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

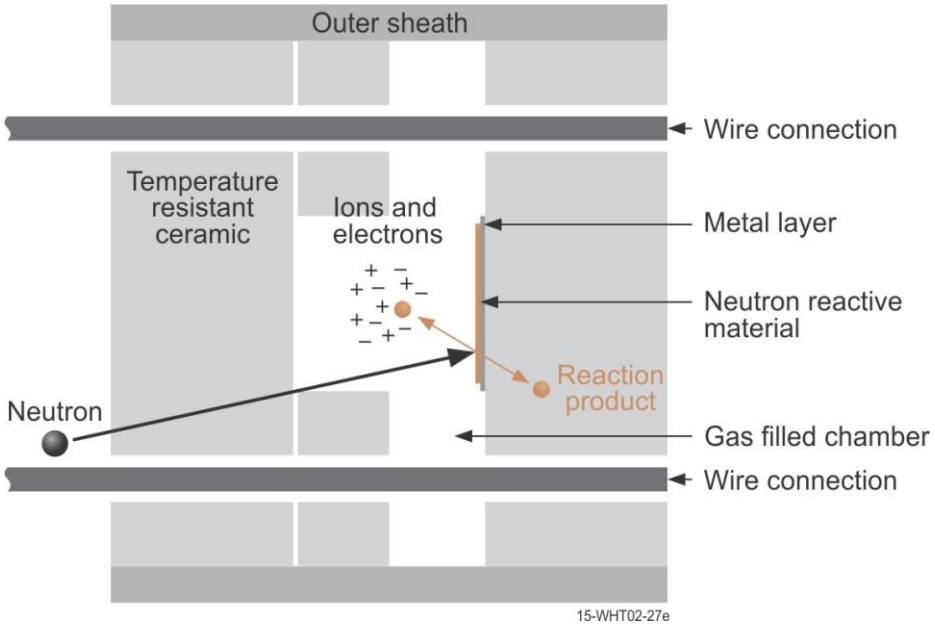
October 18-19, 2017

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

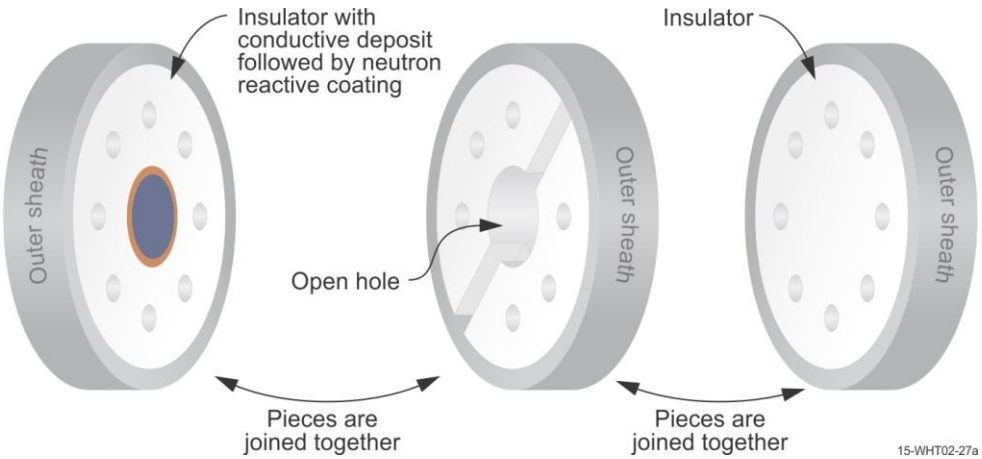
Project Overview

Goal, and Objectives

- Develop and test high temperature capable 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



Micro-Pocket Fission Detector Diagram

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

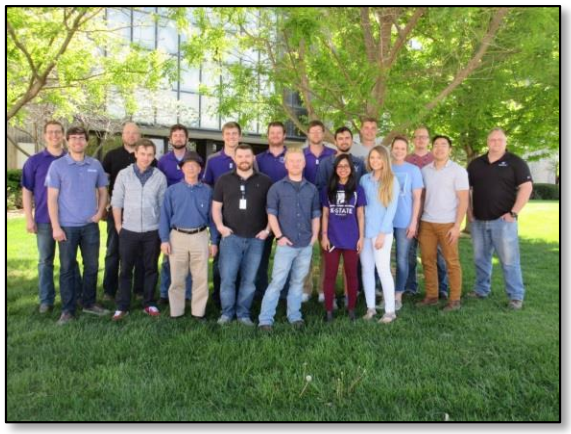
Project Overview

NEET Participants

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

NEET
Nuclear Energy Enabling Technologies

K-STATE
Kansas State University



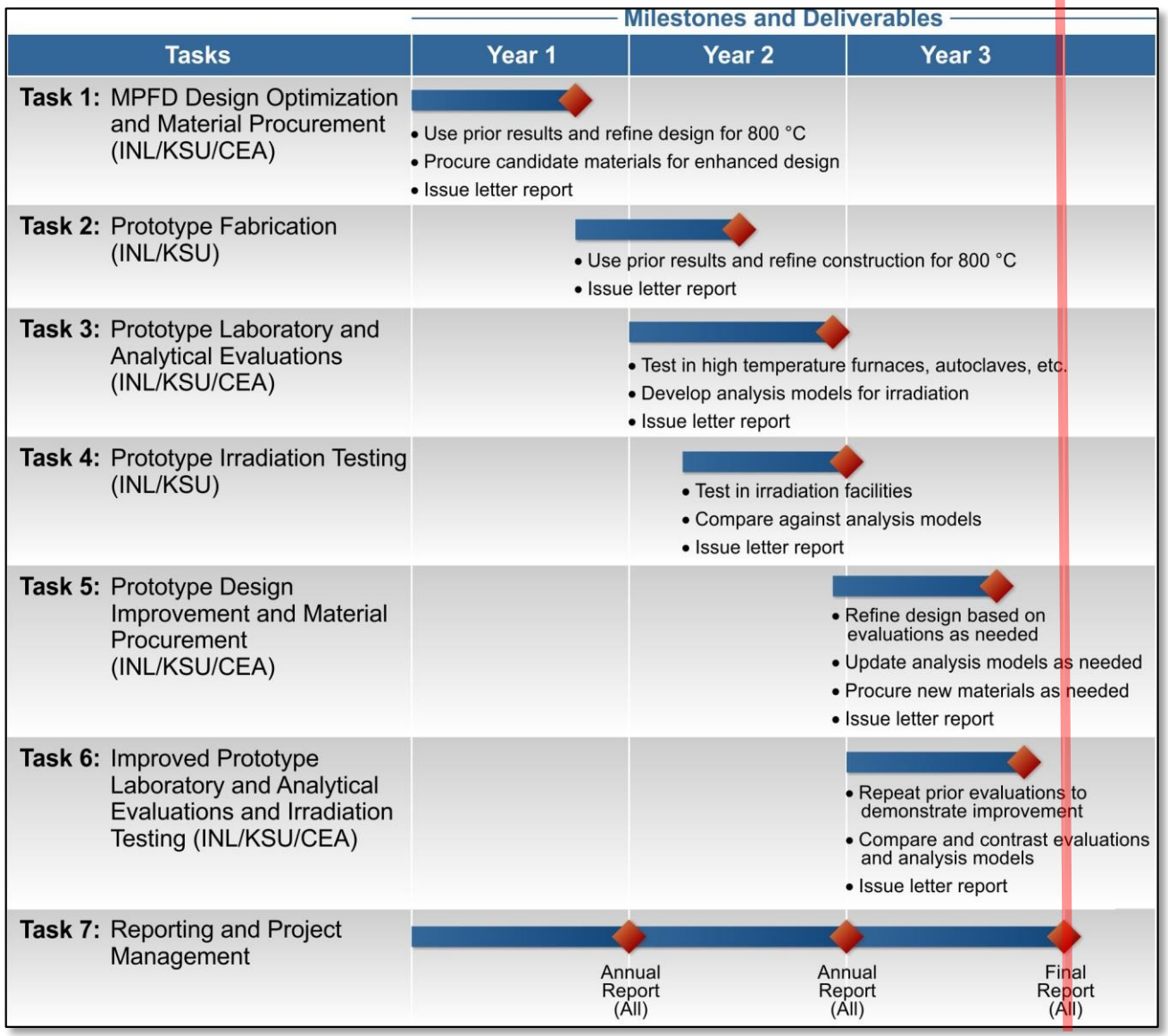
INL
Idaho National Laboratory

cea
energie atomique • energies alternatives

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Project Overview

Schedule

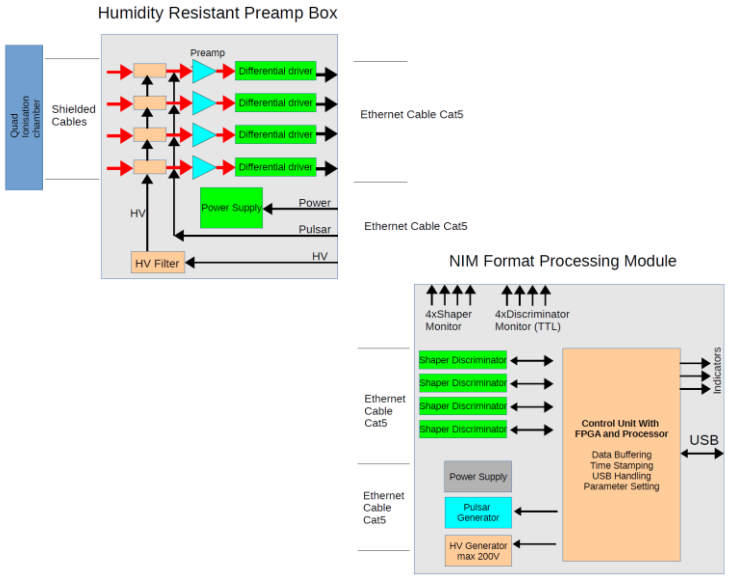


U.S. DEPARTMENT OF ENERGY
Nuclear Energy

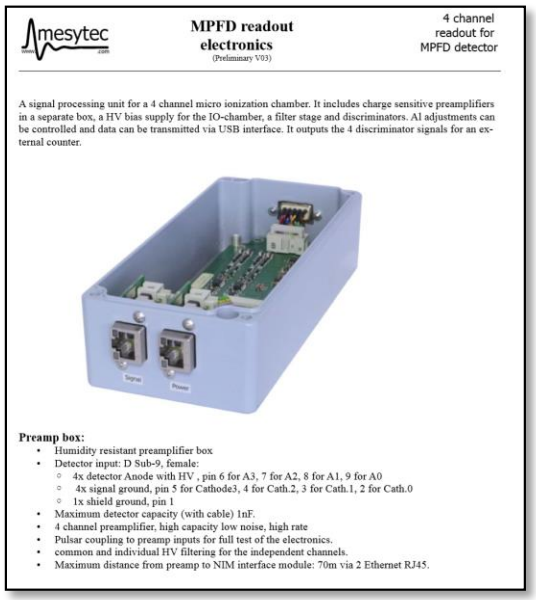
Accomplishments

FY17 Milestones, Deliverables and Outcomes

- Complete electroplating and amplifier development at KSU (M4), 7/7/2017
- Receive high temperature MPFD components from KSU for assembly (M3), 3/31/2017



MPFD electronics layout


mesytec

MPFD readout electronics
(Preliminary V03)

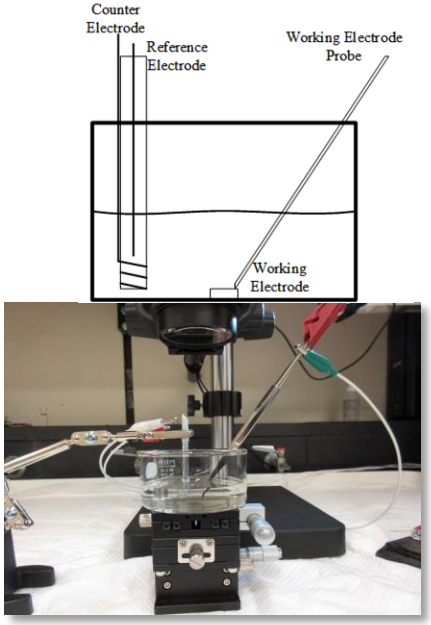
4 channel readout for MPFD detector

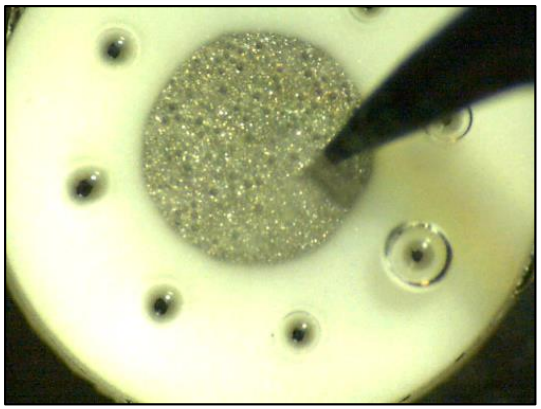
A signal processing unit for a 4 channel micro ionization chamber. It includes charge sensitive preamplifiers in a separate box, a HV bias supply for the IO-chamber, a filter stage and discriminators. Al adjustments can be controlled and data can be transmitted via USB interface. It outputs the 4 discriminator signals for an external counter.

Preamp box:

- Humidity resistant preamplifier box
- Detector input: D Sub-9, female:
  - 4x detector Anode with HV , pin 6 for A3, 7 for A2, 8 for A1, 9 for A0
  - 4x signal ground, pin 5 for Cathode3, 4 for Cath.2, 3 for Cath.1, 2 for Cath.0
  - 1x shield ground, pin 1
- Maximum detector capacity (with cable) 1nF.
- 4 channel preamplifier, high capacity low noise, high rate
- Pulsar coupling to preamp inputs for full test of the electronics.
- common and individual HV filtering for the independent channels.
- Maximum distance from preamp to NIM interface module: 70m via 2 Ethernet RJ45.

Pre-Amp/Amplifier specifications





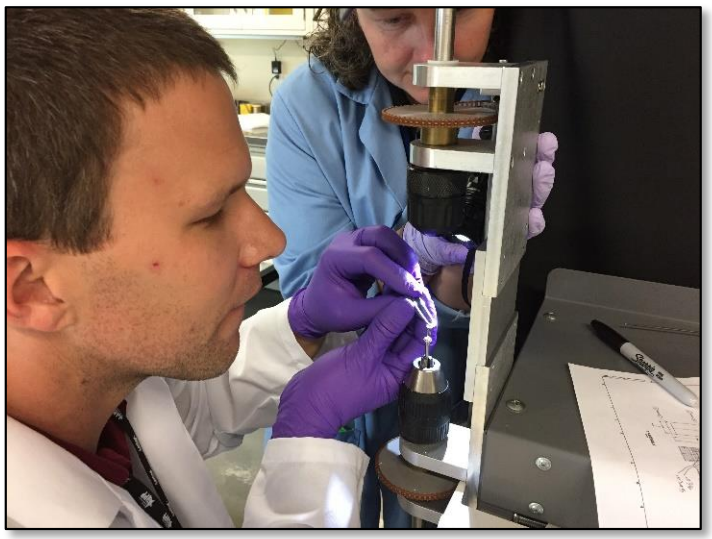
MPFD electrodeposition equipment

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Accomplishments

FY17 Milestones, Deliverables and Outcomes

- Assembly and deployment
  - Evaluate HT MPFD for temperature characterization (M3), 3/30/2017
  - Evaluate HT MPFD for flux characterization (M2), 7/30/2017



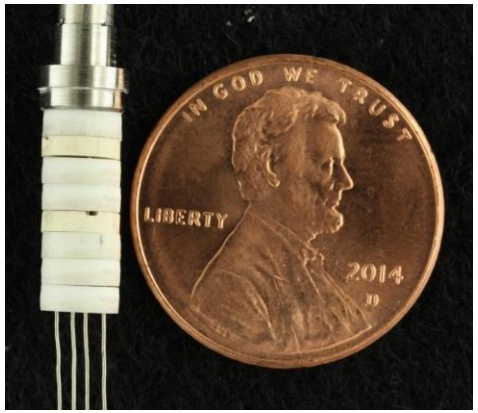
HT MPFD for MITR under fabrication

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Accomplishments

FY17 Milestones, Deliverables and Outcomes

- Assembly and deployment
  - Evaluate HT MPFD for temperature characterization (M3), 3/30/2017
  - Evaluate HT MPFD for flux characterization (M2), 7/30/2017



MPFD components prior to final assembly

X-ray (left) and 3D CT (right) images of MPFD showing wire connections

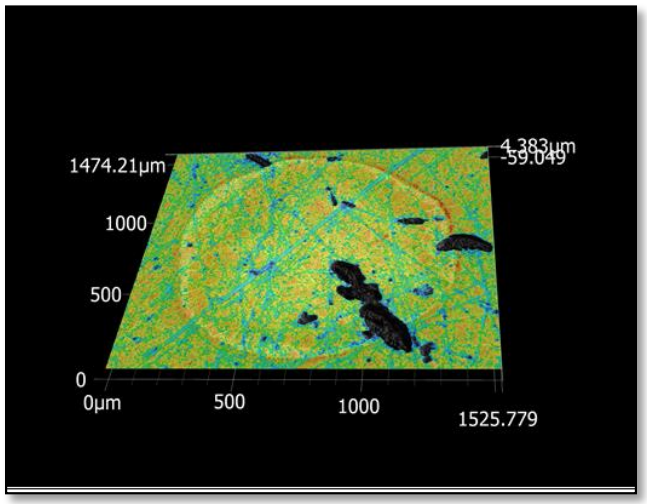
Micro-focus 3D CT scan of MPFD

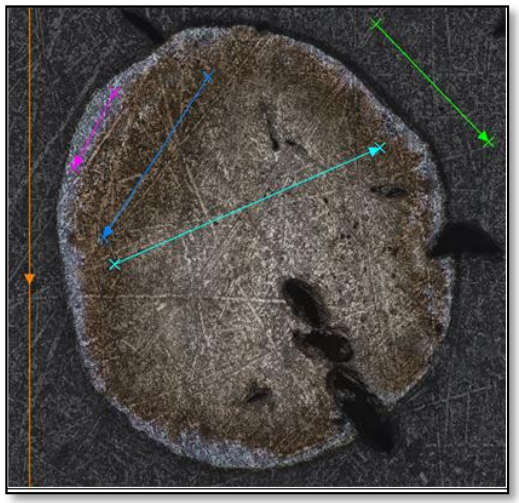
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Accomplishments

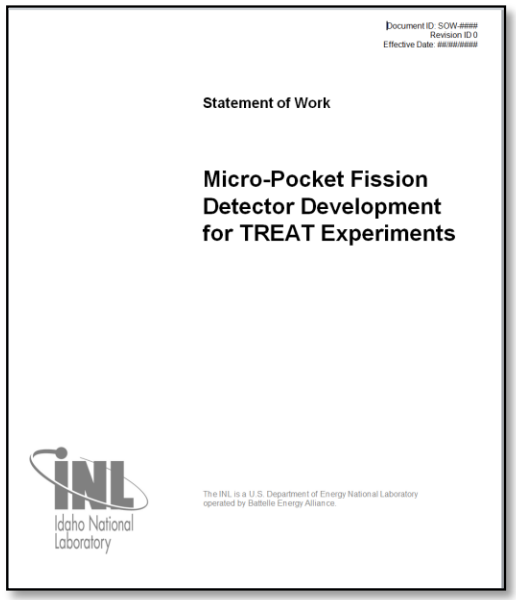
FY17 Milestones, Deliverables and Outcomes

- TREAT deployments (TREAT funded)
  - Pre/Post TRIGA pulse analysis
  - SOW for KSU support in experiments and modeling

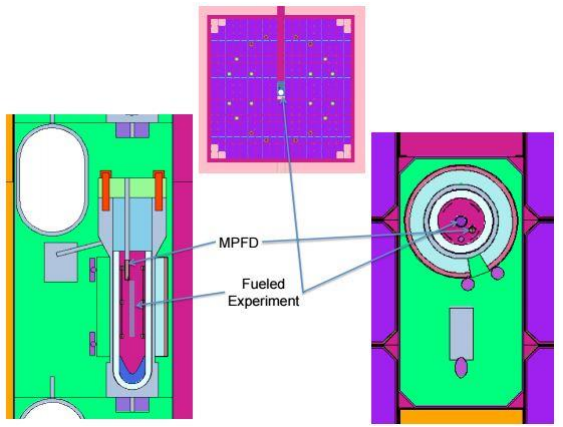




MPFD 3D surface map and image (pre-transient)



TREAT SOW with KSU



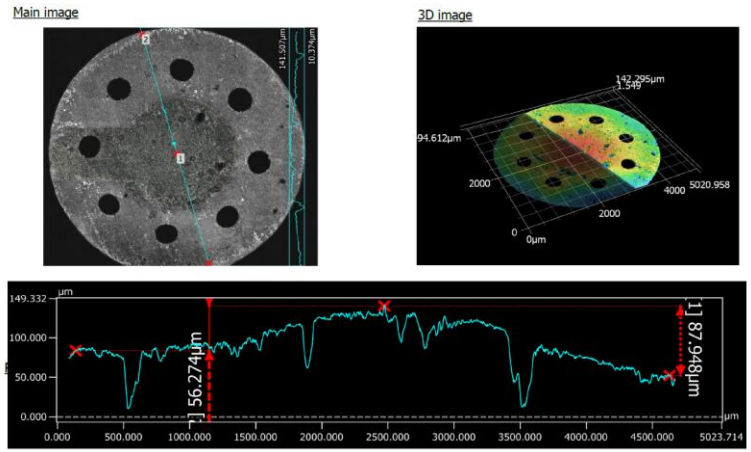
MCNP Transient MPFD in experiment

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

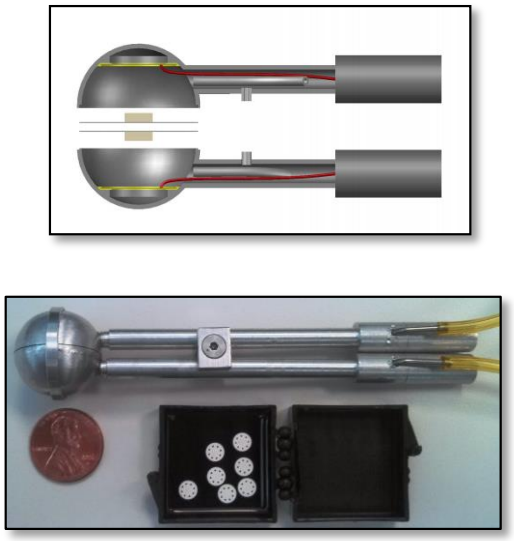
Accomplishments

FY17 Milestones, Deliverables and Outcomes

- Fission material characterizations underway
  - Idaho State University (ISU) MS student (funded by TREAT IRP)
    - Alpha counting
    - Back-to-back fission chamber comparisons
    - 3D confocal laser scanner
    - ISU reactor measurements



3D laser scans of MPFD (fissile) surface roughness



BTB fission chamber for MPFD characterization

MPFD fissile deposit characterizations in AGN-201

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Accomplishments

FY17 Milestones, Deliverables and Outcomes

- Issue "Enhanced Micro-Pocket Fission Detector for High Temperature Reactors - FY17 Final Project Report, INL/EXT-17-43397" (M2), 9/28/2017
- Additional papers and presentations of the HT MPFD technology


INL/EXT-17-43397
Draft Revision: 0

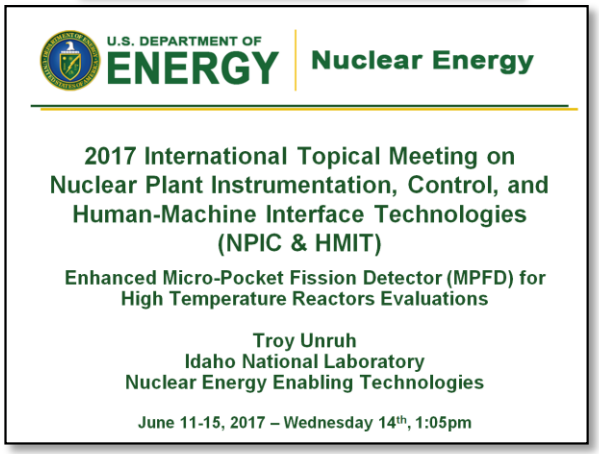
Enhanced Micro-Pocket Fission Detector for High Temperature Reactors - FY17 Final Project Report

T.Unruh, M. Reichenberger, S. Stevenson, K. Tsai
D. McGregor

September 2017

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

INL Idaho National Laboratory

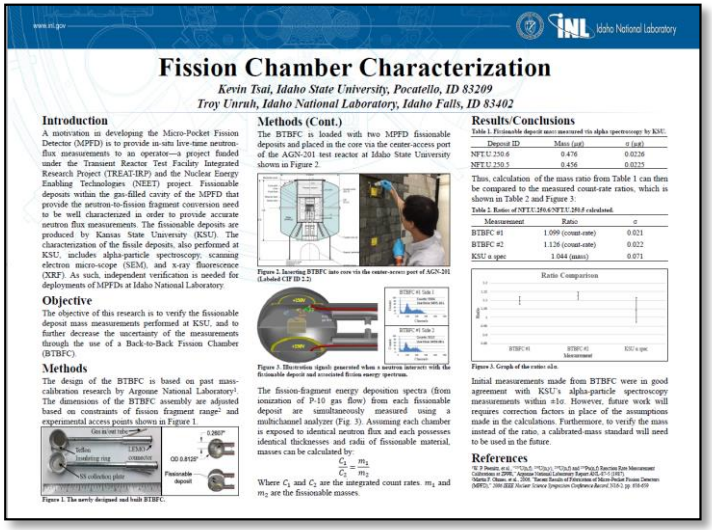

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

2017 International Topical Meeting on Nuclear Plant Instrumentation, Control, and Human-Machine Interface Technologies (NPIC & HMIT)

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

Troy Unruh
Idaho National Laboratory
Nuclear Energy Enabling Technologies

June 11-15, 2017 – Wednesday 14th, 1:05pm


Fission Chamber Characterization

Kevin Tsai, Idaho State University, Pocatello, ID 83209
Troy Unruh, Idaho National Laboratory, Idaho Falls, ID 83402

Introduction

Objective

Methods

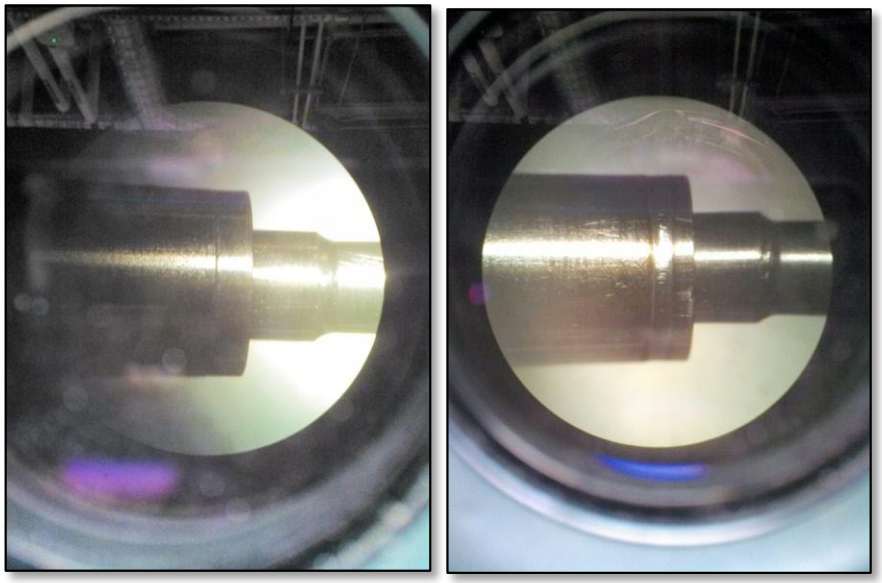
Methods (Cont.)

Results/Conclusions

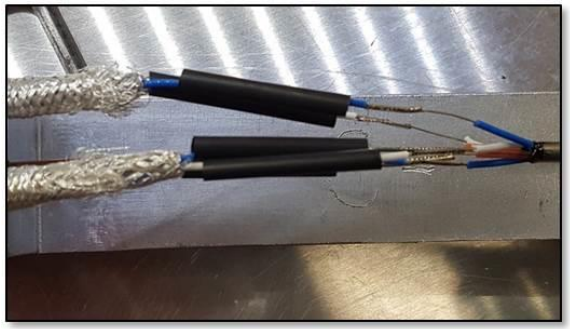
References

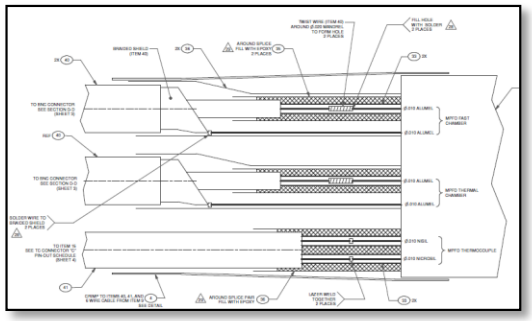
Crosscutting Accomplishments

- ***Accident Tolerant Fuel (ATF) Deployments***
  - *ATF-2 Sensor Qualification Test in ATR Irradiation*
    - *HT MPFD (Irradiation funded by ATF-2)*
    - *In ATR for one cycle (~59 days)*
    - *Irradiated with other advanced sensors*



HT MPFD laser welding (before/after)





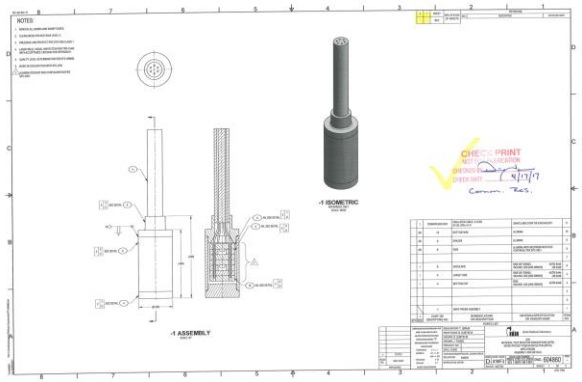
MPFD splice and drawing details

Completed HT MPFD

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Crosscutting Accomplishments

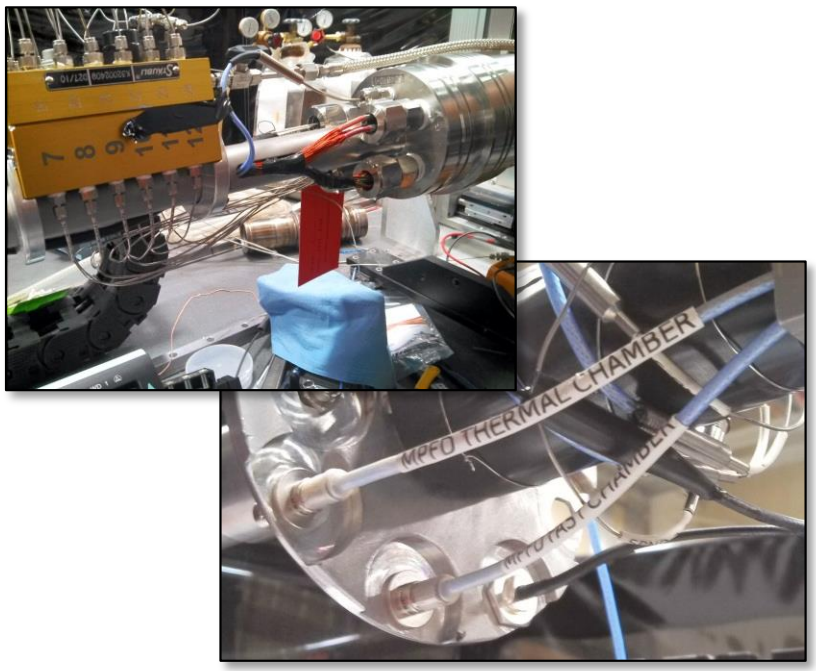
- ***Advanced Gas Reactor (AGR) Deployment***
  - *AGR-5/6/7 Irradiation in ATR (funded by AGR)*
    - *HT MPFD with Type N thermocouple*
    - *Irradiation for entire test (~3 years)*
    - *Irradiated with other advanced sensors*
    - *Installed in test train, irradiation in FY18*



HT MPFD drawing for ATF-2 and AGR 5/6/7

Element	P-19000101	NFT.A.250.4	NFT.U.250.9
MgO	0.088	-	-
Al_2O_3	99.6	93.9	98.7
SiO_2	0.10	6.04	1.22
Cl	0.031	0.044	0.049
CaO	0.035	-	-
Cr_2O_3	0.026	-	-
Fe_2O_3	0.084[b]	0.021[b]	0.040[b]
NiO	0.017[b]	0.011[b]	0.016[b]
Ga_2O_3	0.015	-	-
	Areal Densities of deposits (in µg/cm²)		
Pt	N/A	72.3	61.4
Th	N/A	2.7	-
U	N/A	-	6.3

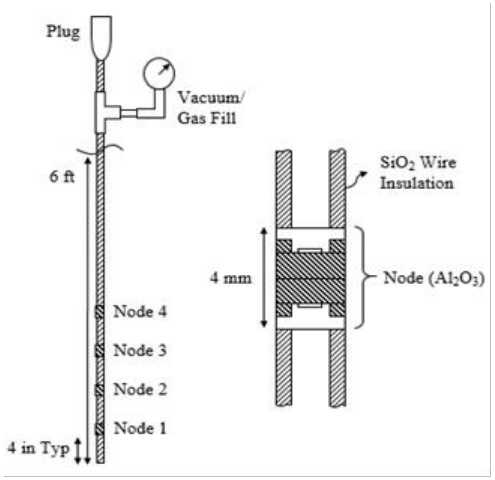
HT MPFD material certification shipment and results

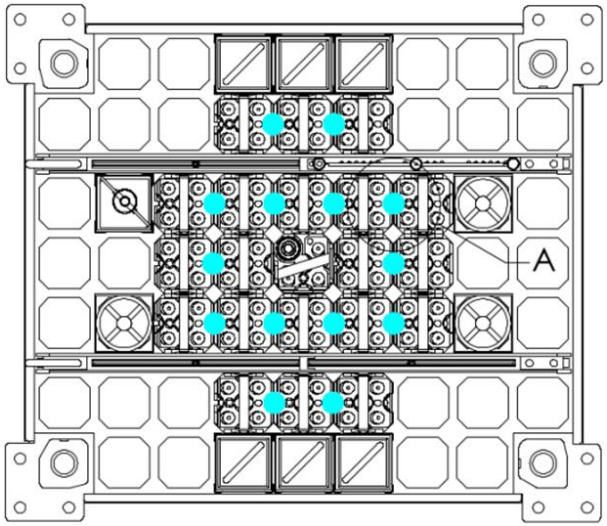


HT MPFD in AGR 5/6/7 test train.

Crosscutting Accomplishments

- ***Nuclear Energy Advanced Modeling and Simulation (NEAMS) Deployment***
  - *A Transient Reactor Physics Experiment with High-Fidelity, 3-D Flux Measurements for Validation and Verification*
    - *Kansas State University led: Dr. Jeremy Roberts*
    - *University of Wisconsin-Madison reactor*
    - *Specially designed MPFD wands deployed for steady state and transient response*



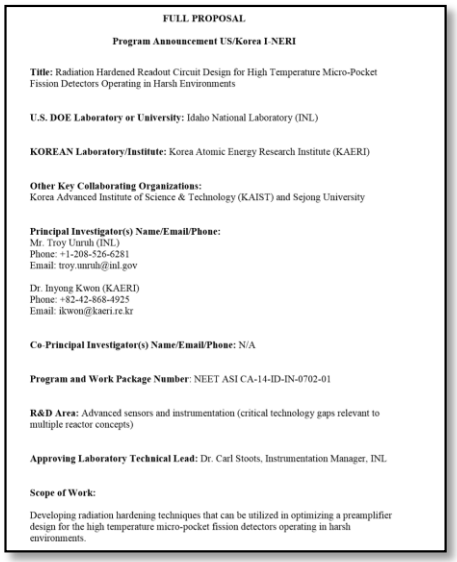


MPFD wands (left) and locations in University of Wisconsin-Madison reactor (right)

Crosscutting Accomplishments

- **Radiation Hardened Readout Circuit Design for High Temperature Micro-Pocket Fission Detectors Operating in Harsh Environments**
  - International Nuclear Energy Research Initiative (I-NERI) between United States of America and the Republic of Korea
  - INL and KAERI
  - Kickoff meeting at INL, progress meeting at NPIC-HMIT 2017
  - Circuit design sent to manufacturers to make a chip

Korea Atomic Energy Research Institute (KAERI)



FULL PROPOSAL

Program Announcement US/Korea I-NERI

Title: Radiation Hardened Readout Circuit Design for High Temperature Micro-Pocket Fission Detectors Operating in Harsh Environments

U.S. DOE Laboratory or University: Idaho National Laboratory (INL)

KOREAN Laboratory/Institute: Korea Atomic Energy Research Institute (KAERI)

Other Key Collaborating Organizations:
Korea Advanced Institute of Science & Technology (KAIST) and Sejong University

Principal Investigator(s) Name/Email/Phone:
Mr. Troy Unruh (INL)
Phone: +1-208-526-6281
Email: troy.unruh@inl.gov

Dr. Inyong Kwon (KAERI)
Phone: +82-42-868-4925
Email: ikwon@kaeri.re.kr

Co-Principal Investigator(s) Name/Email/Phone: N/A

Program and Work Package Number: NEET ASI CA-14-ID-IN-0702-01

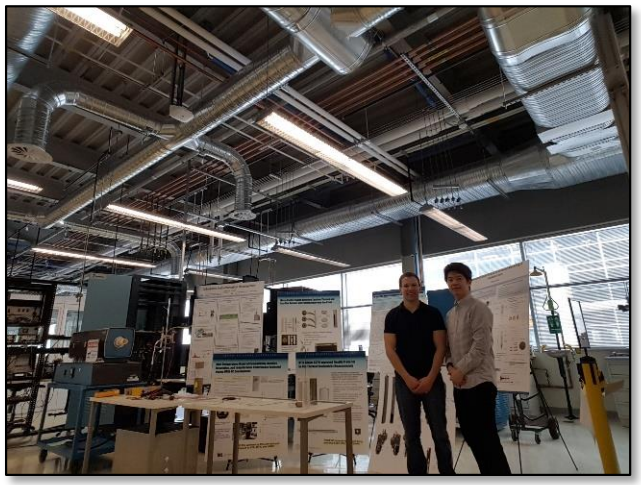
R&D Area: Advanced sensors and instrumentation (critical technology gaps relevant to multiple reactor concepts)

Approving Laboratory Technical Lead: Dr. Carl Stoots, Instrumentation Manager, INL

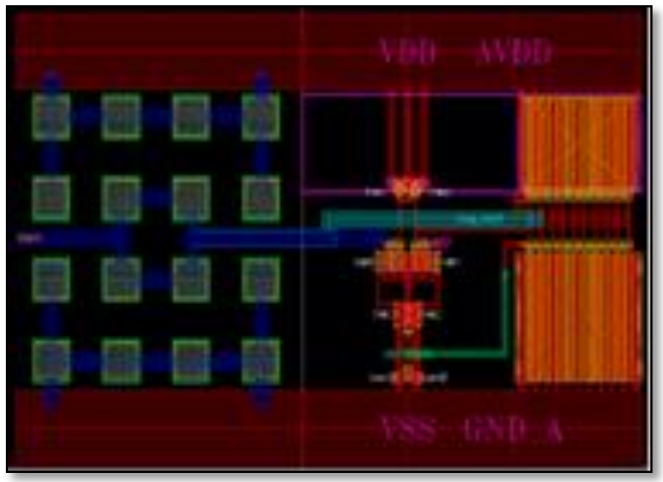
Scope of Work:

Developing radiation hardening techniques that can be utilized in optimizing a preamplifier design for the high temperature micro-pocket fission detectors operating in harsh environments.

US ROK I-NERI proposal



2017 Kickoff meeting at INL



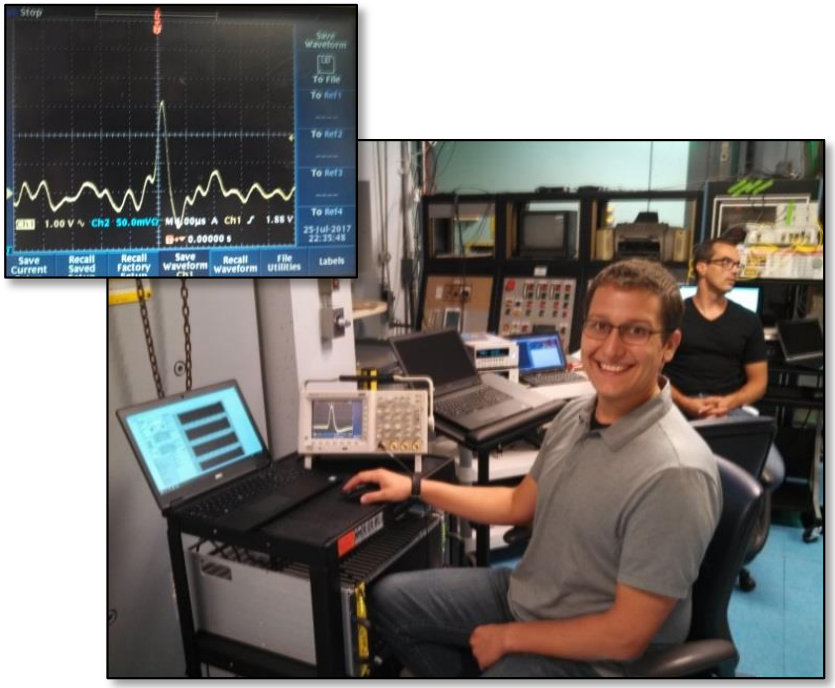
Radiation hardened pre-amplifier design for HT MPFD

Crosscutting Accomplishments

- ***TREAT Integrated Research Project (IRP)***
  - *Computational & Experimental Benchmarking for Transient Fuel Testing*
    - *Oregon State University led: Dr. Wade Marcum*
    - *MITR irradiation test*
    - *2 week irradiation testing campaign*
    - *HT MPFD Irradiated at MIT in July 2017*

Massachusetts Institute of Technology
Nuclear Reactor Laboratory

MIT reactor core

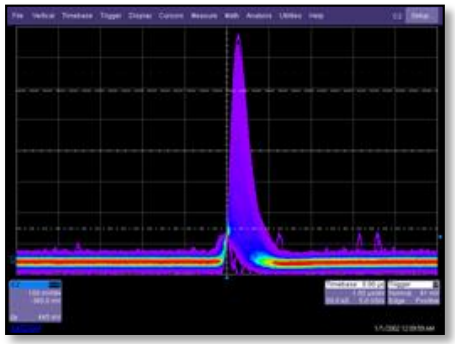


MPFD testing at MIT Reactor with INL intern

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Crosscutting Accomplishments

- ***Fission Chamber characterization at CEA Cadarache and INL***
  - *MINERVE reactor calibrations* (CEA/DOE collaboration WG 3.5 In-Pile Instrumentation)
    - *Intern from INL/Kansas State University*
    - *MPFD received at CEA in May 2017*
    - *Initial calibrations completed June 2017*



HT MPFD pulse from CEA calibrations

HT MPFD for CEA calibrations

CEA and INL researchers at MINERVE reactor (France)

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

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 geometries, 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
  - Higher fidelity data for modeling and simulation of materials and fuels[1]
  - Permits 3D modeling and triangulation of data for validation[1]

[1] J. Roberts, et al. , "FY15 NEUP: A Transient Reactor Physics Experiment with High-Fidelity, 3-D Flux Measurements for Validation and Verification"

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Conclusion

- **All HT MPFD project milestones completed successfully and on schedule**
- **HT MPFD will continue to be deployed by several DOE-NE irradiation testing programs**
- **Radiation Detection Technologies (RDT) developing a HT MPFD commercialization strategy under a Small Business Innovative Research Phase I Project, "Advanced Manufacturing of Micro-Pocket Fission Detectors"**

RADIATION DETECTION TECHNOLOGIES, INC.