Development, Fabrication, and Testing of a Prototype High Temperature Fission Chamber

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INTRODUCTION

The next generation of nuclear reactors will operate in a new regime of high temperature and corrosive environments, requiring modification or complete redesign of instrumentation, as well as structural and mechanical components. One such technology requiring improvement is the neutron detection instrumentation for reactor control and safety systems. Commercial fission chambers used for boiling water reactor (BWR) in-core power measurements are generally limited to service temperatures of 300°C [1]. Oak Ridge National Laboratory (ORNL) has worked for several years to develop an in-core fission chamber capable of operating at temperatures up to 800°C, in corrosive molten salt environments, and at reactor powers spanning many orders of magnitude. Significant work has gone into proper selection of materials compatible at high temperatures, testing of fill gas mixtures to effectively slow high energy fission fragments while increasing electron mobility, and geometrical optimization to maximize neutron detection efficiency at low reactor power. Bell, et al. documented this work in a comprehensive report [2] and included several material suggestions, design considerations, and sensitivity requirements for a fission chamber intended for use in a molten salt or high temperature gas reactor. This report served as a guideline for fabricating a prototype high temperature fission chamber (HTFC) to be tested in a conventional research reactor. A prototype HTFC was designed and assembled at ORNL, along with a customized testing apparatus to simulate conditions found in an advanced high temperature reactor. A complementary suite of signal processing electronics was also developed to continuously acquire signals from the device while operating in pulse-counting or current mode. This electronics development will be discussed in a future publication. The HTFC, electronics, and test assembly were used to characterize the detector response at the Ohio State University Research Reactor (OSURR) under a range of temperature and neutron flux conditions. Aspects of the HTFC design, fabrication, and certain test results are discussed herein.

MATERIALS AND METHODS

Fission Chamber Design and Assembly

The HTFC (Figure 1) is designed to respond as an ionization chamber in a two-gap three-electrode orientation. The HTFC's neutron-sensitive area is composed of three concentric titanium-zinc-molybdenum (TZM) cylinders, each with a selectively located thin coating of low enriched uranium (LEU). Cylinders were coated via electrodeposition [3], and then annealed in argon to remove residual moisture. The coating process deposited LEU in the form of U_3O_8 on the inner and outer surfaces of the three cylinders. Following annealing, the cylinders were assembled concentrically using two pairs of perpendicular alumina rods to provide proper spacing and electrical insulation between electrodes. Braided $Al_2O_3/SiO_2/B_2O_3$ sleeving was placed over the alignment rods to dampen mechanical vibrations between the cylinders and minimize electronic noise. Prior to coating, the TZM wires were brazed in multiple locations at the proximal end of the three cylinders, surrounded by alumina insulating beads, and brazed to electrical connections at the top of the HTFC's primary containment. The electrode assembly was then placed within an alumina cylinder for electrical isolation and loaded into the primary containment.

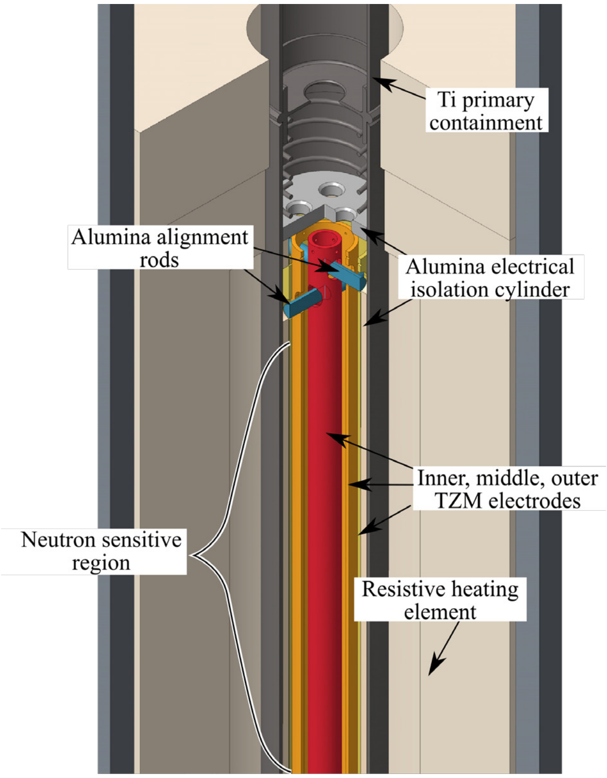

Fig. 1. Principal components of HTFC within the high temperature in-situ testing apparatus.

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The primary containment used for testing the prototype HTFC was constructed from a grade-9 titanium tube (5 cm outer diameter), sealed with a welded endcap on the distal end and a removable ConFlat® flange on the other. Although the containment material selected for use in a corrosive molten salt environment would likely be a high nickel alloy, titanium was selected for prototype testing due to its high melting point and low residual activity following neutron irradiation. The assembled length of the primary containment measured approximately 80 cm, nearly double the length of the TZM electrodes. An electrical feedthrough on the ConFlat® flange was used to couple wires from the TZM cylinders to a mineral insulated (MI), twisted pair, 314 stainless steel sheathed cable. The assembly was then baked in a furnace under rough vacuum to remove moisture from the primary containment.

Following assembly, the primary containment ConFlat® flange was sealed with a copper gasket and backfilled using a custom gas mixture of 99% argon, with 1% nitrogen included for improved electron mobility [2]. The backfill pressure was selected such that the containment would reach atmospheric pressure at the testing temperature of 800°C. The sealed chamber was then leak tested, imaged via X-ray radiography, tested using a low-level Am-Li neutron source, and shipped to the OSURR for in-situ testing.

In-Situ Testing Apparatus

To simulate conditions prototypic of an advanced high temperature reactor, a testing apparatus (Figure 2) was designed to heat the HTFC to 800°C. The 10-inch in-pool dry-tube facility at the OSURR was selected as a suitable location for prototype characterization, and the testing apparatus was designed for compatibility with the facility's dimensional and loading restrictions. Materials were selected to minimize neutron activation in the testing apparatus, relying primarily on titanium, aluminum, and ceramic components. A vertical resistive FeCrAl heating element was used to heat the neutron-sensitive section of the HTFC during irradiation using a 2.5 kW DC power supply. Three k-type thermocouples were spot welded to the HTFC primary containment for temperature logging and control. The heating element was placed within a larger secondary containment and connected to power feedthroughs in the containment lid. A supply of high purity, continuously flowing helium was introduced via fittings in the lid and was exhausted to a continuous air monitor to screen for fission products escaping from the primary containment. A ferruled fitting in the secondary containment lid was used to pass the MI cable from the HTFC to a BNC cable above the assembly, and on to the associated electronics. The secondary containment was also designed for ease of transport between experiment locations at the OSURR (in-pool and out-of-pool) and was equipped with a hook mount for easy relocation via overhead crane.

Fig. 2. Schematic for in-situ testing apparatus showing temperature control, data acquisition, and fission product monitoring systems used for HTFC characterization.

Experimental Test Conditions

Test conditions for the HTFC were designed to characterize the detector's response over a wide range of neutron fields, gamma fields, and temperatures. Primary objectives of the test plan were to determine the neutron flux at which the pulse-to-current mode transition occurs and the lower threshold of detection sensitivity. For these measurements, the testing apparatus was positioned adjacent to the thermal column of the OSURR before testing was conducted in the high flux 10-inch dry tube. The thermal column is a facility external to the reactor pool and shielding, composed of high purity graphite and designed to provide a reduced thermal flux to an experimental location in open air. This location allows the reactor to be critical at minimum stable power while providing a steady-state flux low enough to simulate startup. Testing was initiated in this location while acquiring signals from the HTFC over a range of temperatures. Reactor power was limited to 2 kWth while experimenting in the thermal column and 200 kWth in the 10-inch dry tube due to personnel dose rate restrictions.

RESULTS

The HTFC was intended to be tested over a range of reactor power levels and temperatures simulating the conditions experienced during startup of an advanced reactor. With the HTFC positioned in the OSURR thermal column, fission product spectra were acquired at several low reactor powers (50–2,000 Wth) while the temperature of the detector was increased from 20°C to 500°C. Figure 3 shows a representative low temperature (140°C) pulse spectrum from the detector, with a broad continuous peak at high energies from fission fragments, and an intense low energy peak that was likely due to gammas from the reactor, alpha decay from ^{234}U in the detector coating, and thermal electronic noise. ADC channels in the spectrum correspond to energy deposited in the detector gas by individual fission fragments or other ionizing radiation events. Multiple spectra were acquired during temperature ramping, with the low energy peak demonstrating a dependence between count rate and temperature.

High-frequency noise from the test environment obstructed the signal processing electronics, requiring the instrumentation to remain in close proximity to the HTFC. This eliminated the possibility of testing in the high flux 10-inch dry tube. Neutron testing was therefore limited to the thermal column location, with the electronics placed nearby behind reactor shielding material. During temperature ramping to 500°C, the fission chamber experienced a high resistance internal electrical short, causing the detector's pulse output to change. Testing was halted and the HTFC was analyzed for determination of the failure point. Results from this experiment, along with lessons learned and suggestions for future work, will be presented in this talk.

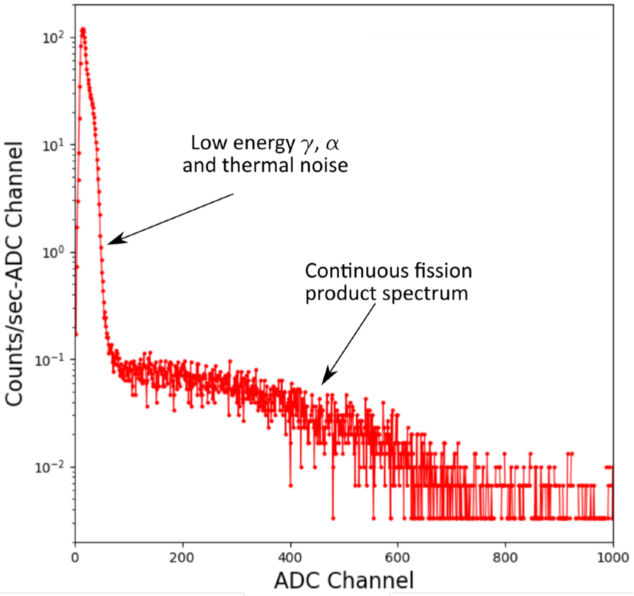

Fig. 3. Representative HTFC pulse spectrum measured during low temperature, low reactor power (150 Wth) testing.

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