INL/CON-24-77588-Revision-0

Instrumentation for the In-Core Real-Time Mechanical Testing of Structural Materials (INCREASE) Project

April 2024

Changing the World's Energy Future

Malwina A Wilding

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By

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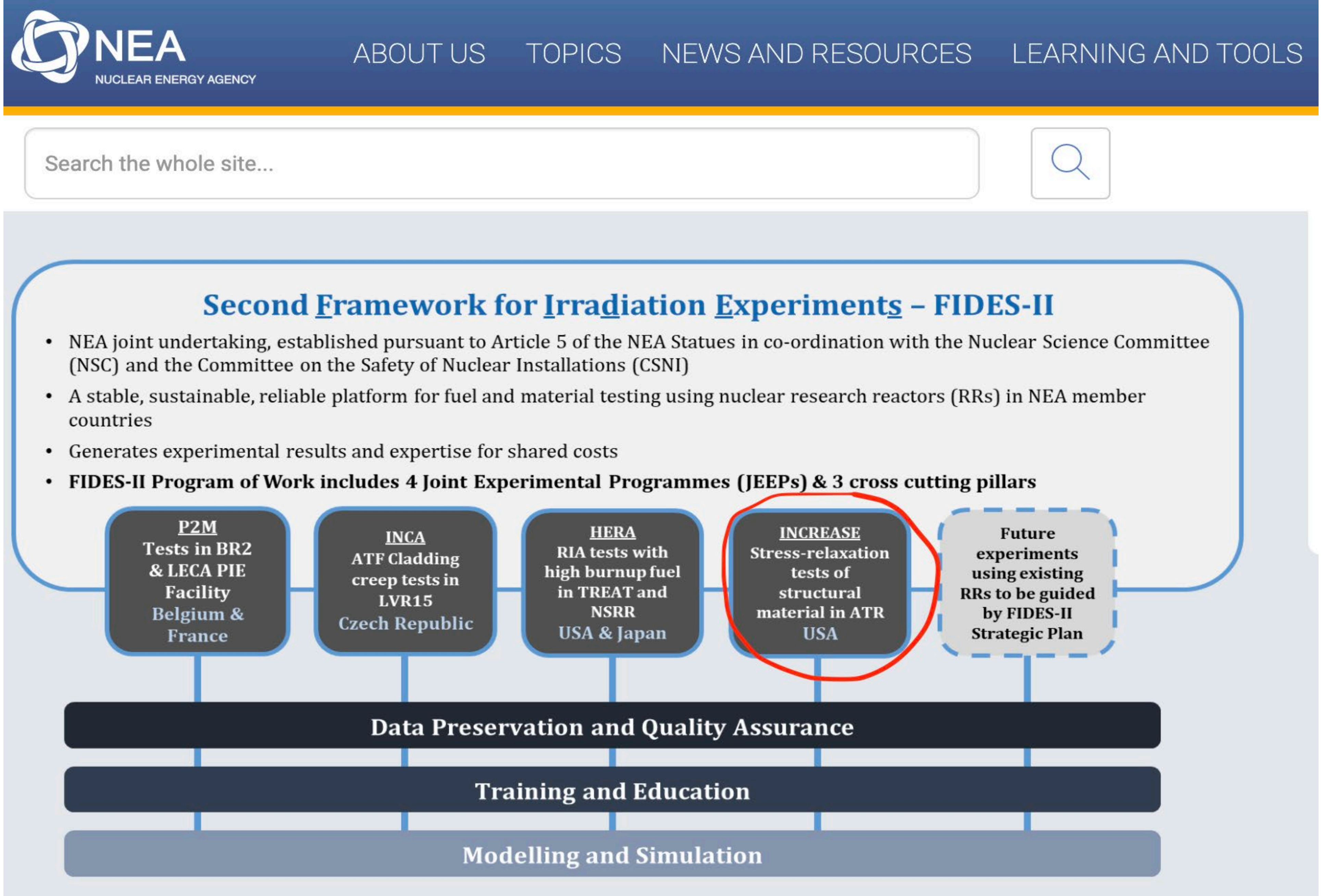
Overview

- Joint Experimental Program (JEEP) proposal by:
  - USA:
    - Idaho National Laboratory (INL)
    - Electric Power Research Institute (EPRI)
    - Nuclear Regulatory Commission (NRC)
  - France: French Alternative Energies and Atomic Energy Commission (CEA)
  - Netherlands: Nuclear Research and Consultancy Group (NRG)
  - European Commission: Joint Research Centre (JRC)
  - Czech Republic: Research Centre Řež (CVR)
- Operate under Nuclear Energy Agency's Framework for Irradiation Experiments (FIDES II) program
- Awarded March of 2023



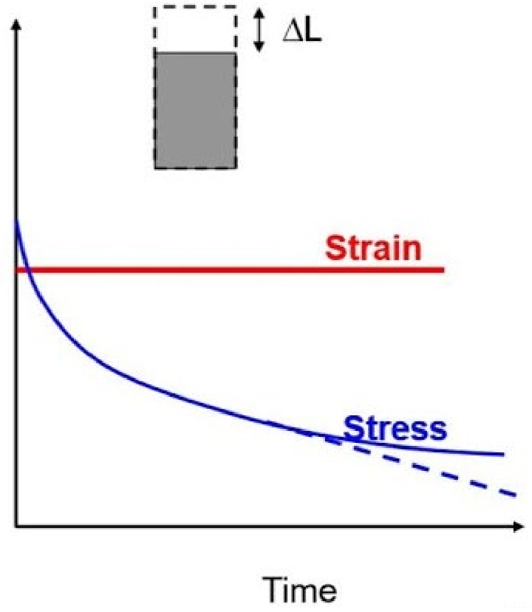
https://www.oecd-nea.org/jcms/pl_70867/second-framework-for-irradiation-experiments-fides-ii

Background

- Halden Boiling Water Reactor Shutdown in 2018
  - Halden Reactor Project provided unique testing and evaluation capabilities (in-core creep, stress relaxation and crack growth testing capabilities)
  - No facility is currently capable of such capabilities
  - FIDES framework emerged
- Light Water Reactor (LWR) life extension
  - Basis for assessing materials degradation and developing aging management practices for key LWR components during license renewal
  - Basis for economic decisions related to plant asset management and continuing plant viability
- Advanced Test Reactors
  - Provide quantitative demonstrations that show the durability and longevity of the materials selected

Purpose: In-core Stress Relaxation Data

- Stress relaxation is the loss of stress generated in a material that is held at a constant strain over time
- Critical measurement for any material qualification
  - Longevity and safety of the reactor components
- Reactor vessel internals and core support structures are held together and aligned by pre-loaded elements, especially bolts and fixtures
- Fairly limited data on the irradiation-enhanced stress relaxation and irradiation creep behavior of austenitic stainless steels
  - Fast neutron spectrums are much different from the spectra generated in LWRs
- Stress relaxation are commonly estimated through PIE:
  - A magnitude of difference in results when compared to real-time (in-core) data



STRESS RELAXATION

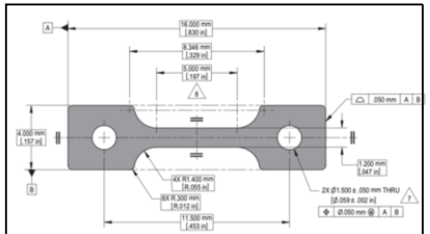
Objective

Enable the international community to perform, at reduced cost, in-core mechanical testing of structural materials that include:

- develop the in-core LVDT-based instrumentation for stress relaxation measurements
- complete the design and fabrication of the universal capsule
- design and irradiate the capsule at MITR (Phase 1) and HFR (Phase 2)
  - deliver in-core temperature, pressure, fluence, and stress relaxation data on 4 types of high priority stainless steel materials provided by EPRI and CEA

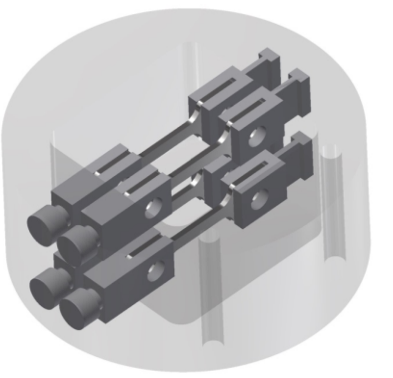
Specimen	Material	Configuration	Temperature	Initial Stress	Data
1	SS 316CW	LVDT bellows pre-loaded	320 °C to 360 °C	~80% of the nominal yield strength at test temperature	Real-time, LVDT stress relaxation
2	SS 347				
3	SS 321				
4	SS 304(L)				
5	SS 316CW	Pre-loaded, static			Deflection from pre-load, PIE in later phases
6	SS 347				
7	SS 321				
8	SS 304(L)				
9	SS 316CW	Non-loaded			PIE only in later phases
10	SS 347				
11	SS 321				
12	SS 304(L)				

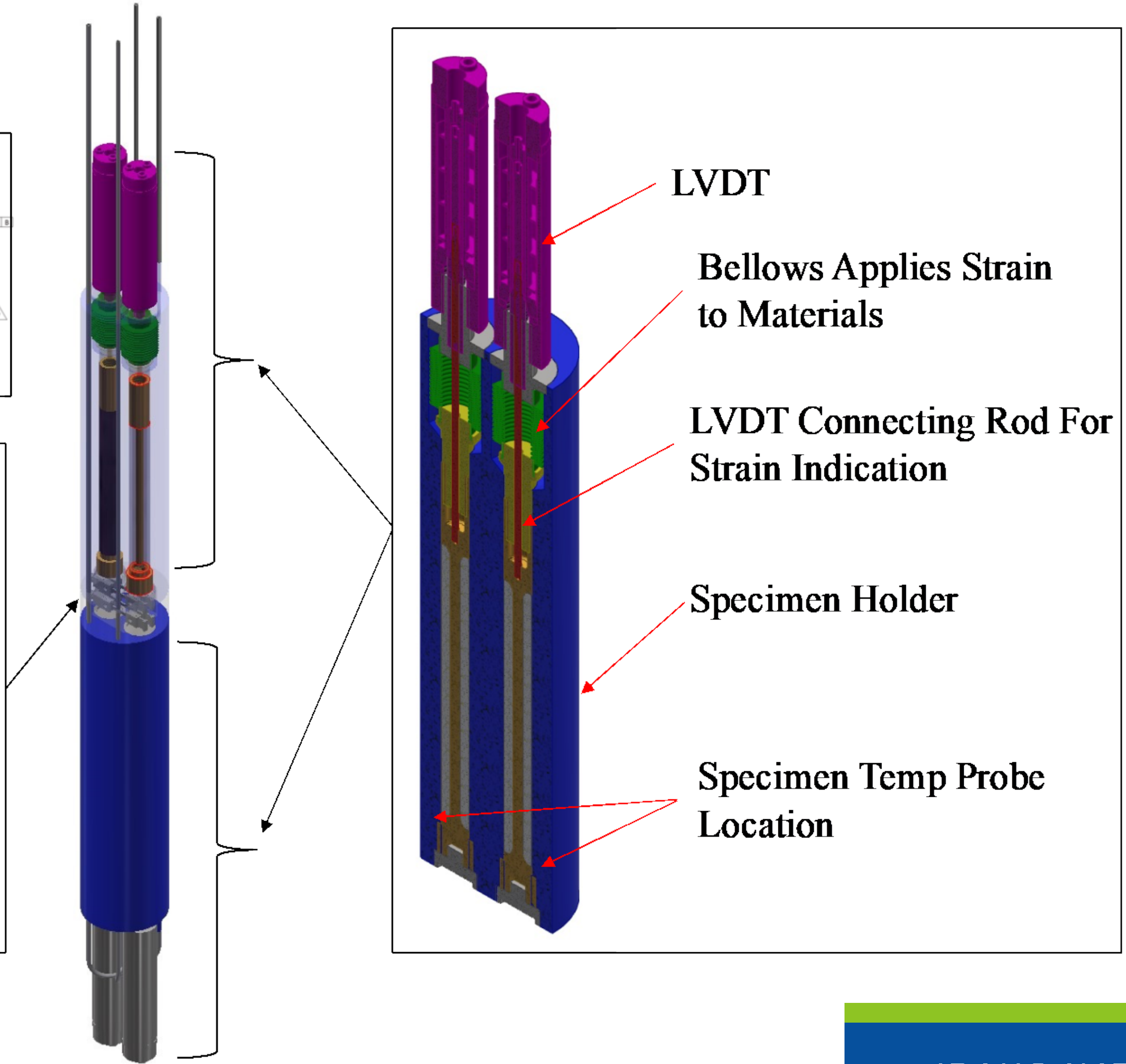
Design and Instrumentation


Mini SSJ3 Specimens

+

Passive pre-strained specimen concept





Capsule Dimensions: OD ~30 mm and Length ~270 mm

INCREASE Instrumentation

1. Miniature Type 3 LVDT 700°C

- Linear Variable Differential Transformer provided by IFE/Halden are reactor grade sensors that can measure deformation at micro-level that will measure real-time stress relaxation for each test specimen
- Two of the LVDTs will be used to do verification testing in flowing autoclave of the whole design prior to MITR irradiation
- Status: Received 2 LVDTs in March, and waiting for 4 more LVDTS to be delivered in April/May

2. N-type TCs

- Two of the thermocouples will measure temperature of each stress relaxation specimen
- Four of the thermocouples will be used for autoclave verification testing
- Quote received from ILC

INCREASE Instrumentation Cont'd

3. SPNDs

- Self-powered neutron detectors will use one to two types for each capsule depending on the space available
- Received quote from Mirion Technology

4. SiC TMs

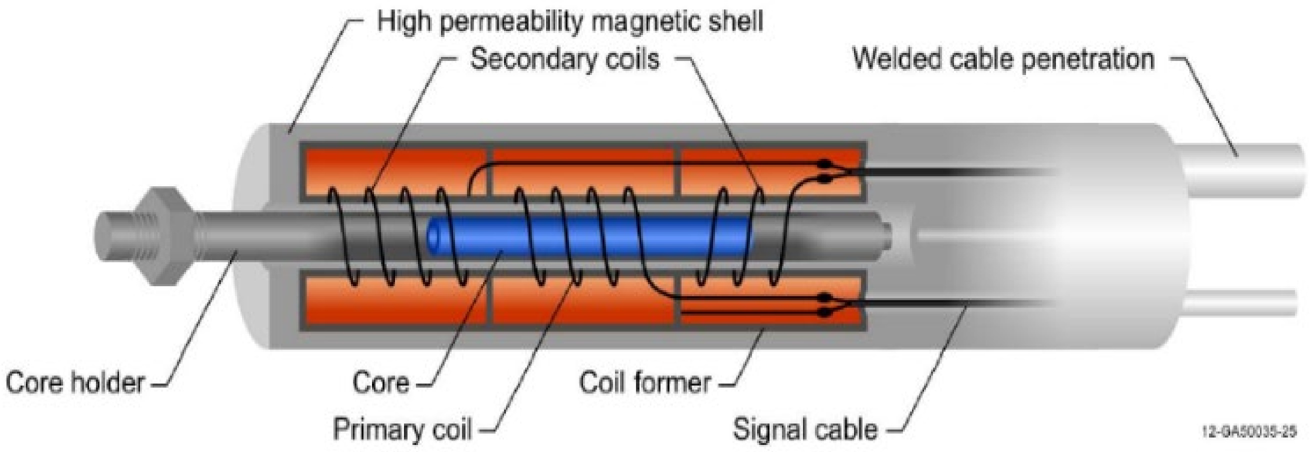
- Silicon Carbibe temperature monitors will measure the averaged peak irradiation temperature for each capsule after the irradiation is done in PIE
- Already in inventory

5. Passive flux wires

- Each capsule will have multiple flux wires that will rotate between irradiation cycles for measuring thermal and fast flux for each capsule in PIE
- Waiting for quotes for various types of wires

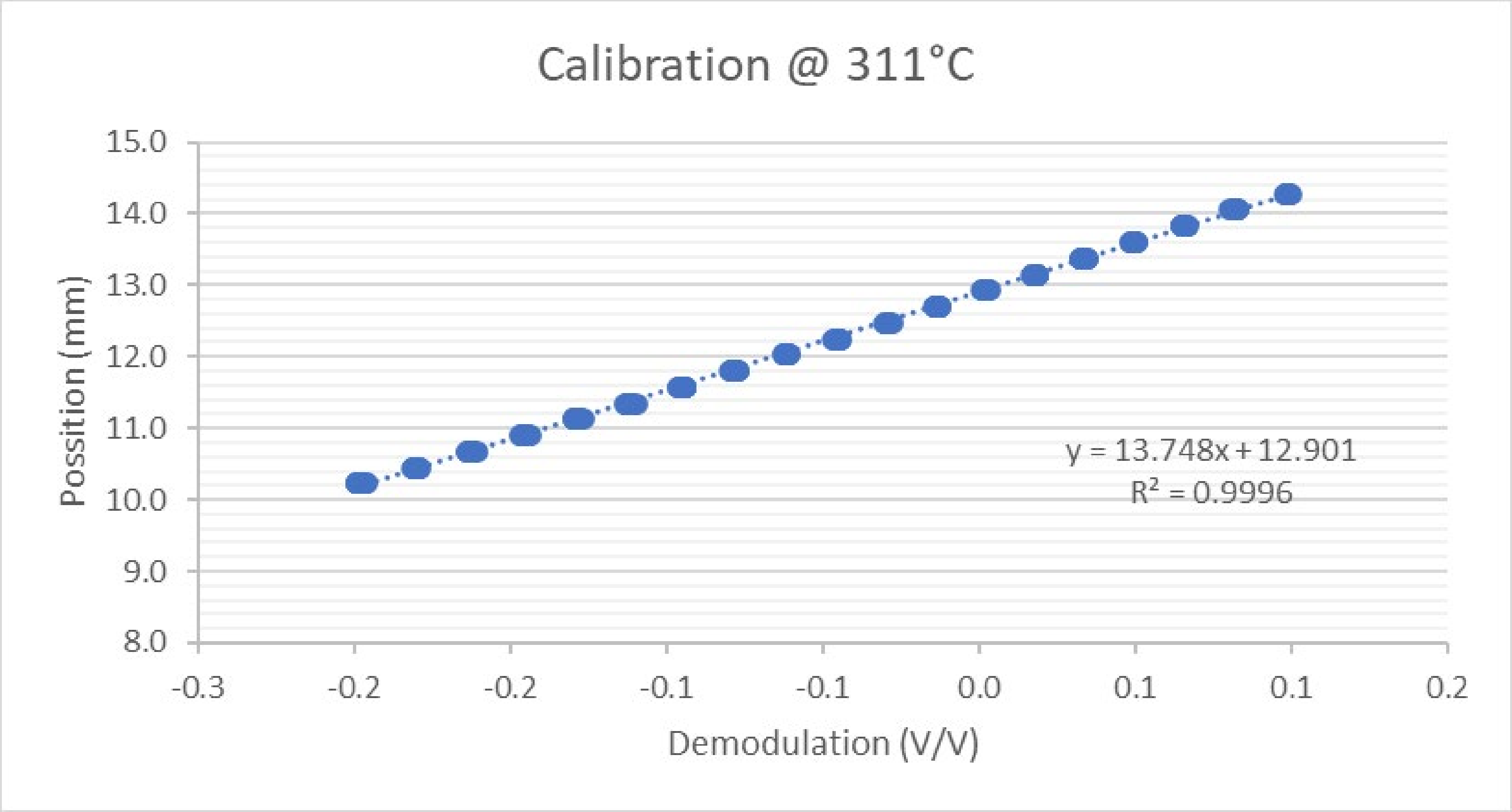
Stress Relaxation: 6 Mini LVDTs provided by IFE

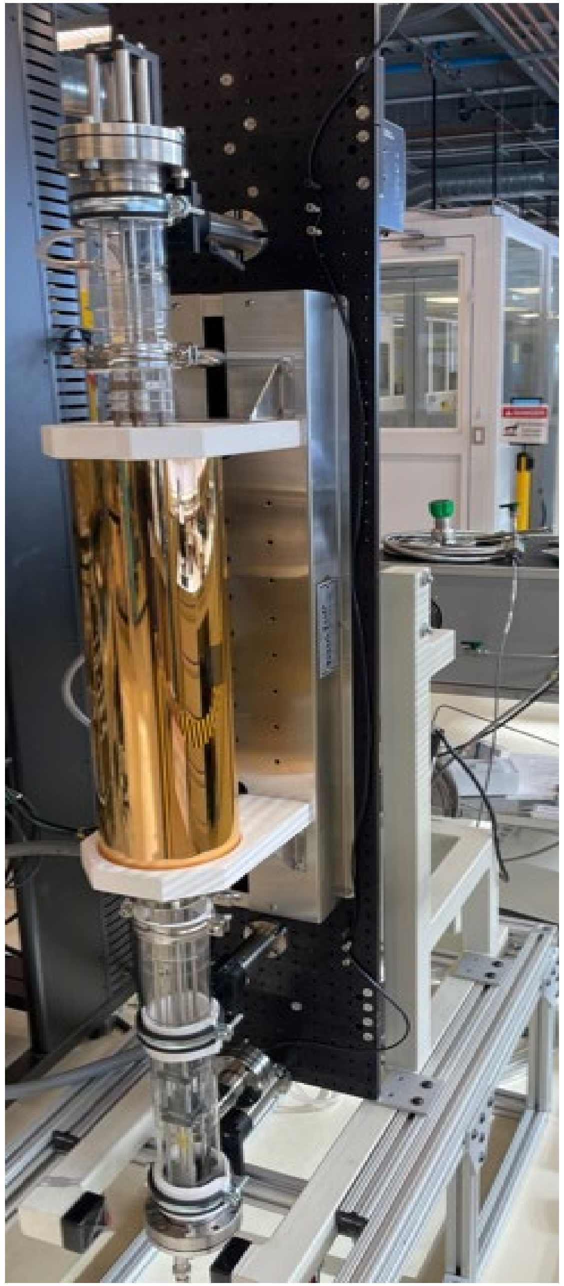
- MITR:
  - **Miniature type 3** with OD 8.3mm and length 22mm that measures +/- 1.5 mm linear range
  - Accuracies within 1% (~10% failure rate within 5 years of operation)
  - 1mm MI cables (3 wire and 2 wire)
- IFE/Halden LVDTs:
  - **Short type 5** with OD 12mm and length 46mm that measures +/- 2.5 mm linear range
  - Accuracies within 1% (~10% failure rate within 5 years of operation)
  - 1mm MI cables (3 wire and 2 wire)



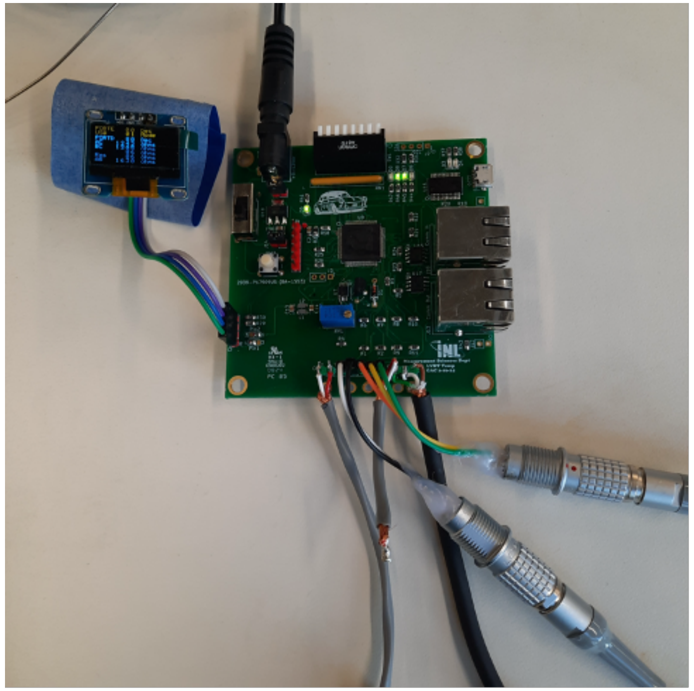
LVDT Calibration System

- Characterize and optimize LVDT performance for a specific target environment
- Calibrate LVDT with a known relative displacement (strain) between the LVDT coil and its ferritic core



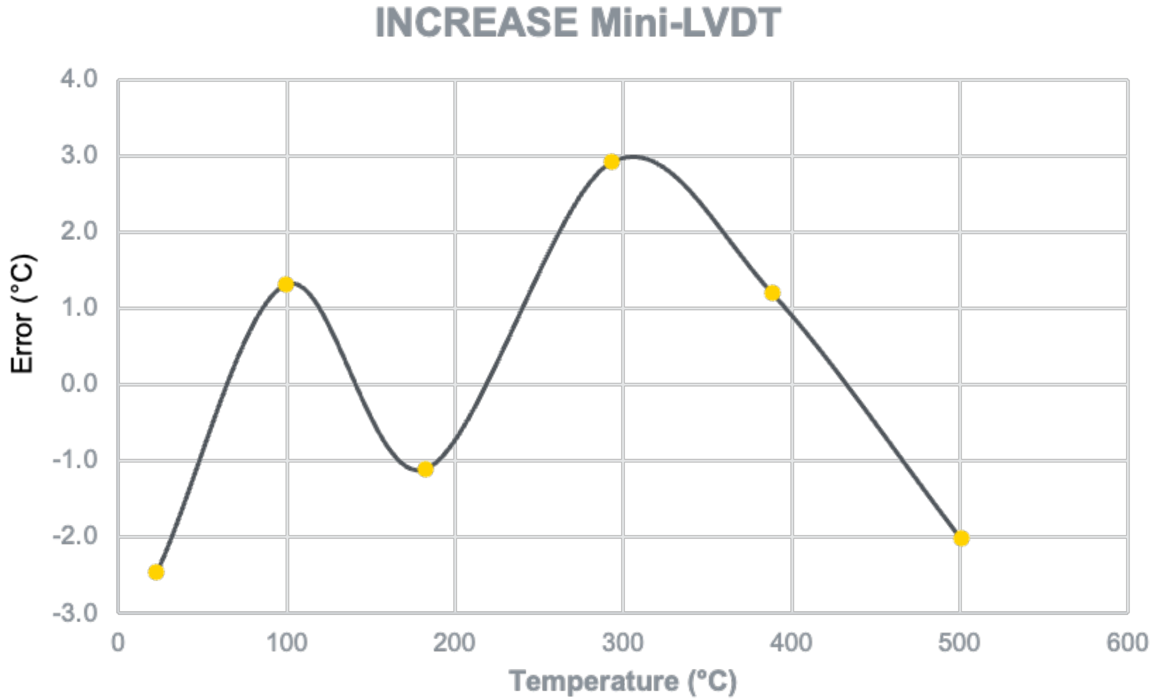


Mini LVDTs can also read Temperatures = no need to install TCs



ELVIS (Enhanced Linear Variable Integrated Sensor)

Actual (°C)	LVDT Sensor (°C)	%Error	Error (°C)
388.6	389.8	0.3	1.2
182.4	181.3	-0.6	-1.1



The error for a standard grade K-type thermocouple is ±2.2 °C or ±0.75 % of the measurement temperature which ever is greater (ASTM-E608).

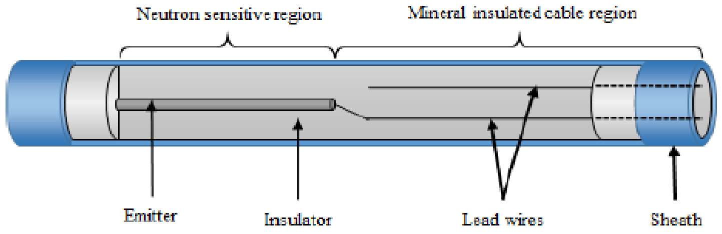
Temperature: 12 Thermocouples

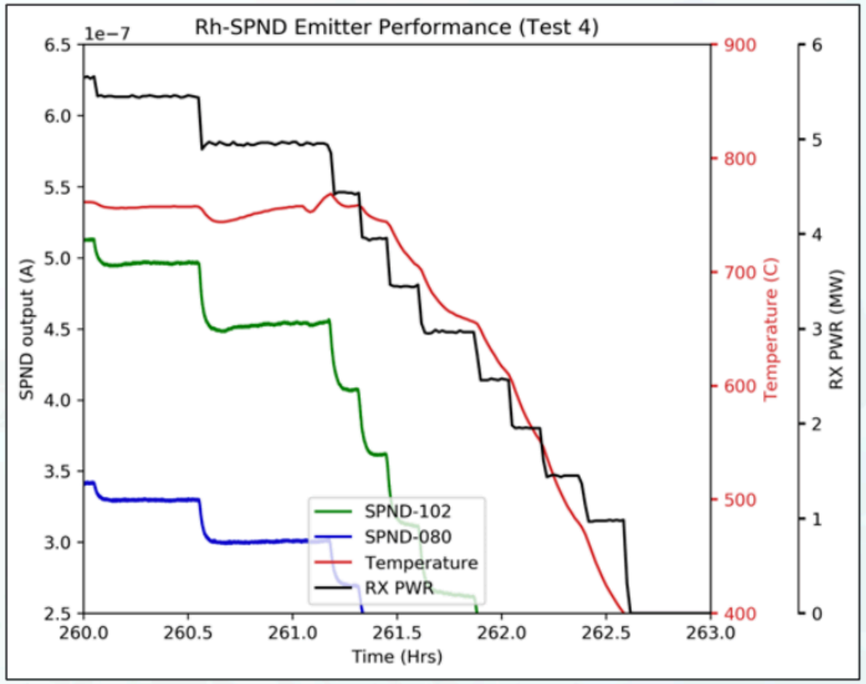
- Type N for specimen and LVDT monitoring
  - Type N (Nicrosil/Nisil) thermocouples (1.6 mm or 2.6 mm OD)
  - Up to 1260℃ operating temperature
  - Accuracy within 0.5-1%
  - Better repeatability between 300 ℃ to 500 ℃ than type K
  - Quotes received from Idaho Laboratories Corporation (ILC)

Neutron Flux: 12 SPNDs

- Self-Powered Neutron Detectors (SPNDs)
- Thermal: Rhodium-SPND
  - Data analysis includes automated delayed-response compensation (data analysis and temperature compensation algorithm under development)
  - Quote received from Mirion Technology
- Fast: Possibility of using Ta-SPND or Bi-SPND for fast neutron flux evaluation (CEA collaboration for evaluation and modeling efforts)
  - No room for fission chambers that would be best for measuring fast neutron flux

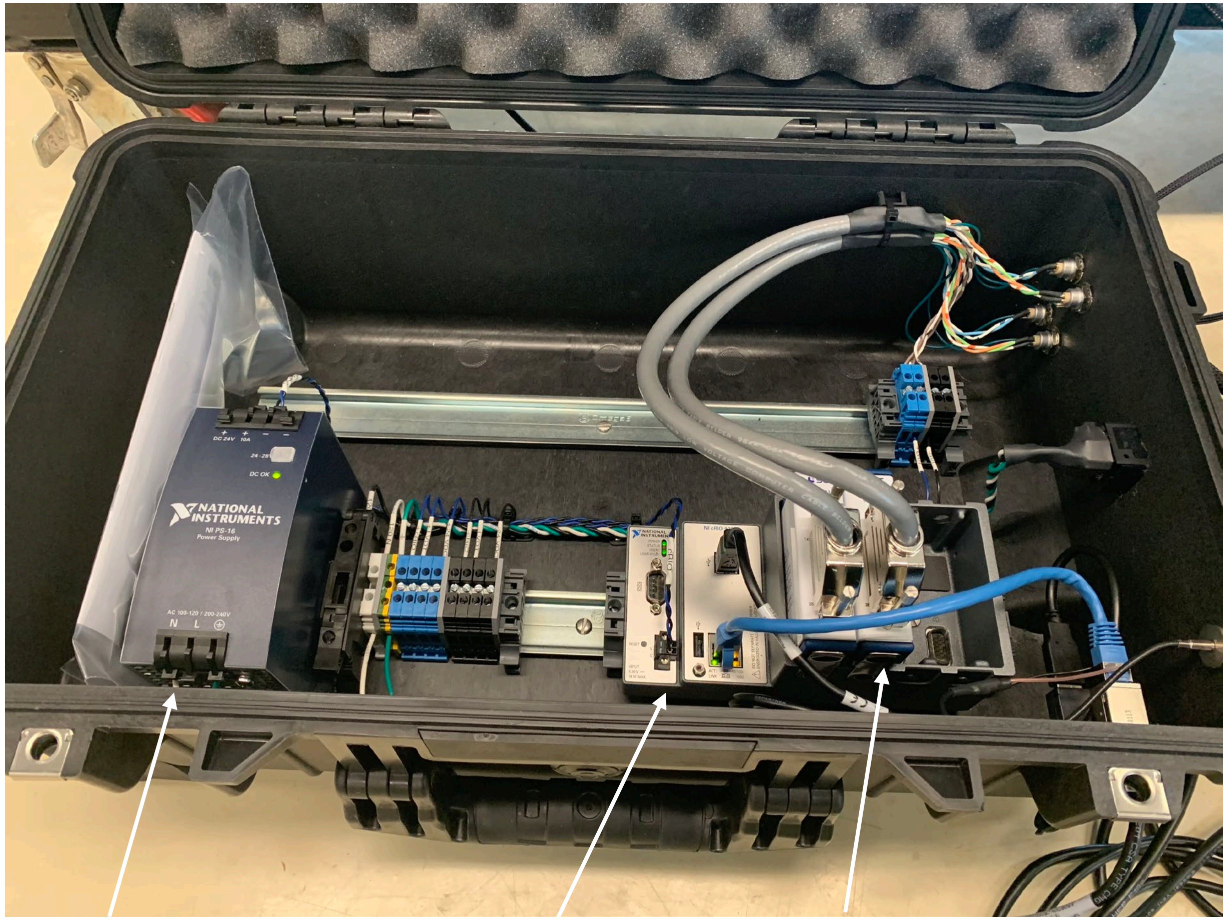
SPND Design	Emitter	Insulator at NS region	Sheath
Large Rh-SPND (ILC-102-RhSPND)	Rhodium 0.032 in. OD 3.50 in. L	Al_2O_3 0.072 in. OD 0.032 in. ID	I-600 0.102 in. OD 0.072 in. ID
Small Rh-SPND (ILC-080-RhSPND)	Rhodium 0.020 in. OD 3.50 in. L	MgO 0.056 in. OD 0.020 in. ID	I-600 0.080 in. OD 0.056 in. ID





NI DAQ System

- National Instruments (NI) data acquisition system (DAQ) is fully customizable:
  - Reads and records sensor signal:
    - TC signal
    - LVDT signal
    - SPNDs
    - Pressure signal
  - Pelican case makes it portable (moves with your experiment)



Power Supply

CompactRIO

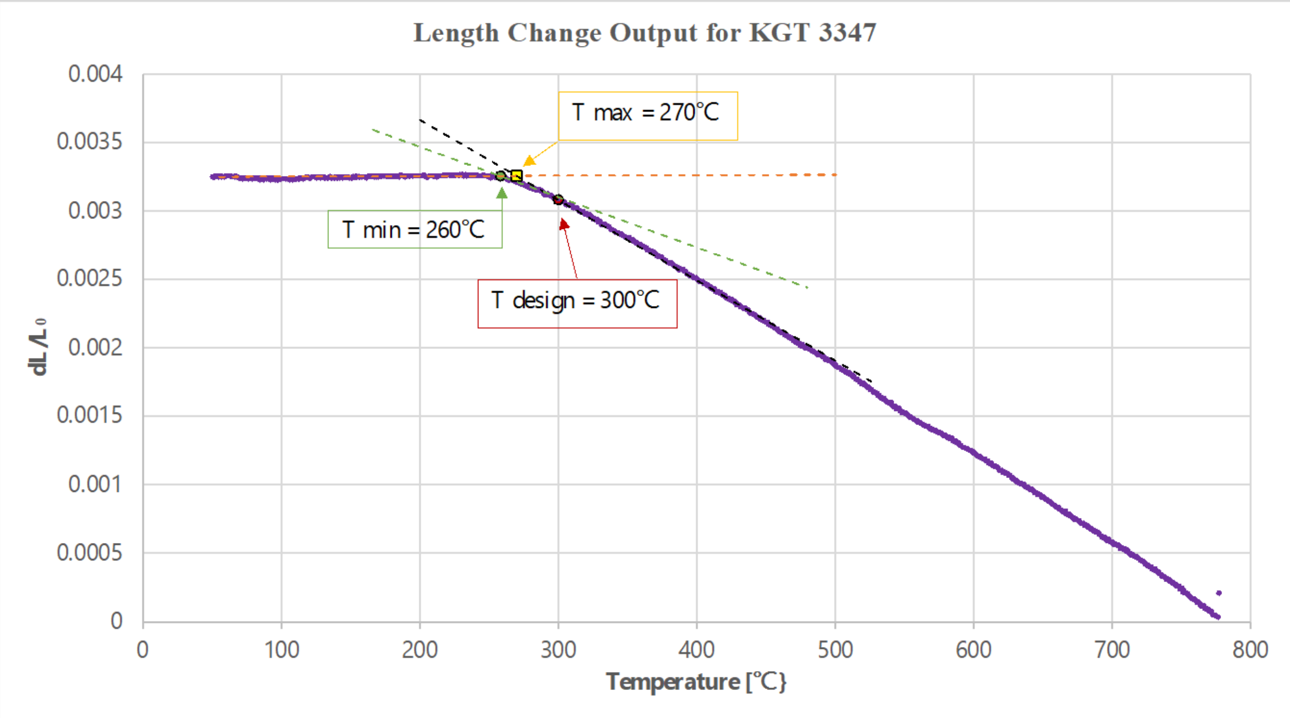
LVDT and TC Modulator Cards

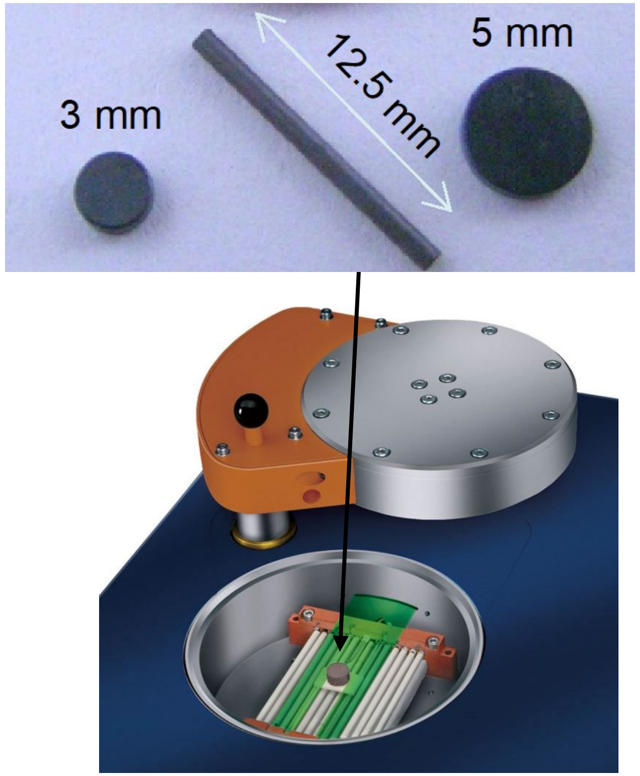
Autoclave Verification Testing

- Autoclave testing is used for calibrating and verifying all of the instrumentation as well as the design for stacking them
  - Plan to test 2 LVDT bellow assemblies with active TCs for stress relaxation measurement verification and any final design consideration
- Flowing Autoclave:
  - Typical PWR/BWR conditions
  - Maximum allowable working pressure of 15.5 MPa
  - Maximum temperature of 315°C
  - Maximum flow rate of 50 gal per minute (0.18927 m^3/min)

Temperature: 4 Passive SiC Monitors

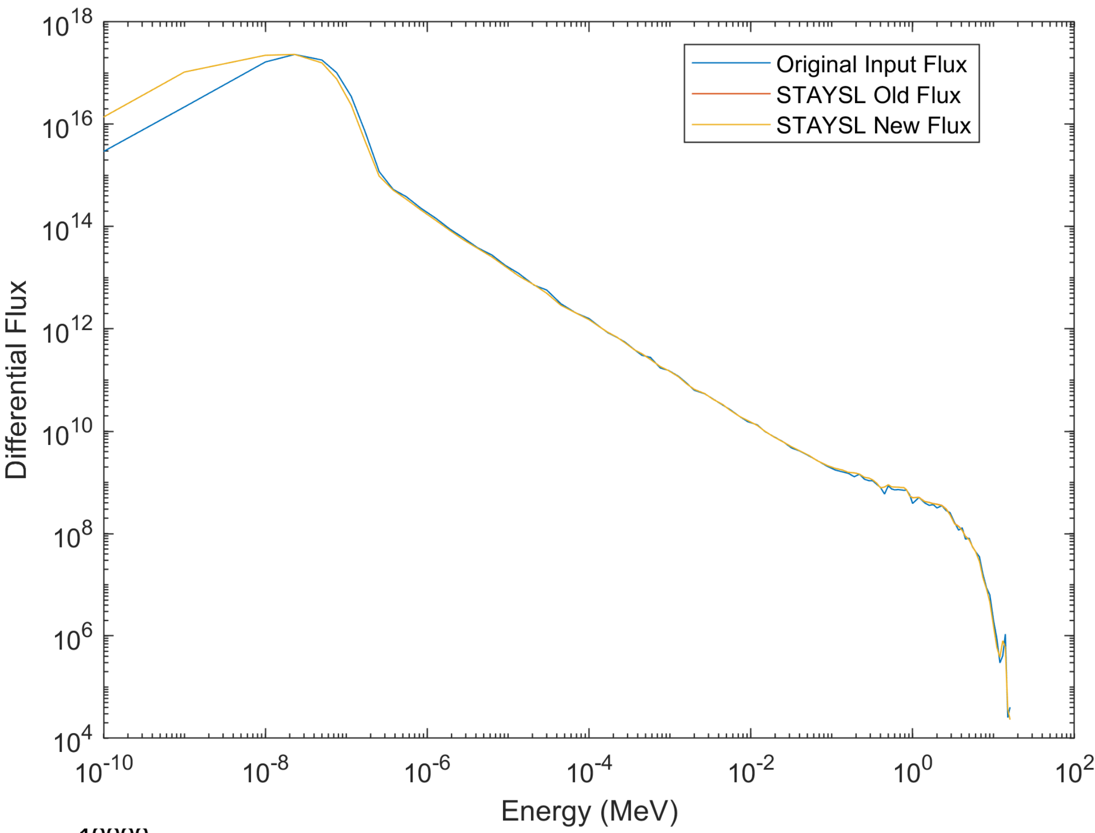
- Thermal expansion from continuous dilatometry is an automated process
- Temperatures: 200 – 1200°C within +/-20°C
- Recommended dose ranging from 0.5 – 8 dpa
- Rod shape monitor that is 12.5mm in length with 1mm OD
  - Can swell in reactor up to 0.25mm (in length and OD)
- Procured from PremaTech Advanced Ceramics
- Already in stock

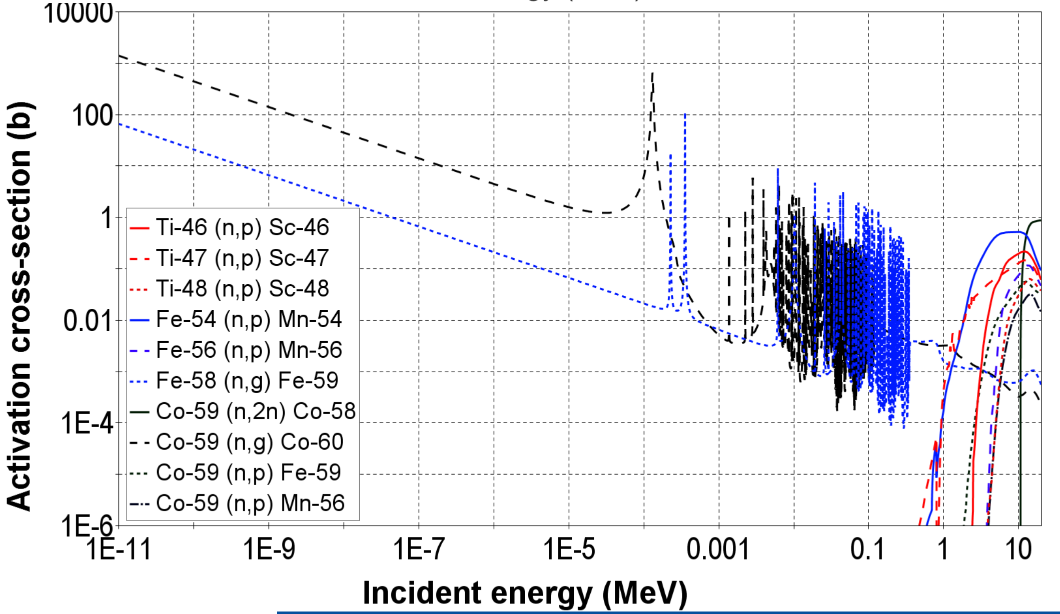




Neutron Flux: Dosimeters

- The shape of the adjusted flux originates from each isotope's reaction rate(s).
- The magnitude of the flux is determined from a thermal reaction, typically
- Thermal and Fast neutron flux and fluence evaluation
- Waiting for quotes for various types of wires





Conclusion

- INCREASE Project was awarded about a year ago under NEA's FIDES II Program
- Minimum of 2-3 dpa for each SS specimen at MITR, but desire up to 5-6 dpa
- Conceptual design includes types of instrumentation:
  - 4 Mini LVDTs 700℃ for irradiation and 2 for autoclave verification
  - 12 TCs Type-N: 8 for all the active specimens and 4 for the autoclave verification
  - 4-8 SPNDs: one for thermal region and one for fast region is space available
  - Passive SiC TMs: 1 for each active specimen, and X number for the remaining specimens based on space available
  - Passive neutron dosimeter: various types for thermal and fast region
  - All modular DAQ for reading and recording real-time data from each active instrument
- Target irradiation for Spring/Summer of 2025

Thank you!

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