In-Core Evaluation of Online Instrumentation in the TREAT Reactor

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INTRODUCTION

The recent resumption of operations at Transient Reactor Test (TREAT) Facility at Idaho National Laboratory has opened the door to a new generation of fuels and materials testing under transient irradiation conditions. Capability development and qualification of advanced in-pile instrumentation is ongoing to support the goals of advanced reactor technologies and a variety of other science missions. A fundamental component of instrument qualification for experiment deployments is in-core evaluation of the sensor performance under transient irradiation conditions. In-core testing of multiple advanced sensor technologies are planned for qualification in the TREAT reactor core.

The primary purpose of current instrumentation deployments at the TREAT Facility is to integrate advanced instrumentation technologies and to evaluate the performance of miniature on-line neutron flux detectors and optical-fibers in the reactor core during transient irradiations. A second purpose is to support ongoing reactor physics testing to characterize reactor performance during transient and steady-state operations. The instrument technologies are of strategic importance for achieving near- and long-term, cross-cutting experiment objectives at TREAT [1],[2]. Instrument characterization in TREAT is critical for providing qualified instruments for future experiments.

The specific objectives of instrumentation deployments in the TREAT reactor core include:

1. Perform measurements of physics parameters including in-pile, real-time neutron flux and temperature in TREAT coolant channels and other locations having vertical access holes approximately 1.27 to 5 cm (0.5 to 2 inch) in diameter.
2. Evaluate the effects of neutron and gamma irradiation (including very high flux levels ~10^{17} thermal neutrons/cm^2) on the performance of in-pile flux and fiber optic sensors and of ex-core instrumentation components such as data acquisition systems, signal conditioning electronics, and sensor lead cabling.

The overall strategy of these deployments is focused on accompanying other planned concurrent irradiations in TREAT. The suite of sensors have been chosen because of their design to have minimal impact on reactor operations and concurrent experiments.

DESCRIPTION OF IN-PILE INSTRUMENTATION

Instrumentation hardware has been prepared to facilitate insertion of sensors in TREAT coolant channels and other top-access holes such as the experiment hole, empty control rod guide tubes, or the vertical access hole fuel assembly. The general sensor designs consist of an elongated probe made of insulator wrapped in metal sheathing. Specifically, the sensor design enables locating the sensors down the coolant channels, empty control rod positions, and vertical-access-hole dummy fuel assemblies for versatile applications. The flux sensors to be deployed in this phase of testing include the Micro-Pocket Fission Detector (MPFD) and fast-response Self-Powered Neutron Detectors (SPND) coupled with passive dosimetry for cross-validation. Fiber-based sensors include single-mode fibers coupled to a pyrometer and a distributed temperature fiber sensor coupled to an optical backscatter reflectometer (OBR) device. In addition, standard Mineral-Insulated Metal-Sheathed (MIMS) thermocouples are included to provide comparative temperature measurements for the fiber-based sensors.

Micro-Pocket Fission Detectors

Micro-Pocket Fission Detectors (MPFD) utilize the same operating principle as coaxial fission chambers but with a different geometry [2],[3]. The MPFD design uses parallel electrodes instead of coaxial cylinders. Figure 1 provides a schematic of an MPFD assembly. The primary components include a stacked chamber design containing a thin fissile layer on one side of each chamber, ceramic insulators to isolate chambers and electrical lines, and metallic electrical lines.

The MPFD design is distinguished from other fission chambers because its signal is not based on full energy deposition in the electrode gap from the fission products. This departure from conventional fission chamber design and operating characteristics allows the MPFDs to have a smaller chamber size with a lower fill gas pressure. The MPFD design has good discrimination characteristics because the energy deposited by the fission products is greater than background radiation interactions in the detector. An additional benefit of the small size is a faster response time. The construction materials chosen for the MPFD include temperature and radiation resistant ceramics well suited for transient conditions in TREAT experiments.

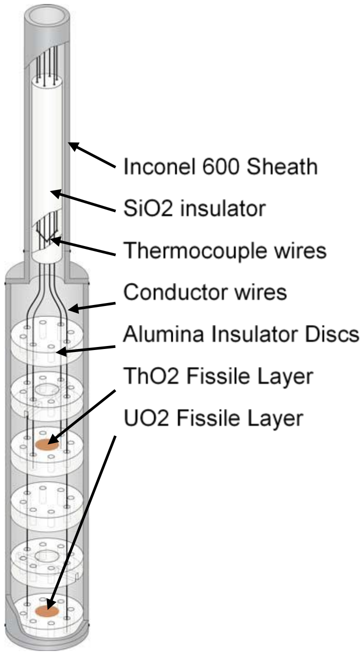

Fig. 1. Schematic overview of Micro-Pocket Fission Detector (MPFD) assembly components.

Currently, the TREAT experiments program views the MPFD as a high-impact instrument with likelihood to become a primary tool in TREAT measurements. The use of the sensor in future testing at TREAT is extensive and could accompany nearly any experiment placed into the core and become integral to TREAT operations. The MPFD is still largely a developmental technology with initial transient testing performed under pulsed reactor environments at lower flux university reactors. Therefore, early deployments in TREAT will focus on fundamental response of the detector to TREAT fluxes under a variety of reactor transient conditions. This data will represent unique in-core flux data for comparison with fast-response SPND's.

Self-Powered Neutron Detector

Self-Powered Neutron Detectors (SPND) consist of an insulated coaxial cable with an emitter in the sensor region at the end of the cable as shown in Figure 2. The two types of SPNDs, fast- and slow-response, are dependent on the emitter material. The emitter is connected directly to the center lead wire and the sheath collects and transmits the collected current from emitter (n, γ) reaction. These sensors can also include a second lead wire extends the length of the cable, ending just before the emitter portion of the device (see Figure 2). This lead wire collects a gamma induced current that is nearly identical to the gamma induced current collected by the emitter's lead wire. Therefore, it serves to compensate for background gamma effects.

SPNDs were previously used in TREAT to directly measure transient neutron flux in-core [4]. In a historical TREAT study, commercial, SPND's were found to perform very well in steady-state and transient operations. These SPNDs were of the fast-response type utilizing hafnium and gadolinium emitter materials. The same SPND's used historically at TREAT have been located at INL and are planned to be reinserted into TREAT to measure neutron flux levels and in-core power response during rapid reactivity insertion transients. The SPND may be inserted into a thin electrically insulated sleeve to isolate the SPND cabling from metallic surfaces within the TREAT core to reduce unwanted noise.

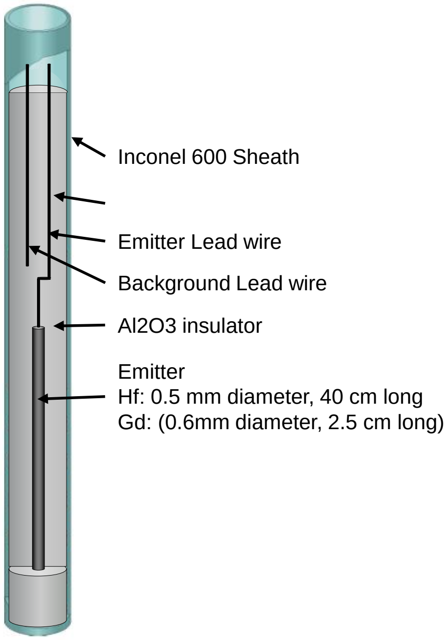

Fig. 2. Schematic overview of a Self-Powered Neutron Detector (SPND) assembly.

Optical-Fiber-Based Metrology

Light transmitted through optical-fibers can provide temperature measurements. The standard Optical Fiber Assembly (OFA) for TREAT will consist of a small metal sheath containing an optical fiber. The fiber in the OFA is SiO_2 with a maximum outer diameter of 1 mm. A schematic representation is shown in Figure 3. The two types of optical-fibers used are single- and multi-mode fibers. Single- and multi-mode fibers are both made from SiO_2. The primary physical difference between the two is the size of the fiber core being much smaller for single mode fiber.

Three measurements will be performed for initial research: fiber irradiation exposure effect measurements; distributed temperature measurements; and temperature validation measurements.

Fiber irradiation exposure effect measurements will be performed at the core mid-plane with single- and multi-mode fibers coupled to a detector system and a light source. Distributed temperature measurements will be performed along the vertical length of the core with a single-mode fiber coupled to an OBR. Temperature validation measurements will be performed at the core mid-plane with a multi-mode fiber coupled to a pyrometer system. A thermocouple, described in the following section, will be inserted directly next to the sheathed fiber assembly with the tips tack-welded together to provide comparative temperature measurements with the pyrometer system.

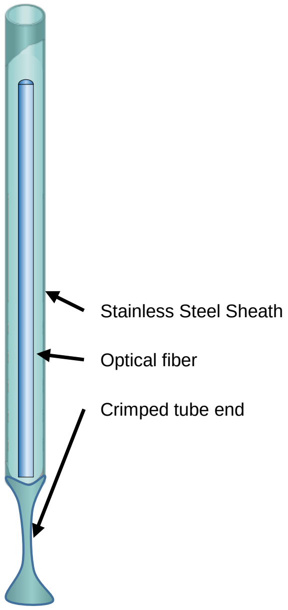

Fig. 3. Schematic overview of the in-core optical fiber.

Thermocouples

Schematics of a standard MIMS Type K thermocouples is shown in Figure 4. The overall construction is similar to MPFD and SPND but having MgO insulation surrounding the pair of thermocouple wires. Thermocouple wires are dissimilar metals joined at a junction that develops voltage differences between the two ends as a function of temperature. Thermocouples are standard sensors for measuring temperature and are only planned to be used to directly accompany other sensors in the TREAT core.

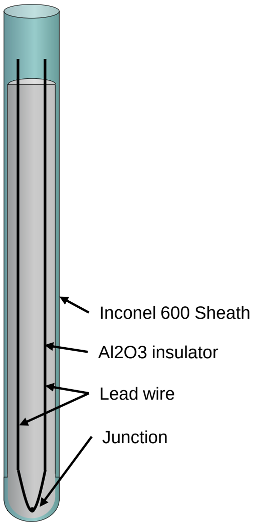

Fig. 4. Schematic overview of a metal-sheathed mineral insulated thermocouple with ungrounded junction.

SUMMARY & CONCLUSIONS

Advanced in-pile instrumentation is critical to achieving the goals of fuel safety research at the TREAT reactor. The TREAT Facility provides unique in-pile accessibility to allow versatile instrumentation and advanced metrology approaches. The recent restart of the TREAT reactor provides a unique opportunity to evaluate and qualify instrumentation for data collection supporting transient irradiation experiments. Initial in-pile exploration is being planned and will begin execution within the next few months to explore the performance of multiple miniature neutron flux sensors and optical fibers in the transient irradiation environment.

REFERENCES

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