ENHANCED MICRO-POCKET FISSION DETECTOR FOR HIGH TEMPERATURE REACTOR EVALUATIONS

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ABSTRACT

A collaboration between the Idaho National Laboratory (INL), the Kansas State University (KSU), and the French Atomic Energy Agency, Commissariat à l'Énergie Atomique et aux Energies Alternatives, (CEA), has been initiated by the Nuclear Energy Enabling Technologies (NEET) Advanced Sensors and Instrumentation (ASI) program for developing and testing High Temperature Micro-Pocket Fission Detectors (HT MPFD), which are compact fission chambers capable of simultaneously measuring thermal neutron flux, fast neutron flux and temperature within a single package for temperatures up to 800 °C. The MPFD technology utilizes small, multi-purpose, robust, in-core fission chambers and can be configured with a thermocouple. The small size, variable sensitivity, and increased accuracy of the MPFD technology represent a revolutionary improvement over current methods used to support irradiations in US Material Test Reactors (MTRs). Previous research conducted through NEET ASI has shown that the MPFD technology could be made robust and was successfully tested in a reactor core.

In addition, the accomplishments of this project have attracted independent funding from other Department of Energy Office of Nuclear Energy (DOE-NE) programs for MTR irradiations of the MPFD technology.

Key Words: Micro, Pocket, Fission, Detector, Neutron

1 INTRODUCTION

During the last 40 to 50 years, various sensors have been developed to meet the needs of irradiation testing for fuels and materials in Material Test Reactors (MTR). Development of these sensors is an on-going process because they are continuously improved and refined to overcome operational shortcomings associated with more complicated irradiation testing requirements. Recent interest in testing to support new reactor fuels and materials can require higher temperatures, higher fluxes, or more corrosive test conditions. The next generation of sensors is under development that can survive these conditions.

In-core fission chamber design has remained relatively unchanged for decades. Improvements in performance, overall size, and operational modes have been implemented; however, all have been based on the same design that utilizes coaxial cylinders with a high pressure fill gas. These design considerations limit the robustness, lifetime, size, and operational performance of such sensors in high performance MTR environments.

The Micro-Pocket Fission Detector (MPFD) technology (Fig. 1) utilizes the same operational concept of existing fission chamber designs, but deploys different geometry, construction, materials and operational characteristics. The small design also allows two or more of these neutron detectors and a thermocouple to be co-located within a single sensor sheath such that thermal flux, fast flux, and temperature can be simultaneously measured at very near the same location in the experiment with a single penetration in the experimental pressure boundary.

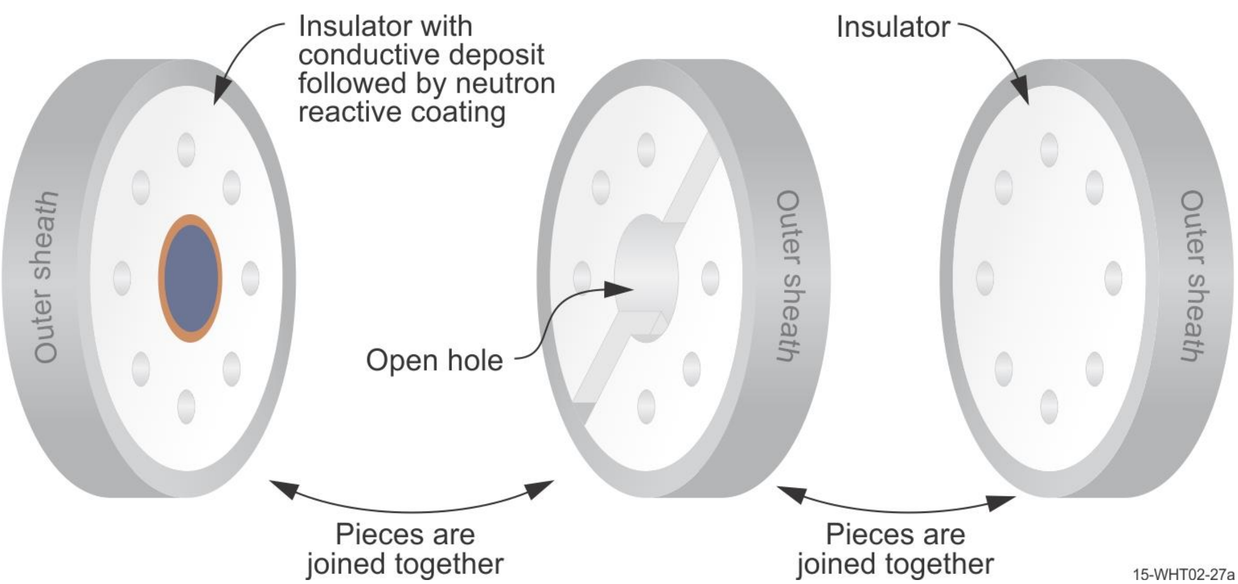

Figure 1. Round geometry parallel wire HT MPFD design suitable for MTR irradiations

Previous research conducted through Nuclear Energy Enabling Technologies (NEET) Advanced Sensors and Instrumentation (ASI) program has shown that the MPFD technology could be made robust and was successfully tested in a reactor core [1-3]. A new NEET ASI project has further refined the MPFD technology for higher temperature regimes and other reactor applications by developing a High Temperature MPFD (HT MPFD) [4-5].

2 BACKGROUND

A key objective of several DOE-NE programs is to understand the performance of candidate fuels and materials during irradiation. Hence, NEET research must produce sensors able to withstand the operating conditions of interest to these DOE-NE programs. It is also important that the sensors be able to measure test parameters with the desired accuracy and resolution required by these DOE-NE programs and that the sensors be compact to minimize their impact on irradiation test data.

The NEET ASI in-pile instrumentation development activities are focused upon addressing cross-cutting needs for DOE-NE irradiation testing by providing higher fidelity, real-time data with increased accuracy and resolution from smaller, compact sensors that are less intrusive [6]. The NEET ASI program initiated the HT MPFD project because it addresses this cross-cutting need by developing, fabricating, and evaluating the performance of compact multi-purpose fission chambers with integral temperature sensors that could survive up to 800 °C.

2.1 Micro-Pocket Fission Detectors to High Temperature Micro-Pocket Fission Detectors

Initial development of several prototypes MPFD designs began in the early 2000's at Kansas State University (KSU). These prototypes were tested in a neutron beam and in the reactor core at the KSU TRIGA research reactor with successful results [7-12]. However, it was recognized that the manufacturing process was not ideal to produce detectors for in-core applications.

The MPFD technology gained interest for further development during a 3 year project to refine previous MPFD designs for use in MTR irradiations. A NEET ASI project, Micro-Pocket Fission Detector, was awarded in 2012 to develop a MPFD design suitable for use in these harsh irradiation conditions [1-3]. This MPFD design for MTR irradiations uses a round stackable geometry that is more suitable for installation in leak-tight swaged, drawn, or loose assembly tubes. This project demonstrated the potential of a new sensor that offers US MTR users enhanced capabilities for real-time measurement of the thermal and fast flux (Fig. 2) and of temperature with a single, miniature detector. These accomplishments attracted funding for MPFD deployments from several DOE-NE irradiation testing programs as well as continued funding from NEET ASI to develop a high temperature compatible MPFD, the HT MPFD.

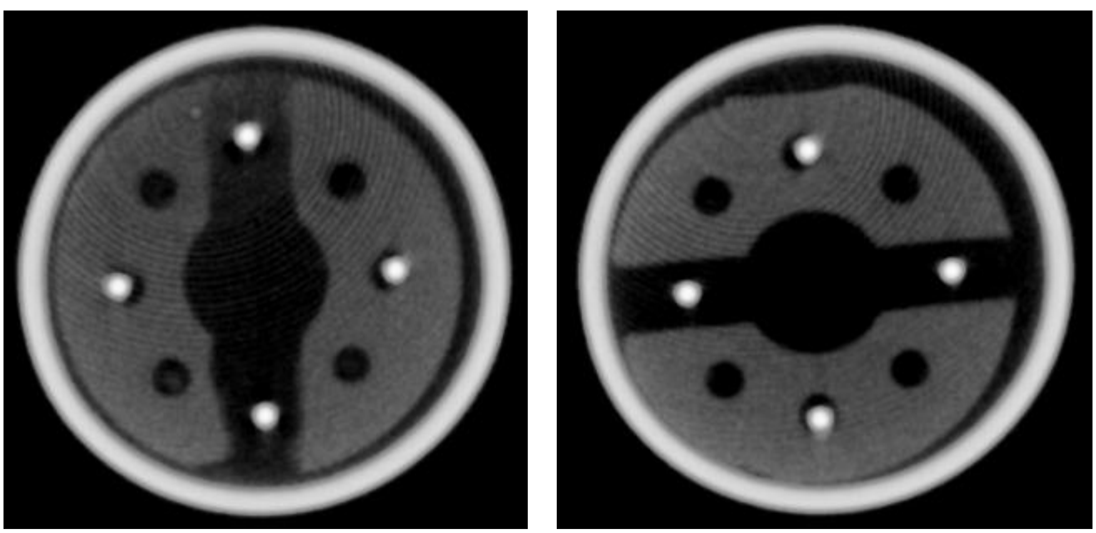

Figure 2. Fast neutron detector (left) and thermal neutron detector (right) X-ray cross section

2.1.1 HT MPFD Design and Fabrication Updates

The HT MPFD sensor design included several updates to improve detector robustness and performance. The sensor design was updated from a parallel plate to a parallel wire design. The parallel plate design uses a conductive adhesive that has a potential failure mechanism due to breakdown of the adhesive during a long duration irradiation test. The parallel wire design (Fig. 3) does not use this adhesive, eliminating that failure mechanism, and represents a significant improvement in HT MPFD survivability.

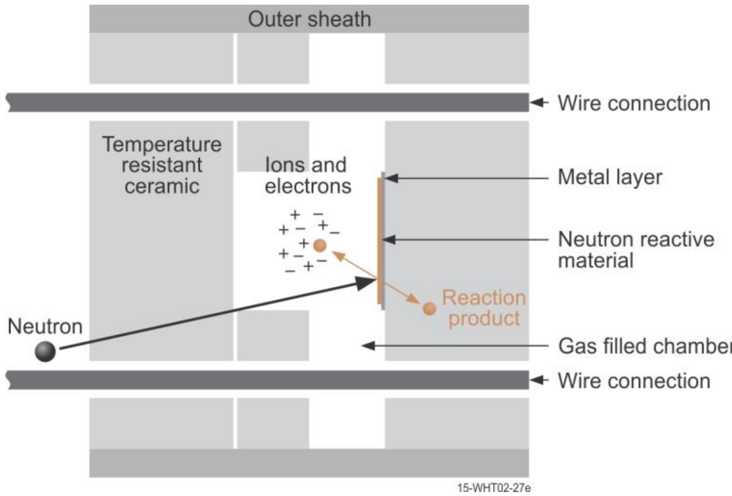

Figure 3. HT MPFD component diagram

Fabrication methods and materials (Fig. 4) were also revisited to produce improved fissile material coatings [13] as well as to use sheath materials compatible for installation into DOE-NE irradiation experiments. Modeling has shown that a wall thickness of 0.020" will allow the integrity of the sheath to survive in accident conditions up to 9000 psi as required for transient irradiation testing. In addition, the HT MPFD design moves the thermocouple to the extension cable to improve thermocouple response.

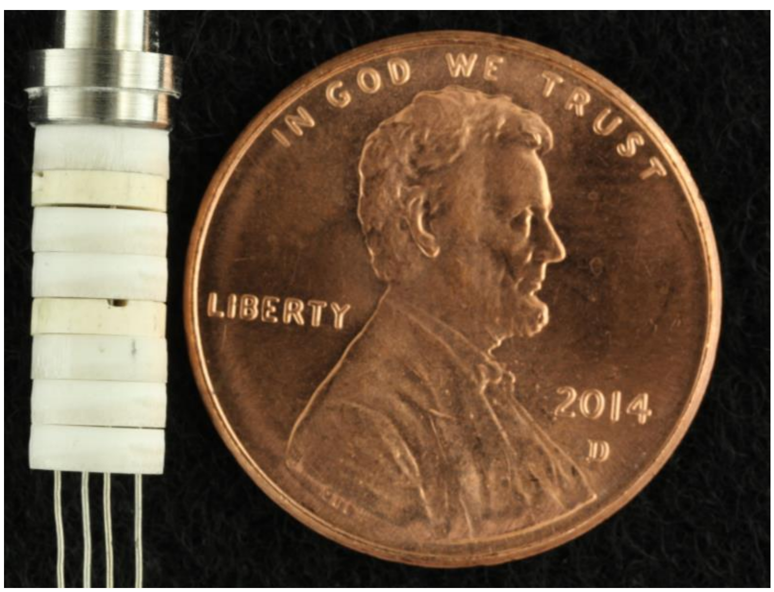

Figure 4. Loose assembly of HT MPFD

2.1.2 HT MPFD Amplifier Electronic Improvements

In addition to improvements in robustness, electrical performance was improved through the development of a specially designed 4 channel amplifier electronic module. The Mesytec MPFD-4 was developed with a humidity resistant pre-amplifier box that interfaces directly with a NIM compatible processing module. This system includes charge sensitive preamplifiers, a HV bias supply, a filter stage and associated discriminators. All adjustments and data can be controlled and transmitted via USB interface. In addition, the electronics will output up to 4 discriminator signals for an external counter offering flexibility for data collection during irradiation tests.

2.1.3 HT MPFD MCNP Model for Transient Reactor Experiments

HT MPFDs will be deployed along with other advanced instrumentation in the multi-Static Environment Rodlet Transient Test Apparatus (SERTTA) vehicle in the central test channel in the Transient REActor Test Facility (TREAT). The current HT MPFD design for tests at the TREAT facility was modeled in MCNP (Fig. 5) and tested in the expected neutron flux profile [15]. The parameters for the current MPFD design were found to have no negative effects on the operation of the sensor or on the neutron flux in the vicinity of the experimental assembly. These results show that the expected interaction rate of the fissile coating of an MPFD during peak flux levels of a TREAT pulse will exceed the operational range of traditional pulse-mode operation. Subsequently, current-mode electronics are being developed in support of transient testing of MPFDs.

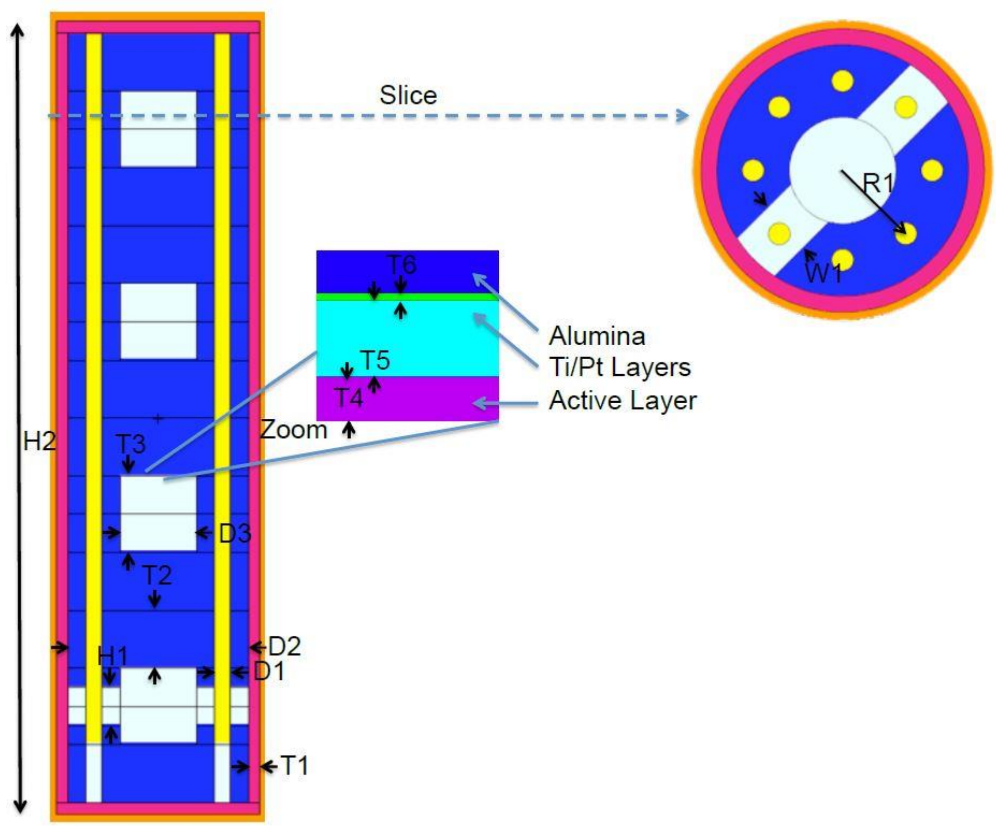

Figure 5. HT MPFD thermocouple placement in final assembly [15]

2.2 HT MPFD MTR Evaluations

As previously stated, sensors developed for NEET ASI projects should strive to meet irradiation testing program needs. Two MTR irradiation programs have recognized the value of the NEET-developed HT MPFD technology and are independently funding deployments of HT MPFDs. These are significant opportunities for the NEET Enhanced Micro-Pocket Fission Detector for High Temperature Reactors project because the expense of these irradiations could not be included in the original project scope.

2.2.1 Advanced Gas-cooled Reactor 5/6/7 Irradiation

The Next Generation Nuclear Plant program is pursing evaluations of a suite of advanced real-time in-core sensors during their 3 year test campaign in the Advanced Test Reactor (ATR). The Advanced Gas-cooled Reactor (AGR) 5/6/7 irradiation program is funding the sensor procurement, data acquisition system and engineering effort required to integrate sensors into the irradiation test. Prototype MPFD's have been built, tested, and analyzed as shown in the X-ray image in Fig. 6.

Figure 6. HT MPFD thermocouple placement in final assembly

The program will use the HT MPFD design, but has requested a change from a Type K to a Type N thermocouple (Fig. 6) to match the other thermocouples installed in the test. The HT MPFD will be tested at unprecedented flux levels by leveraging the AGR 5/6/7 irradiation program. This evaluation will further demonstrate the usefulness of the HT MPFD to simultaneously measure fast flux, thermal flux and temperature in a typical ATR long duration irradiation test. Recent activities include development of a cabinet to house the data acquisition hardware and software associated with the AGR 5/6/7 instrumentation. In addition, appropriate material certifications, drawings and fabrication procedures have been developed to meet program needs.

2.2.2 Accident Tolerant Fuels

The Accident Tolerant Fuels (ATF) program is deploying the HT MPFD technology for two irradiations. The first irradiation, ATF-2, will evaluate a suite of advanced sensors, including the NEET-developed HT MPFD, in the ATR during a sensor qualification test. The ATF-2 irradiation program is funding the construction, installation and testing of a HT MPFD (along with other advanced sensors) during these irradiations. The irradiation isn't expected to be as long as the AGR 5/6/7 irradiation, but will still provide valuable insight into the operation of a HT MPFD in a typical ATR irradiation.

The second irradiation, ATF-3, will evaluate a specialized version of the HT MPFD that is suitable for TREAT transients. This version of the HT MPFD is scheduled to be installed in the multi-SERTTA to aid in the monitoring of experiment transients. This effort will be a departure from previous HT MPFD designs because the focus will be on developing a robust, fast response MPFD that has four neutron detectors and does not include a thermocouple as shown in Figure 7.

Although the transient-specific HT MPFD design developed by ATF-3 will be different from other HT MPFD designs, it is expected that the information gained in the development of this transient-specific MPFD will aid in further developing the HT MPFD to survive the harsh conditions of a reactor transient. In addition, the information gained from initial ATF-3 irradiations will guide the future use of transient-specific HT MPFDs for TREAT irradiation testing in support of various DOE-NE programs requesting advanced instrumentation capabilities suitable for transient testing.

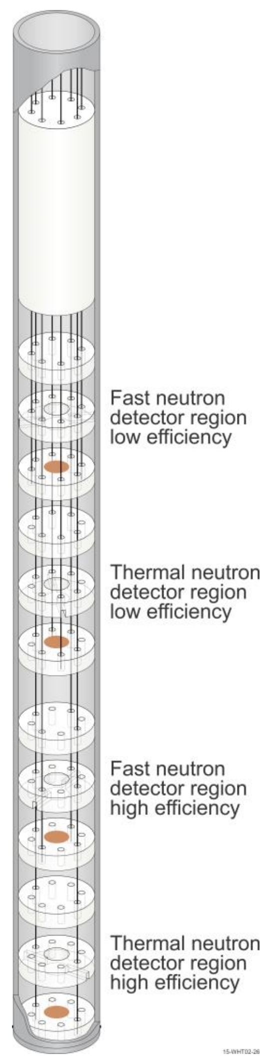

Figure 7. Transient MPFD for ATF-3 multi-SERTTA TREAT irradiation

3 SUMMARY

This HT MPFD research project is continuing to develop a robust sensor for DOE-NE irradiation testing programs. Highlights from recent research accomplishments include an updated parallel wire HT MPFD design, program support for HT MPFD deployments was given to DOE-NE irradiation testing programs, improvement of electrical contact plating and fissile material deposition, a prototype HT MPFD was constructed and analyzed, detector amplifier electronics have been updated and received, and the HT MPFD has been modeled in MCNP to optimize performance for transient irradiation deployments.

4 ACKNOWLEDGMENTS

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