U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Office Of Nuclear Energy
Sensors and Instrumentation
Annual Review Meeting

Enhanced Micro-Pocket Fission Detector (MPFD) for High Temperature Reactors

Troy Unruh
Idaho National Laboratory
Nuclear Energy Enabling Technologies

October 28-29, 2015

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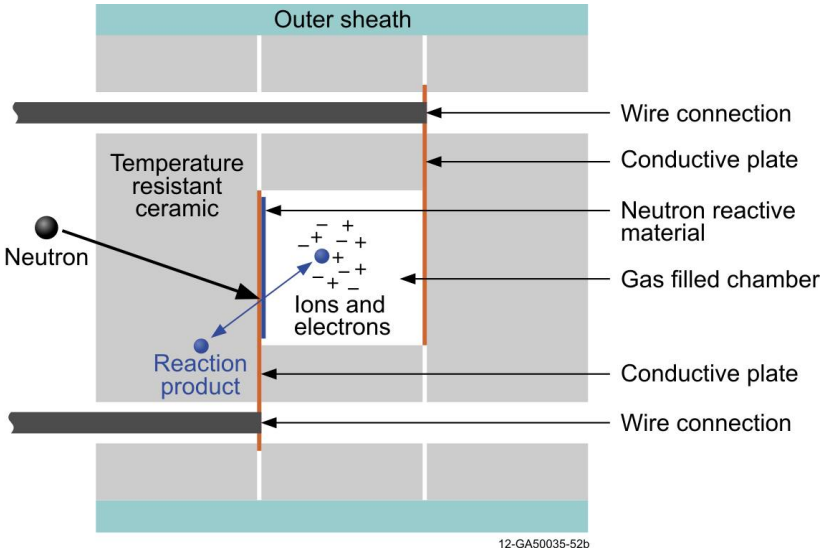
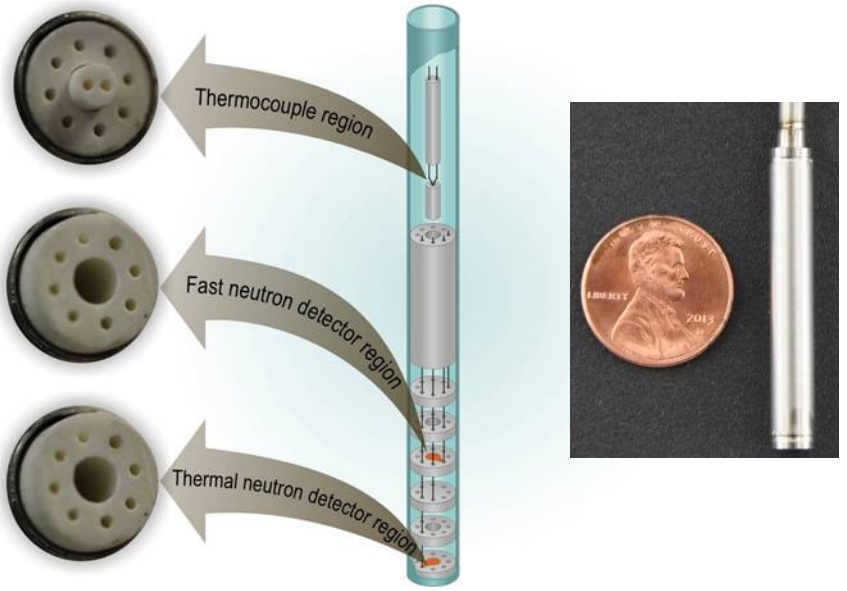
Project Overview

Goal, and Objectives

- Develop and test high temperature capable (to 800 ºC) Micro-Pocket Fission Detectors (HT MPFDs), which are compact fission chambers capable of simultaneously measuring thermal neutron flux, fast neutron flux and temperature within a single package.



Micro-Pocket Fission Detector Theory of Operation



Full Micro-Pocket Fission Detector Diagram and Prototype

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Project Overview

- **Participants**
  - Troy Unruh; Idaho National Laboratory
  - Philip Ugorowski, Douglas McGregor, and Michael Reichenberger; Kansas State University
  - Jean-François Villard; Commissariate a l'energie atomique

NEET Nuclear Energy Enabling Technologies

K-STATE Kansas State University

INL Idaho National Laboratory

cea energie atomique • energies alternatives

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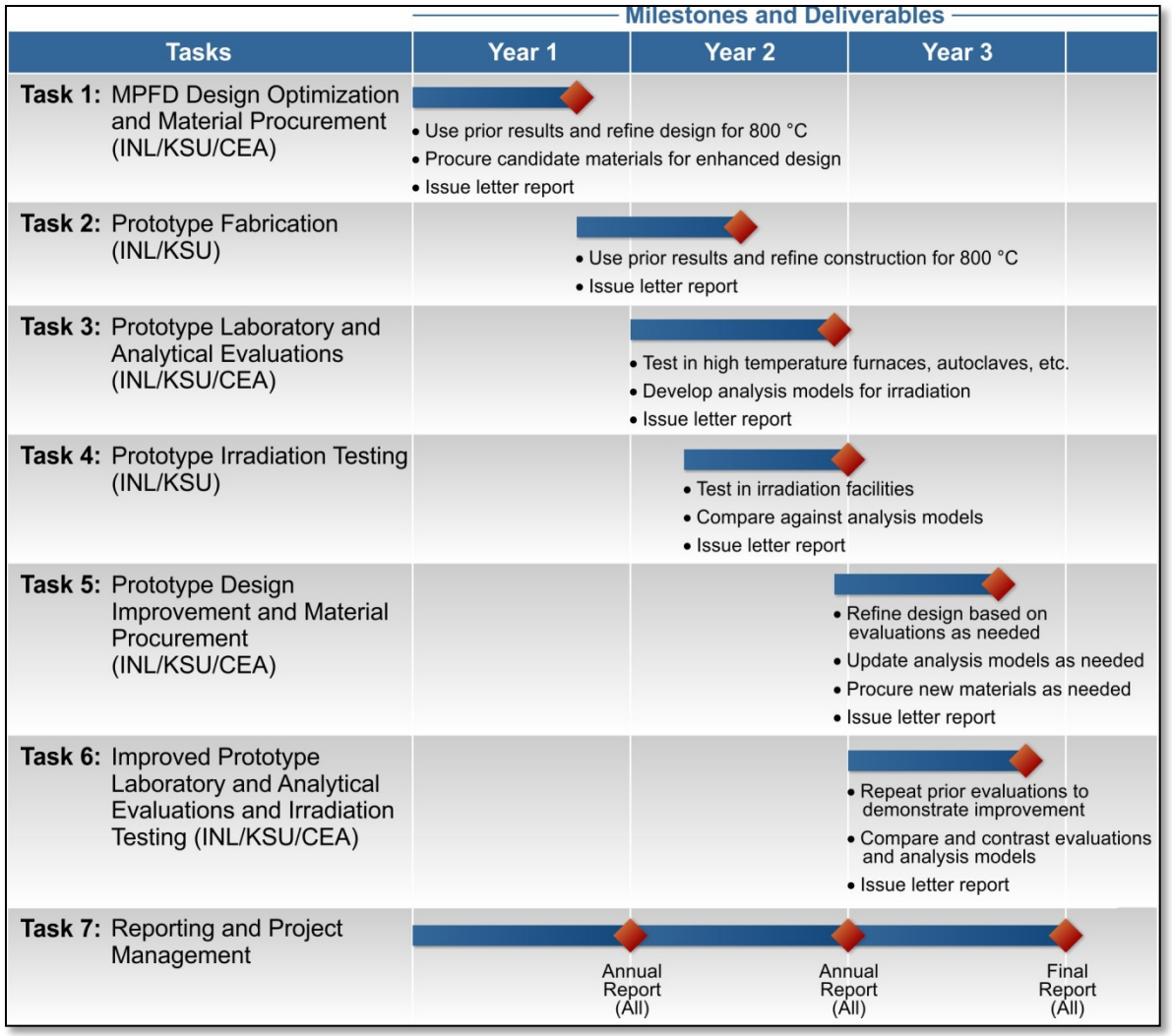
Project Overview

Schedule



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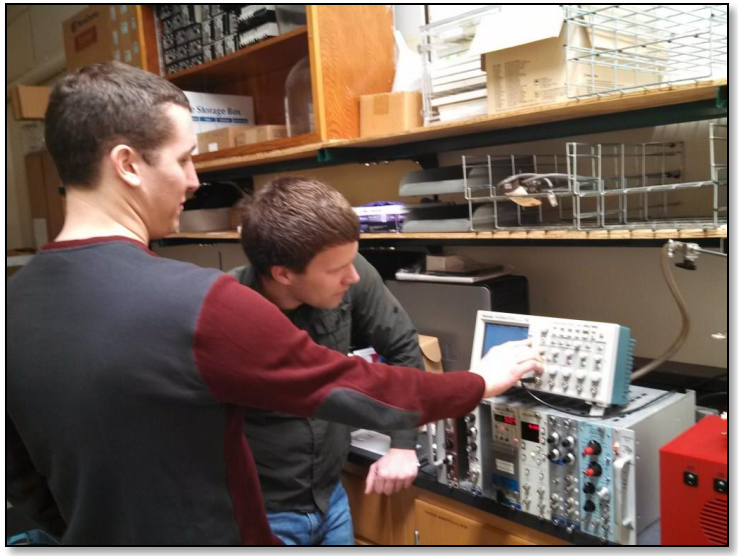
Accomplishments

FY15 Milestones, Deliverables and Outcomes

- Meeting with CEA collaborators to discuss CEA computer modeling capabilities of the MPFD design, 11/13/2014
- Project Kickoff meeting at KSU to discuss roles and responsibilities (M4), 12/22/2014

November meeting with CEA at INL



December meeting at KSU

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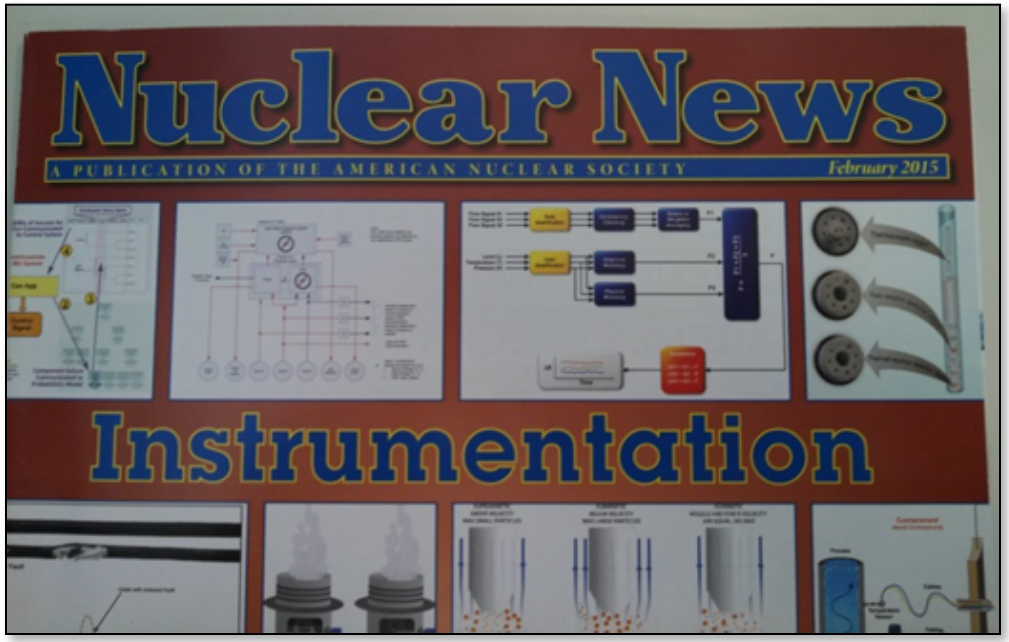
Accomplishments

FY15 Milestones, Deliverables and Outcomes

- Presented "Enhanced Micro Pocket Fission Detector Evaluations" at 2015 Nuclear Plant Instrumentation, Control & Human-Machine Interface Technologies (NPIC-HMIT) Conference, February 23-25, 2015
- Cover and article in Nuclear News, February 2015



February NEET ASI article on page 63

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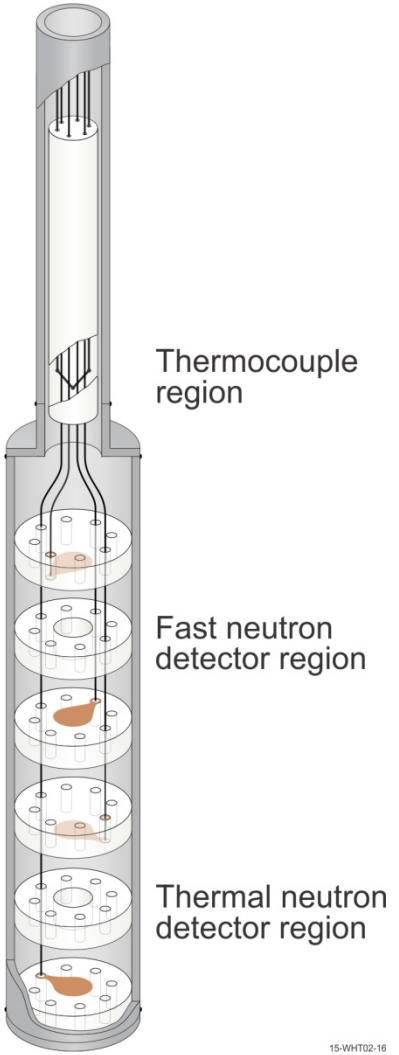
Accomplishments

FY15 Milestones, Deliverables and Outcomes

- Provide input to irradiation programs interested in HT MPFD technology (independently funded)
  - Accident Tolerant Fuels (ATF)
  - Advanced Gas Reactor (AGR)
- Procure candidate materials (M3), 4/30/2015
  - Update to Inconel 625 outer sheath
  - Ultra-smooth alumina instulators
- Develop HT MPFD design (M2), 7/31/2015
  - Move thermocouple to extension cable
  - Increase sheath wall thickness to 0.020” (requested by ATF)
  - Use Type N thermocouple (requested by AGR)
- Initiate electroplating at amplifier development at KSU (M4), 9/30/2015



NEET-developed HT MPFD

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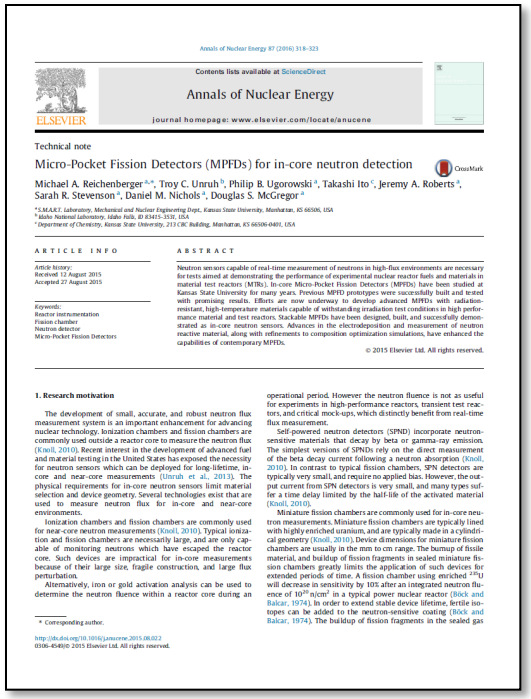
Accomplishments

FY15 Milestones, Deliverables and Outcomes

- KSU Student Paper, “Micro-Pocket Fission Detectors (MPFDs) for In-Core Neutron Detection”, Annals of Nuclear Energy, accepted August 2015.
- Issue “NEET Enhanced Micro-Pocket Fission Detector for High Temperature Reactors - FY15 Status Report, INL/EXT-15-36637” (M2), 9/30/2015



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Technical note

Micro-Pocket Fission Detectors (MPFDs) for in-core neutron detection

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ABSTRACT

Neutron sensors capable of real-time measurement of neutrons in high-flux environments are necessary for tests aimed at demonstrating the performance of experimental nuclear reactor fuels and materials in material test reactors (MTRs). In-core Micro-Pocket Fission Detectors (MPFDs) have been studied at Kansas State University for many years. Previous MPFD prototypes were successfully built and tested with promising results. Efforts are now underway to develop advanced MPFDs with radiation-resistant, high-temperature materials capable of withstanding irradiation test conditions in high performance material and test reactors. Stackable MPFDs have been designed, built, and successfully demonstrated as in-core neutron sensors. Advances in the electrodeposition and measurement of neutron reactive material, along with refinements to composition optimization simulations, have enhanced the capabilities of contemporary MPFDs.

1. Research motivation

The development of small, accurate, and robust neutron flux measurement system is an important enhancement for advancing nuclear technology. Ionization chambers and fission chambers are commonly used outside a reactor core to measure the neutron flux (Knoll, 2010). Recent interest in the development of advanced fuel and material testing in the United States has exposed the necessity for neutron sensors which can be deployed for long-lifetime, in-core and near-core measurements (Unruh et al., 2013). The physical requirements for in-core neutron sensors limit material selection and device geometry. Several technologies exist that are used to measure neutron flux for in-core and near-core environments.

Ionization chambers and fission chambers are commonly used for near-core neutron measurements (Knoll, 2010). Typical ionization and fission chambers are necessarily large, and are only capable of monitoring neutrons which have escaped the reactor core. Such devices are impractical for in-core measurements because of their large size, fragile construction, and large flux perturbation.

Alternatively, iron or gold activation analysis can be used to determine the neutron fluence within a reactor core during an operational period. However the neutron fluence is not as useful for experiments in high-performance reactors, transient test reactors, and critical mock-ups, which distinctly benefit from real-time flux measurement.

Self-powered neutron detectors (SPND) incorporate neutron-sensitive materials that decay by beta or gamma-ray emission. The simplest versions of SPNDs rely on the direct measurement of the beta decay current following a neutron absorption (Knoll, 2010). In contrast to typical fission chambers, SPN detectors are typically very small, and require no applied bias. However, the output current from SPN detectors is very small, and many types suffer a time delay limited by the half-life of the activated material (Knoll, 2010).

Miniature fission chambers are commonly used for in-core neutron measurements. Miniature fission chambers are typically lined with highly enriched uranium, and are typically made in a cylindrical geometry (Knoll, 2010). Device dimensions for miniature fission chambers are usually in the mm to cm range. The burnup of fissile material, and buildup of fission fragments in sealed miniature fission chambers greatly limits the application of such devices for extended periods of time. A fission chamber using enriched ^{235}U will decrease in sensitivity by 10% after an integrated neutron fluence of 10^{20} n/cm^2 in a typical power nuclear reactor (Böck and Balcar, 1974). In order to extend stable device lifetime, fertile isotopes can be added to the neutron-sensitive coating (Böck and Balcar, 1974). The buildup of fission fragments in the sealed gas

* Corresponding author.

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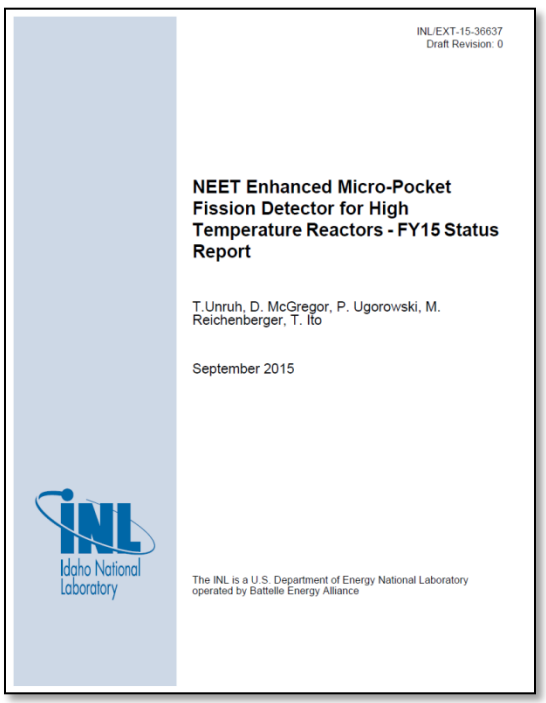
0306-4549/



INL/EXT-15-36637
Draft Revision: 0

NEET Enhanced Micro-Pocket Fission Detector for High Temperature Reactors - FY15 Status Report

T.Unruh, D. McGregor, P. Ugorowski, M. Reichenberger, T. Ito

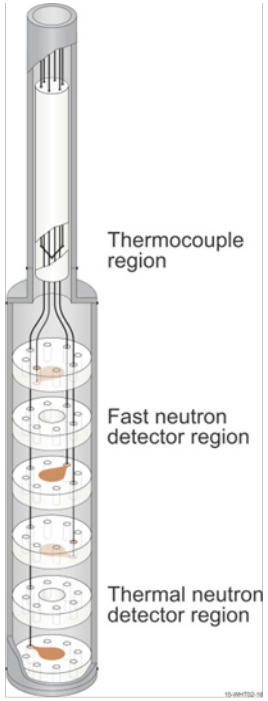
September 2015

INL Idaho National Laboratory

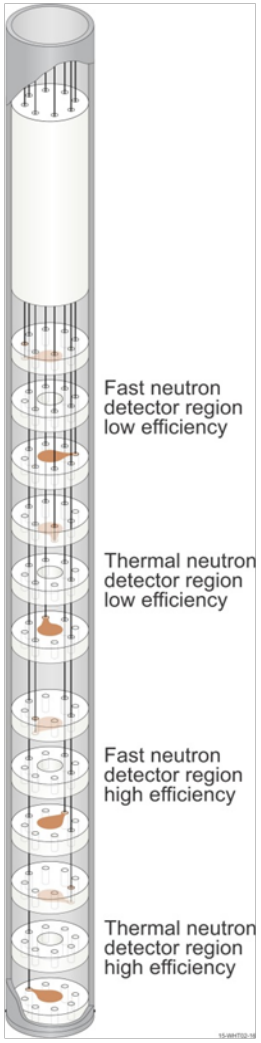
The INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance

Crosscutting Accomplishments

- ***Accident Tolerant Fuel (ATF) Irradiations***
  - *ATF-2 Sensor Qualification Test in ATR Irradiation*
    - *HT MPFD (Irradiation funded by ATF-2)*
    - *Irradiation for one ATR cycle*
    - *Irradiated with other advanced sensors*
  - *ATF-3 multi-Static Environment Rodlet Transient Test Apparatus (multi -SERTTA) Irradiation*
    - *TREAT-designed MPFD (Irradiation funded by ATF-3*
    - *Irradiation for low power calibration and high power transient*
    - *Four fission chambers to capture transient*
    - *No thermocouple*



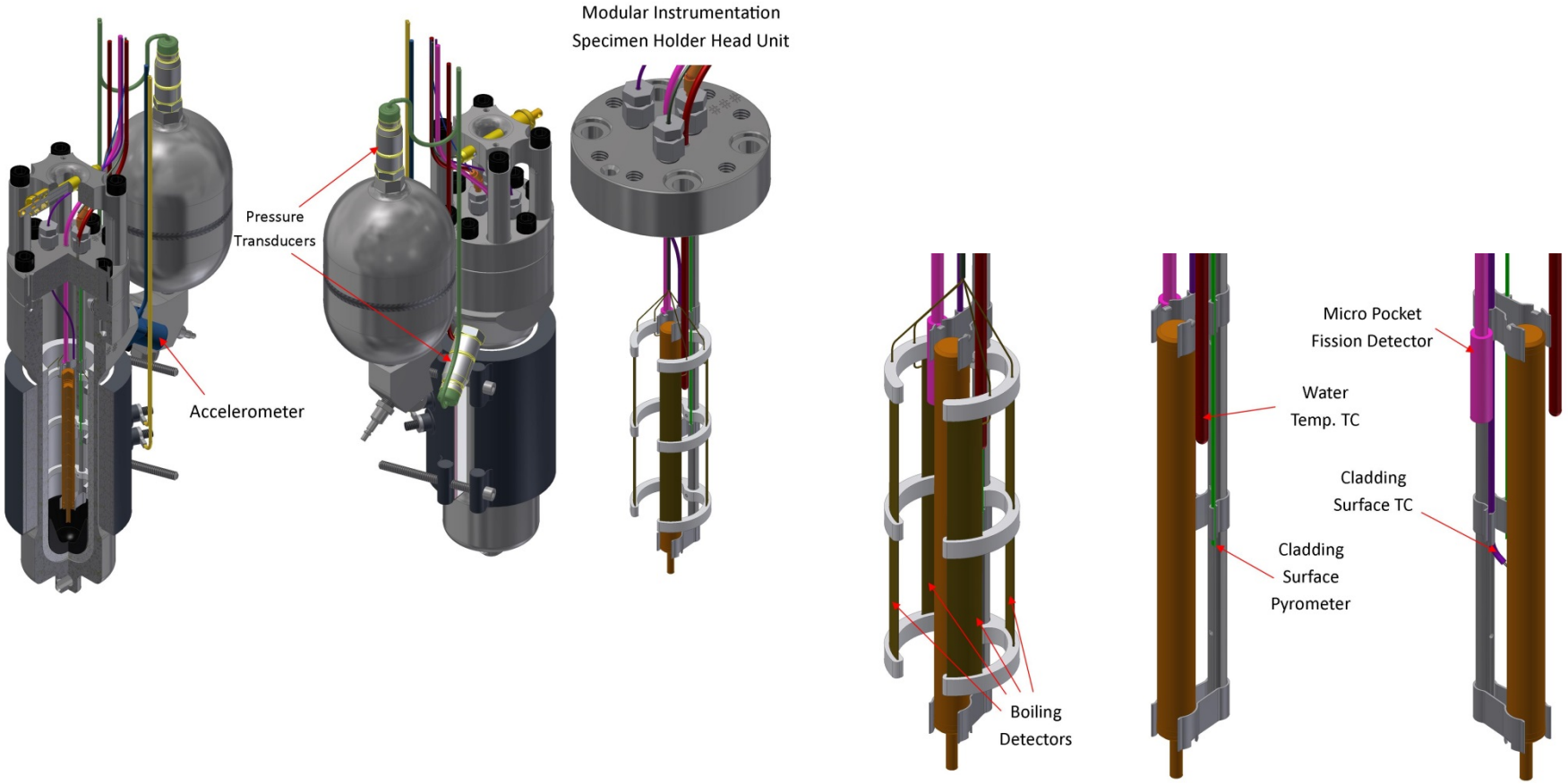
HT MPFD design



TREAT MPFD design

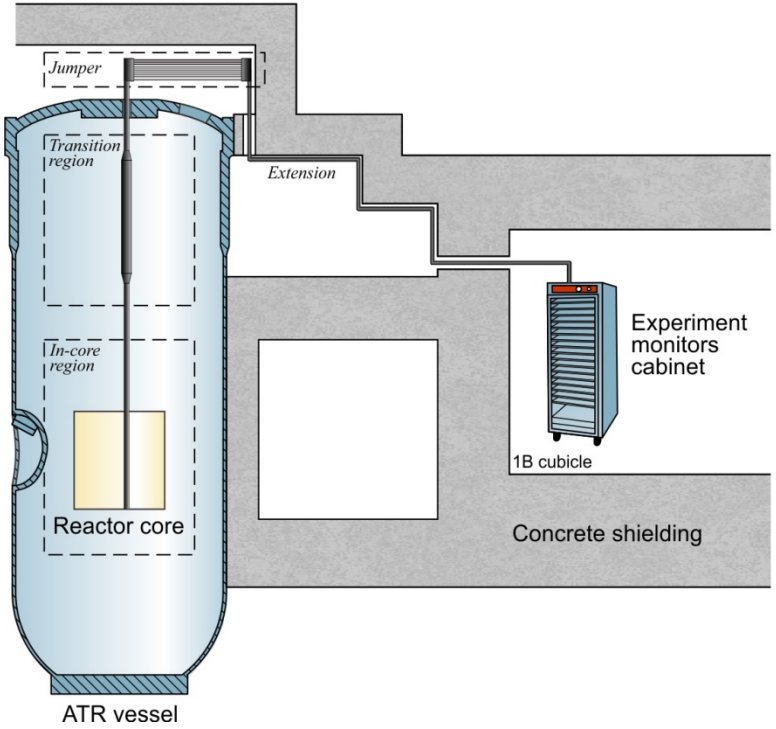
Crosscutting Accomplishments

- ***ATF-3 multi-Static Environment Rodlet Transient Test Apparatus (multi-SERTTA)***



Crosscutting Accomplishments

- ***Advanced Gas Reactor (AGR) Irradiation***
  - *AGR-5/6/7 Irradiation in ATR (funded by AGR)*
    - *HT MPFD with Type N thermocouple*
    - *Irradiation for entire test (~3 years)*
    - *Irradiated with other advanced sensors*



AGR 5/6/7 cable diagram

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Technology Impact

- **Advanced sensor for DOE-NE programs requiring real-time flux detection**
  - Neutron sensitive (BOTH fast and thermal)
  - Temperature sensitive with integral high-temperature thermocouple
  - Compact size
  - Radiation resistant
  - High temperature and pressure compatibility
  - High accuracy, high resolution
  - Flexibility (variable sensitivities, lifetimes and detector responses)
  - Fast response
  - Long lifetime
- **State-of-the-art sensor positions U.S. for leadership in irradiation testing**
  - Minimizes flux perturbation associated with typical real-time in-core sensors
  - Eliminate uncertainty with transient correction factors
  - Permits 3D modeling and triangulation of data for validation
  - Higher fidelity data for modeling and simulation of materials and fuels

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Conclusion

- Compact, multi-purpose advanced neutron detector is essential for high temperature, high pressure, high flux irradiations identified by various irradiation testing programs
- Data from fast response, accurate, miniature neutron detector will be a critical tool for validating high-fidelity computer models under development
- HT MPFD is attracting interest from several DOE-NE irradiation programs
- FY15 HT MPFD research completed successfully and on schedule