# Passive Monitors

**Advanced Sensors and Instrumentation (ASI) Annual Program Webinar**

November 7, 2024

Malwina Wilding – Nuclear Instrumentation Engineer

**Idaho National Laboratory**

# Project Overview

**Brief summary of research scope:**
Passive temperature monitors are needed for when real-time sensors are not practical or economical to install in an irradiation test. The main purpose is to provide a practical and reliable approach to estimate irradiation temperature during post-irradiation examination (PIE) for direct integration in irradiation test designs. Passive temperature monitors have been in use for many decades in irradiation testing experiments, but limited innovation has been applied to these technologies. This work package focuses on two activities: Silicon Carbide (SiC) Temperature Monitors (TMs) and Printed Melt Wires.

•**Participants:**
Malwina Wilding (WPM and PI), Kiyo Fujimoto (co-PI) and Austin Fleming (TPOC) – Idaho National Laboratory

**Collaborators:**
- **US:** David Estrada and Josh Eixenberger – Boise State University
Rene Rodriquez and two undergraduate students – Idaho State University
Padhraic Mulligan and Anne Campbell – ORNL
- **International:** Rafal Prokopowicz (Poland), Viviam Marques Pereira (Netherlands), Mark Luloff and Travis Skippon (Canada)

# Project Overview Cont'd

**Project Schedule:**

1. M3CT-24IN0703011 (Carryover) Assessment of read-out techniques for passive monitors finished by end of March of 2024 (6-month delay)
   - Rad material shipping paperwork between MFC, ATR and IRC; decontaminating twice (MFC and HF wash at ATR), and dilatometer was sent to Germany for repairs (loose TC connection)

2. M3CT-24IN0703012 Optimize data processing for SiC thermometry using dilatometry due by end of December 2024 (3-month delay)

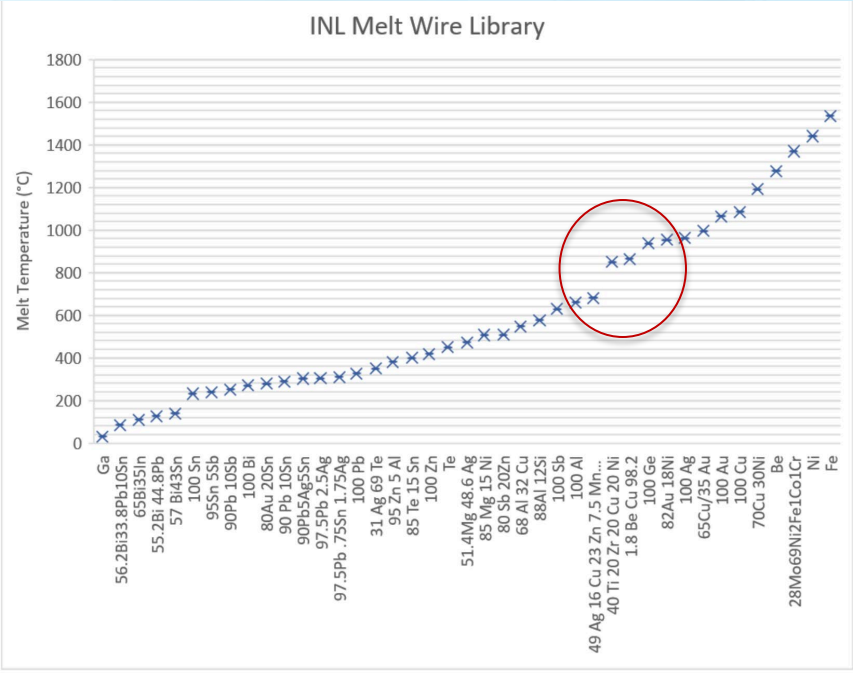
3. M3CT-24IN0703013 ~~"Demonstration of capacitance readout technique for printed melt wires."~~ changed to "An assessment report on melt wire candidates." (6-month delay)
   - FY23 activities for printed melt wires ended in March of 2024 (6-month delay); changed scope of work for FY24 based on BSU summary report for FY23 work; ISU contract was started in June but not awarded yet (waiting for final INL approval)

# Technology Impact

- In less expensive static (drop-in) capsule tests, which have no leads attached for real-time data transmission, melt wires, and SiC temperature monitors (TMs) are essentially the only possibility for measuring irradiation peak temperature
- They have been chosen because they have a proven history for use by stakeholders for deployment and require continued development and characterization to assure successful integration with program schedules and objectives
- Further develop the temperature passive monitor capability for wider rage of temperatures, geometries, MTRs and neutron damage (an ASTM standard)
- Facilitates the development of advanced sensors and instrumentation with cross-cutting technology development to support the existing fleet, advanced reactor technology and advancing fuel cycle technology development

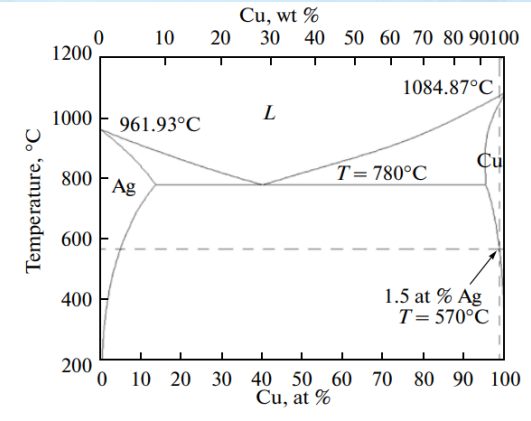
# Results and Accomplishments – Printed Melt Wires

One method to determine irradiation temperature involves placing material wires of known composition and melting temperature in an irradiation test. In this method post-irradiation examination of each melt wire is required to determine if the melting occurred, indicating that the corresponding melting temperature was reached or exceeded. Currently, melt wires used to support experiments within material test reactors are limited in the high temperature ranges (700-900℃). The purpose of this work is to perform a scoping study to identify potential melt wire material candidates to expand the current library of commercially available melt wire materials at INL.

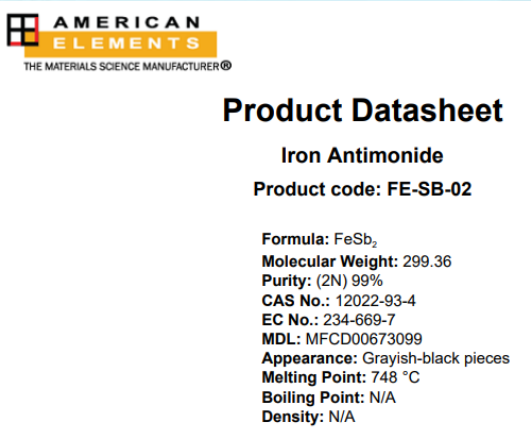


# Results and Accomplishments – Printed Melt Wires

- Scope of Work:
  - Identify possible material alloys as potential candidates for melt wires
  - Begin material synthesis for each material candidate
  - Initial furnace testing to demonstrate the feasibility of these materials for melt wire applications
  - Establish material supply chain/procedure to use for standard melt wire production at INL
  - Most of the assessment will be done by ISU students, at ISU and CAES facility, mentored and guided by the INL PI, WPM and the ISU professor.
- Accomplishment:
  - Identified two potential material candidates for 700-800℃ range: Cu-Ag and Fe-Sb
  - Submitted and rewrote the ISU contract between INL//ISU several times (waiting for final INL approval)




Copper-Silver eutectic at 780 °C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**Product Datasheet**

**Iron Antimonide**

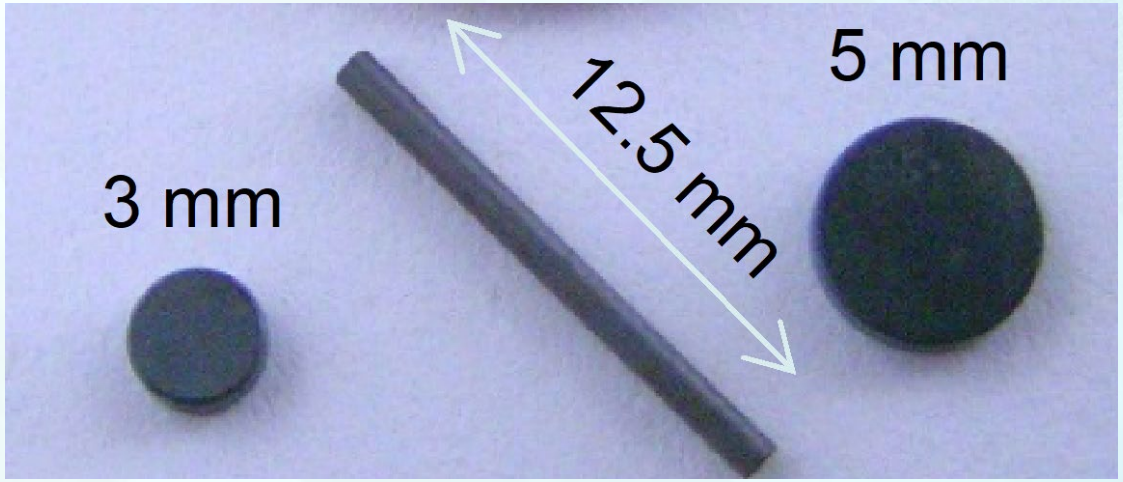
**Product code: FE-SB-02**

**Formula:** $FeSb_2$
**Molecular Weight:** 299.36
**Purity:** (2N) 99%
**CAS No.:** 12022-93-4
**EC No.:** 234-669-7
**MDL:** MFCD00673099
**Appearance:** Grayish-black pieces
**Melting Point:** 748 °C
**Boiling Point:** N/A
**Density:** N/A

Iron-Antimony eutectic melting point at 748 °C

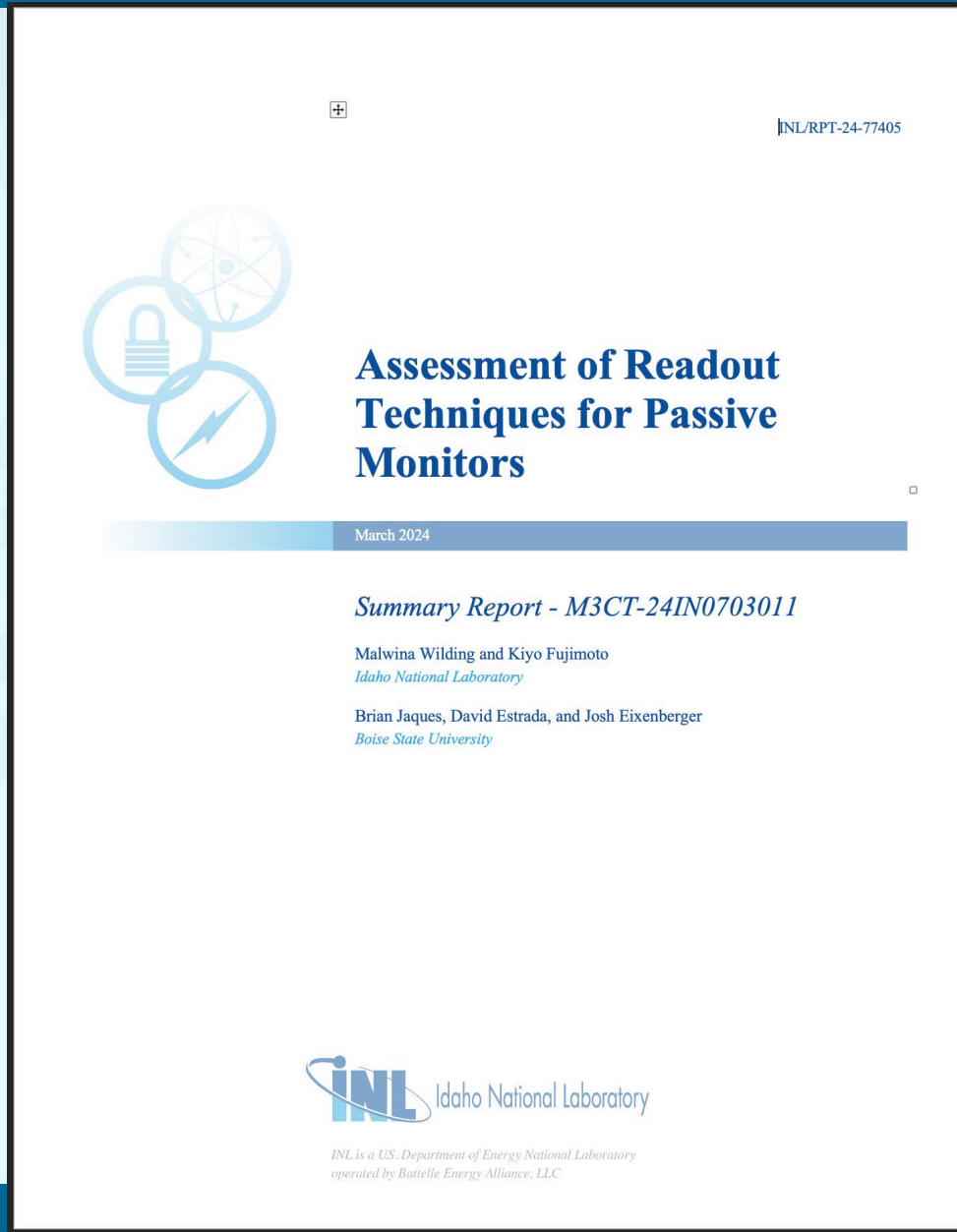
# Results and Accomplishments – Silicon Carbide

Since the early 1960s, SiC has been used as a post-irradiation temperature monitor. Researchers observed that SiC's neutron-irradiation-induced lattice expansion annealed out when the post-irradiation annealing temperature exceeded the peak irradiation temperature. FY24 work for SiC monitors looked into standardizing the way we measure irradiation temperatures between various reactor environments and measuring techniques. This included collaboration with ORNL, and many international partners (Canada, Poland, and Netherlands).



# Results and Accomplishments - SiC

- NSUF provided SiC temperature monitors:
  - N-SERT Experiment with 8 SiC 3-mm disks
- Highlight:
  - All 8 Sic 3-mm disks were processed
  - Optical dilatometer successfully processed 3mm OD by 1mm thick SiC disks
  - Milestone level 3 report finished and submitted in PICS


INL/RPT-24-77405

**Assessment of Readout Techniques for Passive Monitors**

March 2024

*Summary Report - M3CT-24IN0703011*

Malwina Wilding and Kiyo Fujimoto
*Idaho National Laboratory*

Brian Jaques, David Estrada, and Josh Eixenberger
*Boise State University*

Idaho National Laboratory

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# Results and Accomplishments - SiC

- Highlight:
  - Best Engineering Practices for SiC Meeting at ORNL May 8th and 9th organized by Padhraic Mulligan to discuss ASTM standard for SiC
    - Participation from INL, ORNL, MIT, Nielson Scientific, Canada (CNL), Poland (NCNR), and Netherlands (NRG)
- ASTM Standard considerations:
  - E10.05 subcommittee (ORNL will lead as point of contact on that committee)
    - Neutron Radiation Metrology: focus is neutron dosimetry
  - Materials and sourcing (Rohm-Haas material and PremaTech or single crystal material?)
  - Physical dimensions (rods, pillars, or discs) – what's the smallest and largest volume allowed
  - Shipping and handling – how to properly decontaminate and process these in PIE
  - PIE measurement methods (dimensions, electrical resistivity, thermal diffusivity, lattice spacing)
  - Experimental conditions (max. and min. temperatures and neutron damage rates in dpa)
    - Below 100 C and above 1000 C -> need more data to quantify
    - Is it MTR dependent? Compare data between ATR, HFIR, HFR and MARIA
  - Disposal (how to properly dispose of the rad materials)

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# Concluding Remarks

- Printed Melt Wires:
  - Identified two melt wire material candidates (748℃ and 780℃)
  - Waiting for ISU contract to be awarded so the scoping study for both potential materials can be verified for melt wire prototype production
- SiC TMs:
  - Optical dilatometer successfully processed 3-mm SiC disks
  - Started multi-international collaboration for building an ASTM standard for SiC TMs
  - Starting with dilatometry method by using ORNL and INL data and modeling (ATR vs. HFIR results)
- Remaining work:
  - Finish both Level 3 Milestone Reports for SiC and Passive Monitors
- Publications:
  - Malwina A. Wilding, Kurt L. Davis, Richard S. Skifton "Passive temperature sensors for nuclear applications." *AIP Conf. Proc.* 18 October 2024; 3230 (1): 130008. https://doi.org/10.1063/5.0234224


Contact information

Malwina Wilding

Nuclear Instrumentation Engineer (INL)

malwina.wilding@inl.gov

W (208) 526-1674

# Thank You