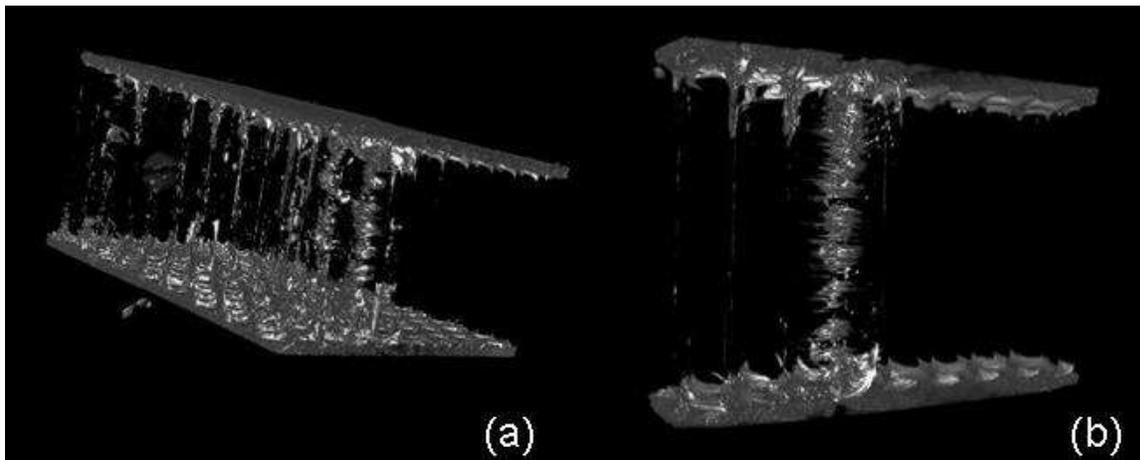


Figure 5: Water Ingress in Honeycomb Core; Full View (a), Section View (b)

3. Conclusions

The SLOWPOKE-2 nuclear research reactor is a powerful and important scientific resource for the CAF. Nuclear capabilities provided by the reactor are used to measure and evaluate a wide range of issues significant to the CAF. NAA is effectively used to determine antimony contamination in SMRs, in coordination with the CAF environmental stewardship program. The design of a DNC system at RMCC provides the CAF with enhanced nuclear forensics capabilities, which can discriminate various SNMs. Lastly the SLOWPOKE-2 Facility has been enhanced to provide neutron imaging, which has proven very effective for the non-destructive evaluation and subsequent repair of CF-188 honeycomb composites. RMCC is committed to continuing to improve and modify the current nuclear capabilities provided by the SLOWPOKE-2 nuclear reactor as well as investigating new opportunities to increase the nuclear capabilities available to the CAF.

4. References

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