INL/CON-23-75755-Revision-0

Measurement Science Laboratory In Core Instrumentation Development

June 2023

Changing the World's Energy Future

Troy Unruh

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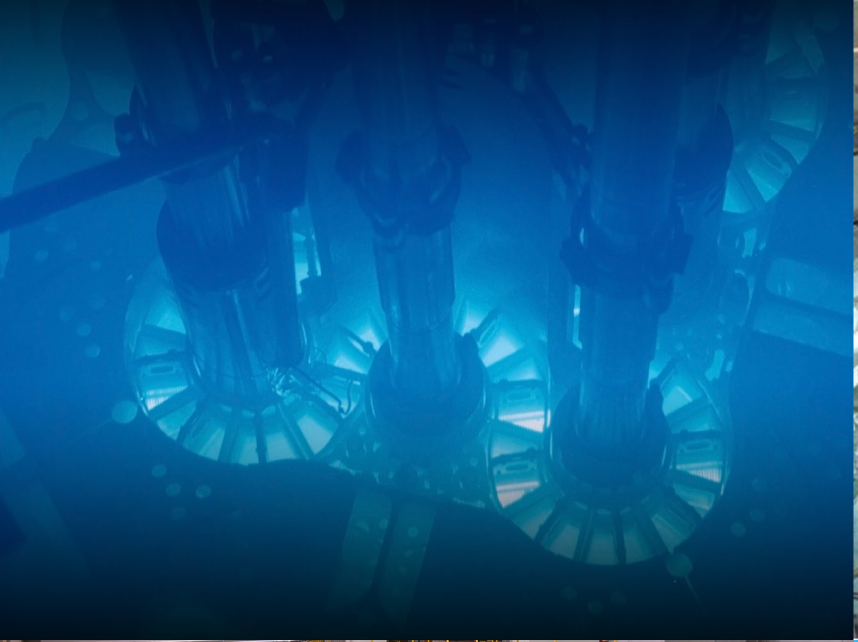
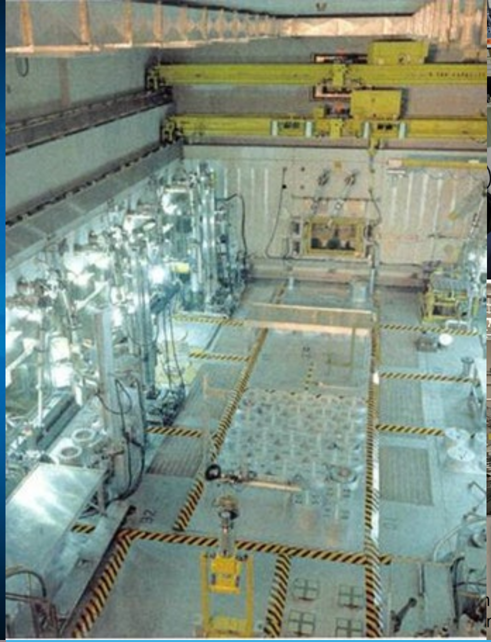
Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

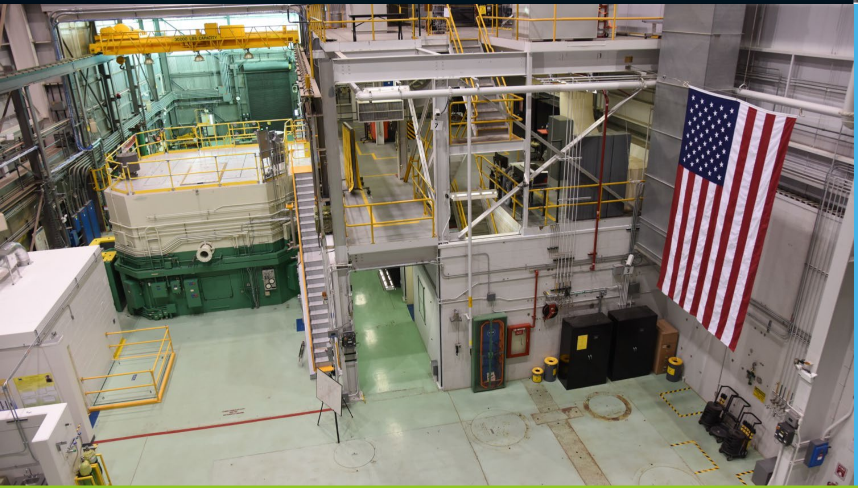
Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517





Presented by Troy Unruh

Manager – INL Measurement Science Department



Capabilities of the INL Irradiation Facilities

–Instrumentation focused view of INL capabilities

Idaho National Laboratory

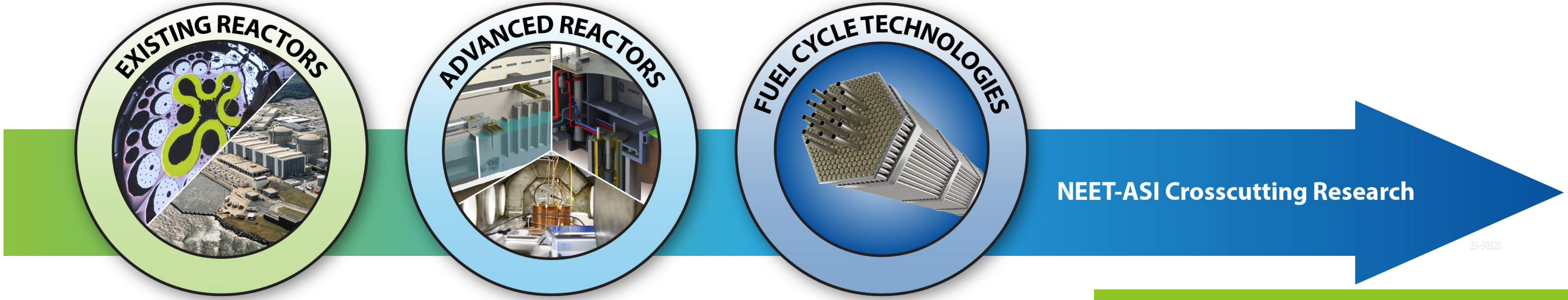
INL/MSL and the DOE Advanced Sensors and Instrumentation (ASI) Program

Mission

Develop **<u>advanced sensors and I&C</u>** that address **critical technology gaps** for monitoring and controlling existing and advanced **reactors** and supporting **fuel cycle** development

Vision

NEET ASI Research results in advanced sensors and I&C technologies that are **<u>qualified</u>, <u>validated</u>, and ready to be <u>adopted</u> by the nuclear industry**



Measurement Science Department & Laboratory

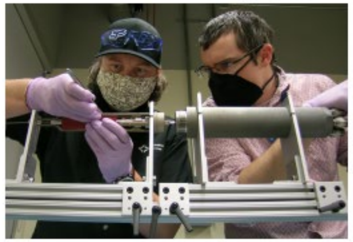
Measurement Science Laboratories

Nuclear instrumentation for irradiation experiments and advanced reactors

Using a microscope to characterize a strain gauge fabricated by advanced manufacturing methods.

A critical part of nuclear energy research is the ability to precisely measure the extreme conditions inside a nuclear reactor. This is a significant technical challenge, but Idaho National Laboratory's Measurement Science Department addresses it with the Measurement Science Laboratories (MSL). MSL are a collection of laboratory spaces, equipment and capabilities supporting the activities of INL's Measurement Science Department. MSL provide broad support to many programs within the U.S. Department of Energy's Office of Nuclear Energy (DOE-NE) and allow access to researchers and engineers from organizations inside and outside INL.

Most MSL facilities are located at INL's Energy Innovation Laboratory (EIL), including the High Temperature Test Laboratory (HTTL). Other labs are in the Idaho National Laboratory Research Center (IRC) and Idaho Engineering Demonstration Facility (IEDF).



Assembling an experimental capsule for the TREAT reactor.

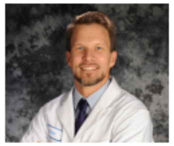
Idaho National Laboratory

MEASUREMENT SCIENCE LABORATORY CAPABILITIES

MSL contain an array of specialized equipment for nuclear instruments development, fabrication and testing.

- The autoclave testing area includes various flowing and static containment vessels that simulate pressurized water reactor temperature, pressure, flow and chemistry. This allows instrument testing of advanced instrument concepts, test assemblies, reactor components, materials, and coatings in prototypic, but non-nuclear conditions.

The HTTL houses specialized instrument fabrication equipment and can perform high-temperature evaluations as well as non-destructive analysis of instruments through a micro focus X-ray computed tomography scanner. The HTTL can also handle radioactive materials relevant for instrument research.

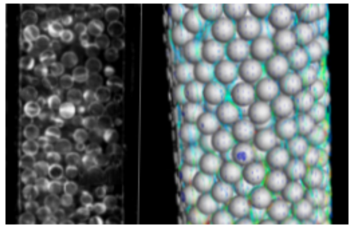


Troy Unruh is the manager of the Measurement Science Department.

- The fiber optics and acoustic sensors fabrication and testing area includes specialized spectrometers, spectrum analyzers, laser interrogators, pulse power system, power meters, and fiber fabrication equipment.

MSL provide research and development, testing and characterization, and engineering services including:

- **Developing and fabricating nuclear instrumentation** for irradiation experiments to provide real-time characterization of local test parameters, such as neutron flux, temperature, pressure and materials mechanical responses. MSL instruments are deployed in INL irradiation facilities, primarily the Advanced Test Reactor (ATR) and the Transient Reactor Test Facility (TREAT), as well as facilities in collaborating institutions, such as the Massachusetts Institute of Technology Research Reactor.
- **Engineering services for instrumented irradiation rigs.** Those include design integration, instrument calibration and out-of-pile testing, assembly processes as well as post-irradiation examination for passive monitors. The assembly of instrumented TREAT experiments, design and calibration of linear variable differential transformers and services related to passive monitors for ATR experiments without sensor leads (melt wires, SiC monitors) are an important component of MSL activities.
- **Development of innovative sensing technologies** for advanced reactors instrumentation and control systems. Through use in irradiation experiments, sensing technologies are matured for commercialization or integration in advanced reactor designs. Innovative technologies such as optical fibers and acoustic measurements are key to enable advanced maintenance (such as early fault detection) and operation modes (toward autonomous operation).



MSL researchers use computed tomography analysis to better understand the conditions inside a pebble bed reactor.

FOR MORE INFORMATION

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General contact
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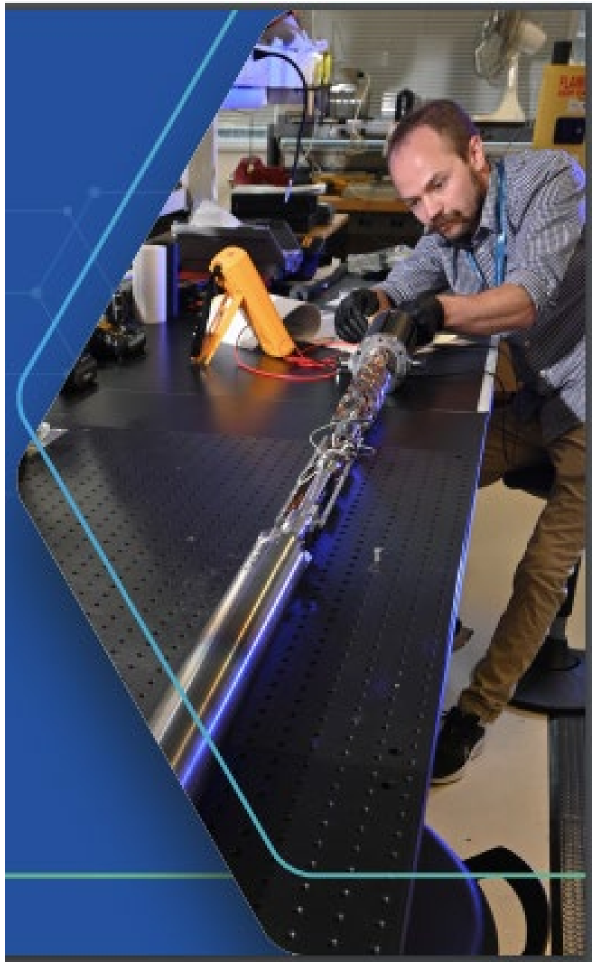
www.inl.gov

A U.S. Department of Energy National Laboratory

A self-powered neutron detector being inserted into INL's Neutron Radiography Reactor.

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy.

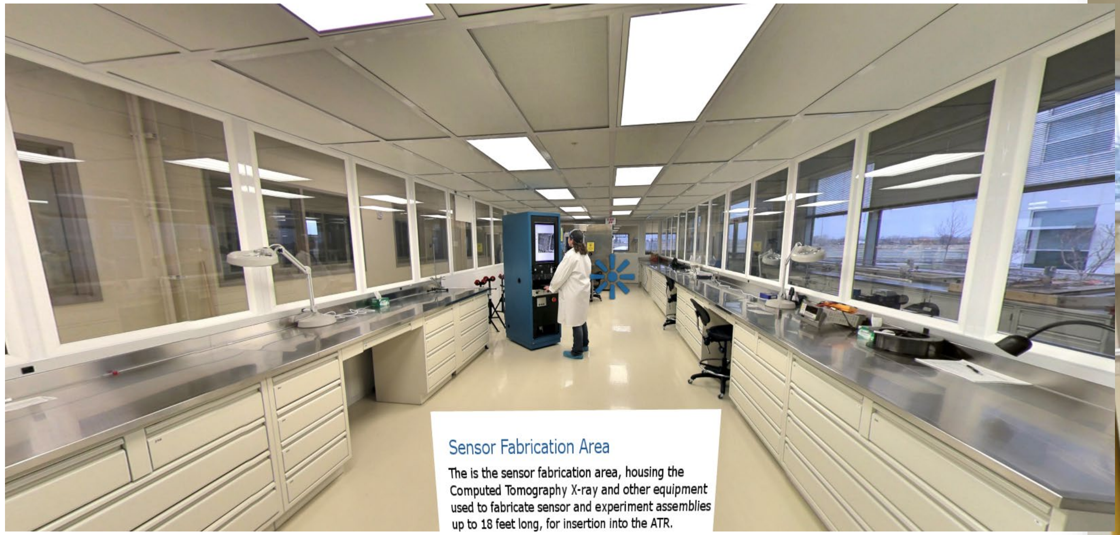
20-50442-010_R0 | 01-2023

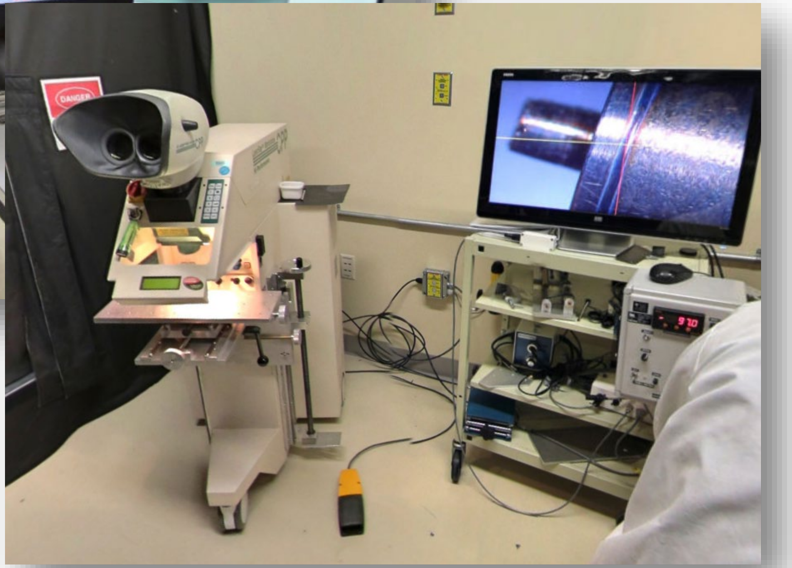


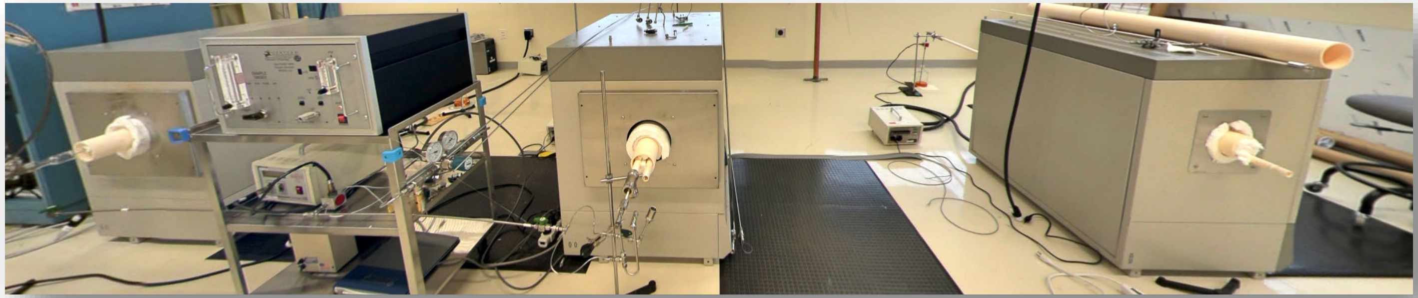
We welcome instrumentation-focused visiting researchers, students, vendors, etc.

https://factsheets.inl.gov/FactSheets/Measurement%20Science%20Laboratories.pdf

Measurement Science Laboratory Equipment Tour



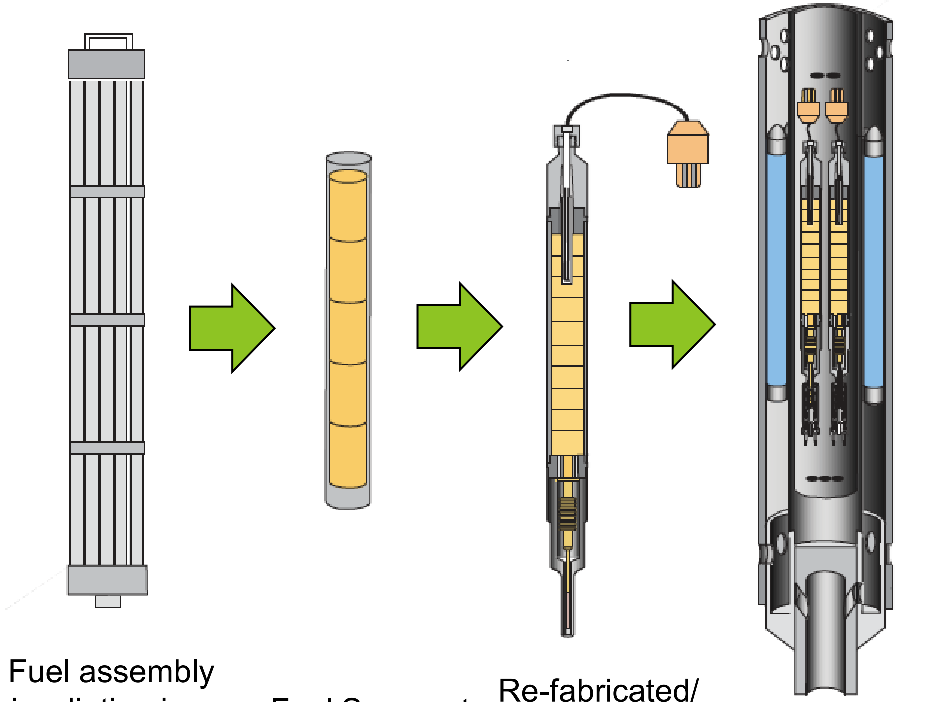




https://inlgov360.b-cdn.net/HTTL/HTTLTour.html

MSL Reinstrumentation for Testing Irradiated Rods

- Fuel rod refabrication, reinstrumentation, and continued irradiation prototyping units
- Hot cell units under development at Materials and Fuels Complex



Fuel assembly irradiation in a commercial LWR or test reactor (ATR)

Fuel Segment from Rod

Re-fabricated/ Re-instrumented segment

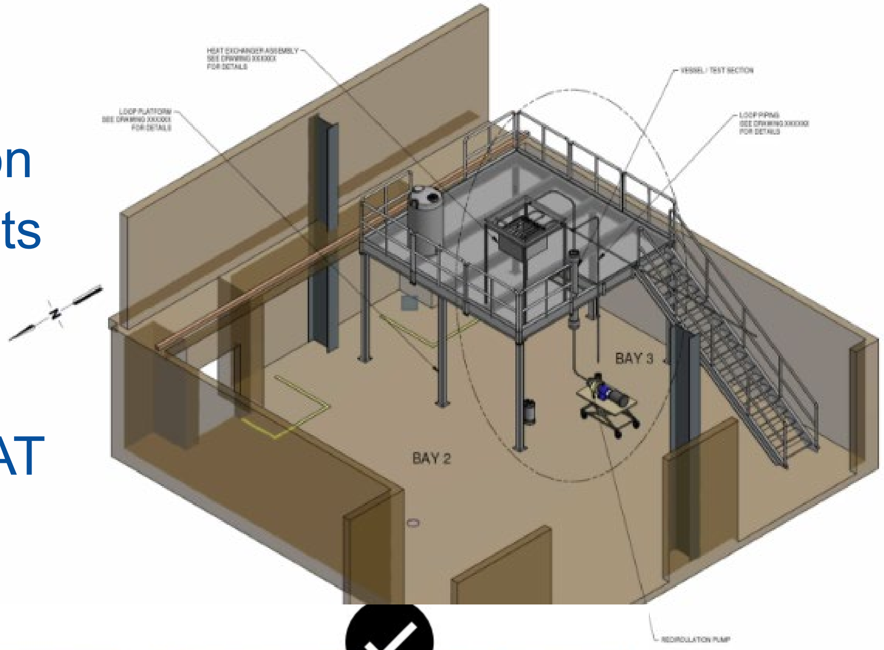
Experiment in ATR or TREAT

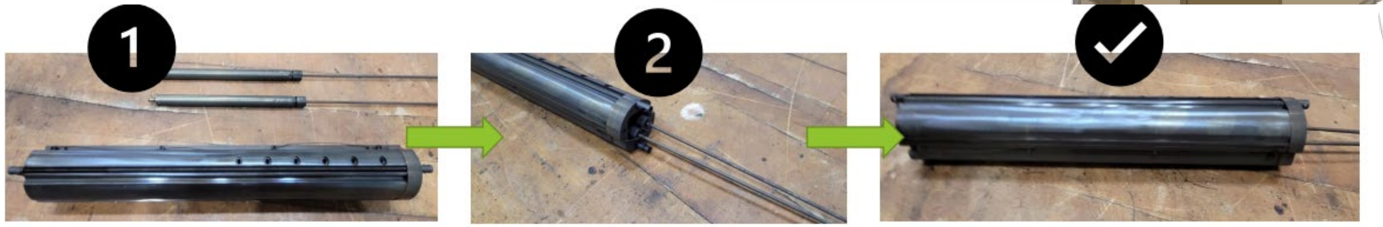
Images adapted from Halden presentations

Cryo-drilling unit with vacuum pumps and guards in place

Flowing Autoclave Laboratory

- Real-time, non-nuclear, high temperature, high pressure evaluations of instrumentation, assemblies, components, and materials
  - Hydrostatic testing
  - Sparce sensing validation
  - Line break measurements
- To be installed:
  - Steam generator
  - Sodium loop(s) for TREAT





Thermocouple performance evaluations in autoclave

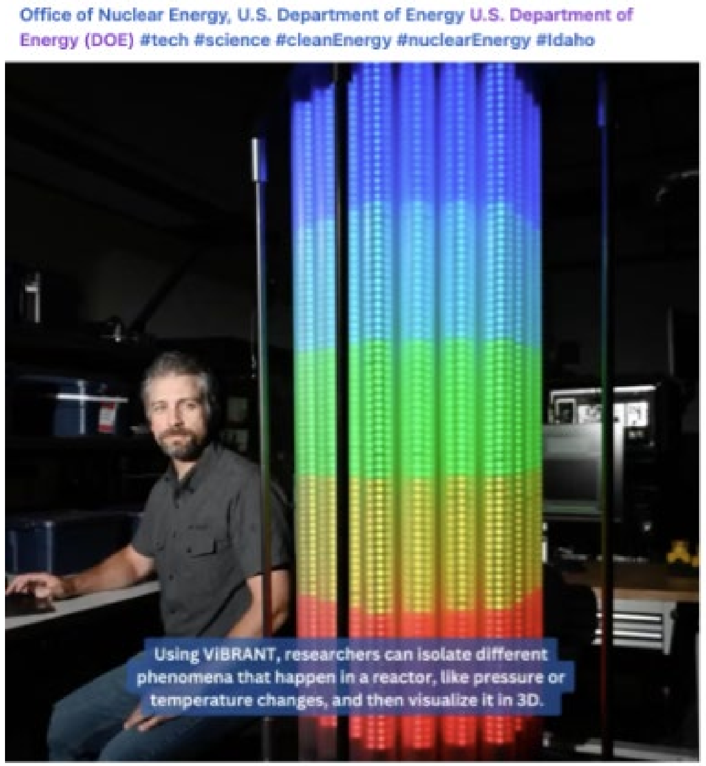
https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_53372.pdf

Flowing Autoclave Laboratory

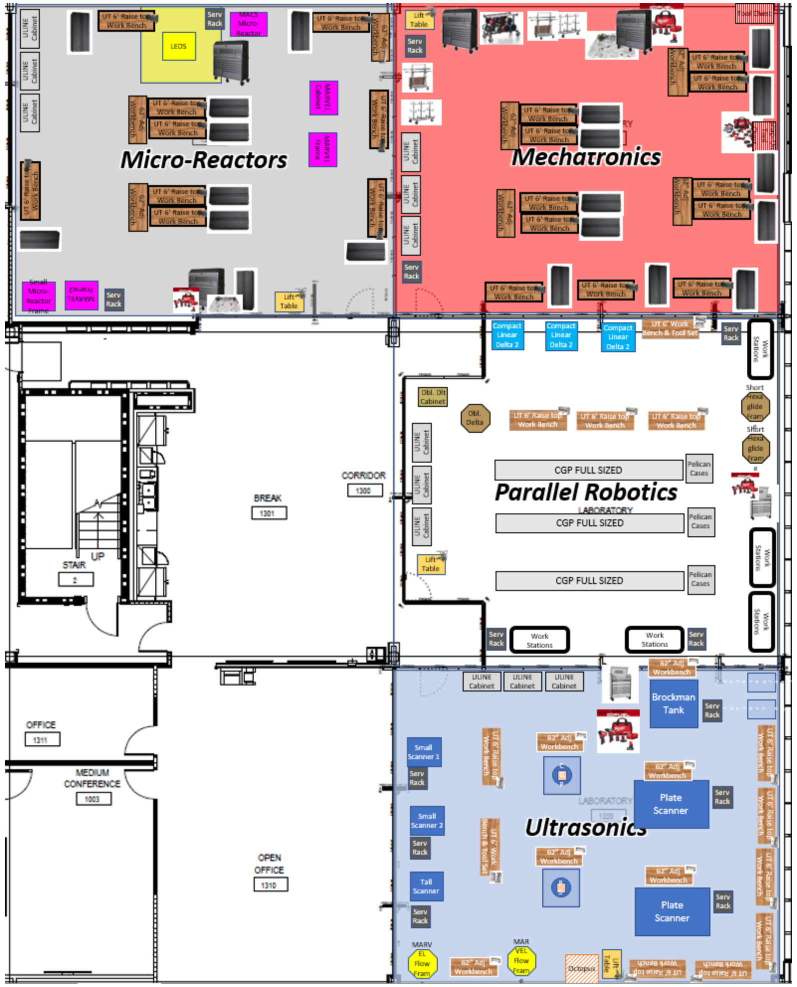
Mechatronics Laboratory (coming soon!)

- Dedicated to the development and demonstration of specialized mechanical and sensing systems for nuclear reactors and reactor experiments with specialized areas:
  - Micro-Reactors
  - Mechatronics
  - Parallel Robotics
  - Ultrasonics

Energy Security Research Laboratory (ESRL) under construction



Visual Benign Reactor as Analog for Nuclear Testing (ViBRANT)

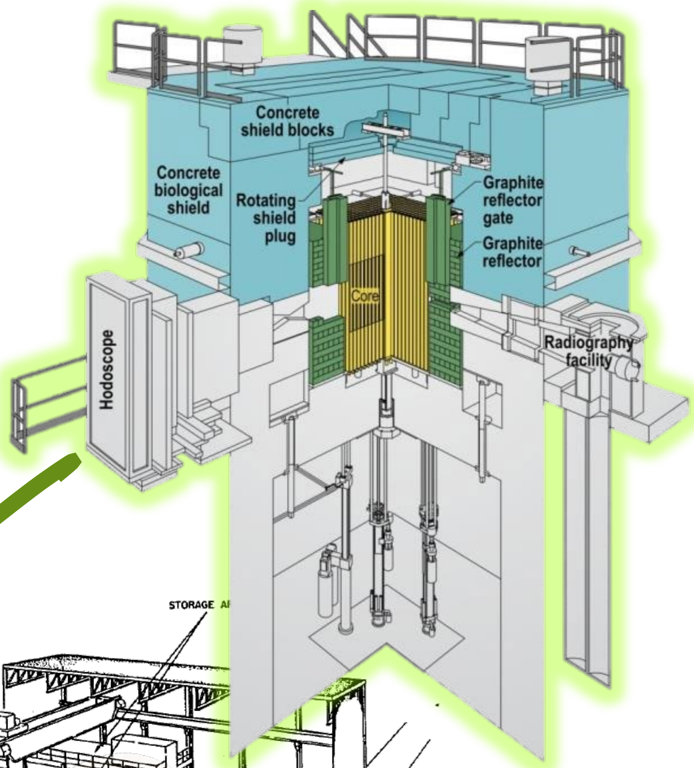


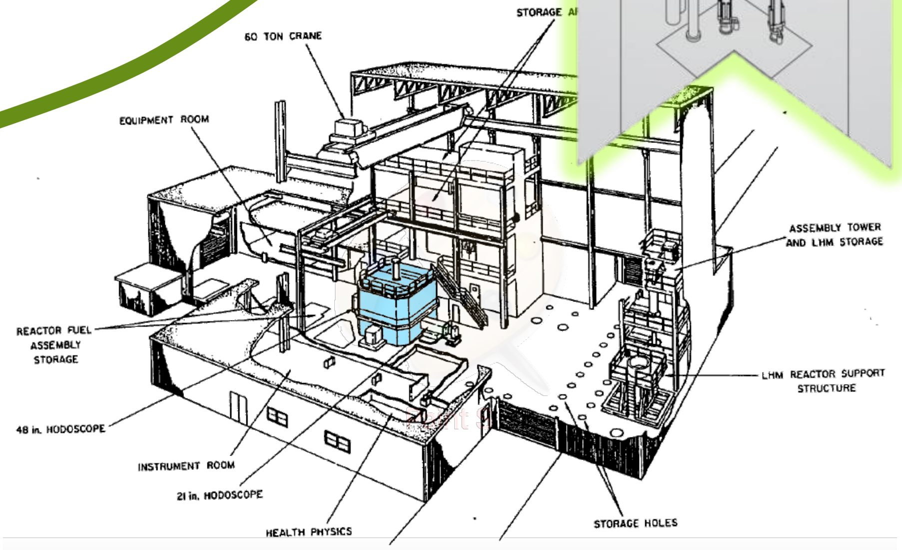
Mechatronics Laboratory Layout

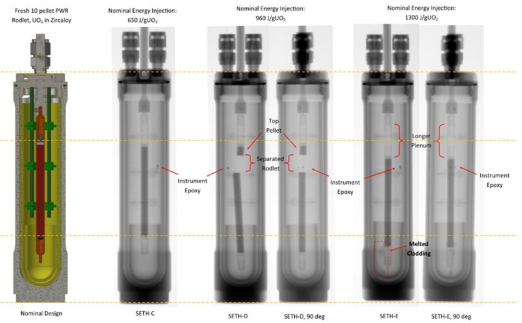
https://www.linkedin.com/posts/idaho-national-laboratory_visual-benign-reactor-as-analog-for-nuclear-activity-7100552458619285504-Oo-D

Transient Reactor Test (TREAT) Facility

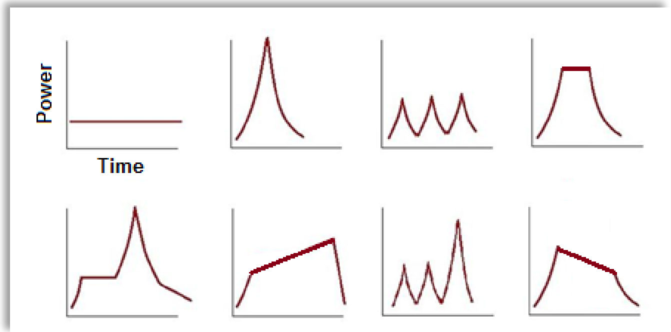
- **TREAT's design provides flexibility to support a variety of testing missions**
  - **19 GW Peak Transient Power (~2500 MJ energy limit)**
  - **Core: ~1.2 m high, 19 x 19 array of 10 x 10-cm. fuel assemblies (air-cooled)**
  - **Instantaneous, large negative temperature coefficient (self protecting driver core)**
- **Operated 1959-1994**
- **Restart 2014-2017**



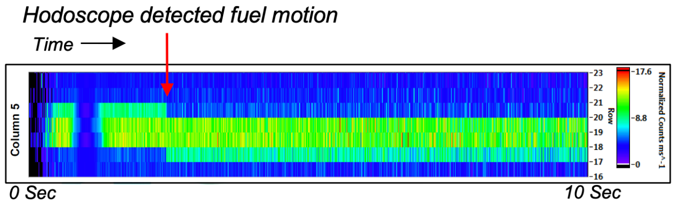




TREAT Neutron Radiographs

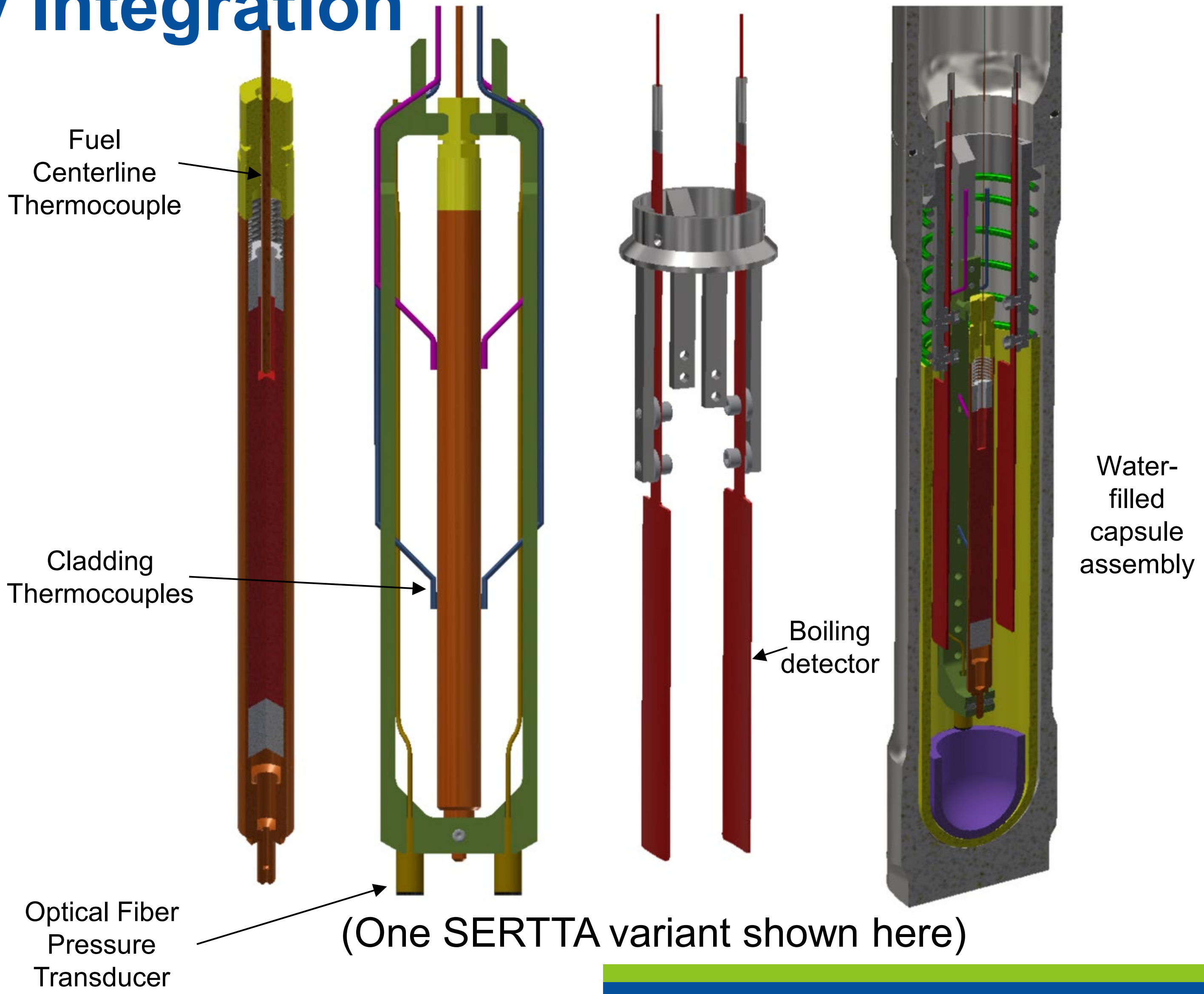


TREAT Hodoscope Data



MSL, TREAT Reactor, and Material and Fuel Complex (MFC) Hot Cell Facility Integration

- Example: Static Water Capsule (SERTTA) Instrumentation:
  - Boiling detector (electroimpedance)
  - Fuel temperature (TC)
  - Cladding surface temperature (bare-wire TC)
  - Plenum/capsule pressure (optical fiber/LVDT)
  - Elongation (LVDT/optical fiber) (not shown)
  - Energy deposition (ex-capsule SPND/n-α thermometer) (not shown)



(One SERTTA variant shown here)

https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_64537.pdf

Office of Nuclear Energy

National Lab Creates New Device to Test Safety Limits of Nuclear Fuel

OCTOBER 26, 2021

NUCLEAR MILESTONE

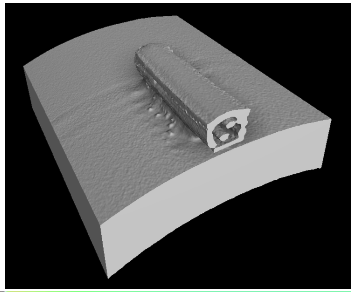
Public release video:

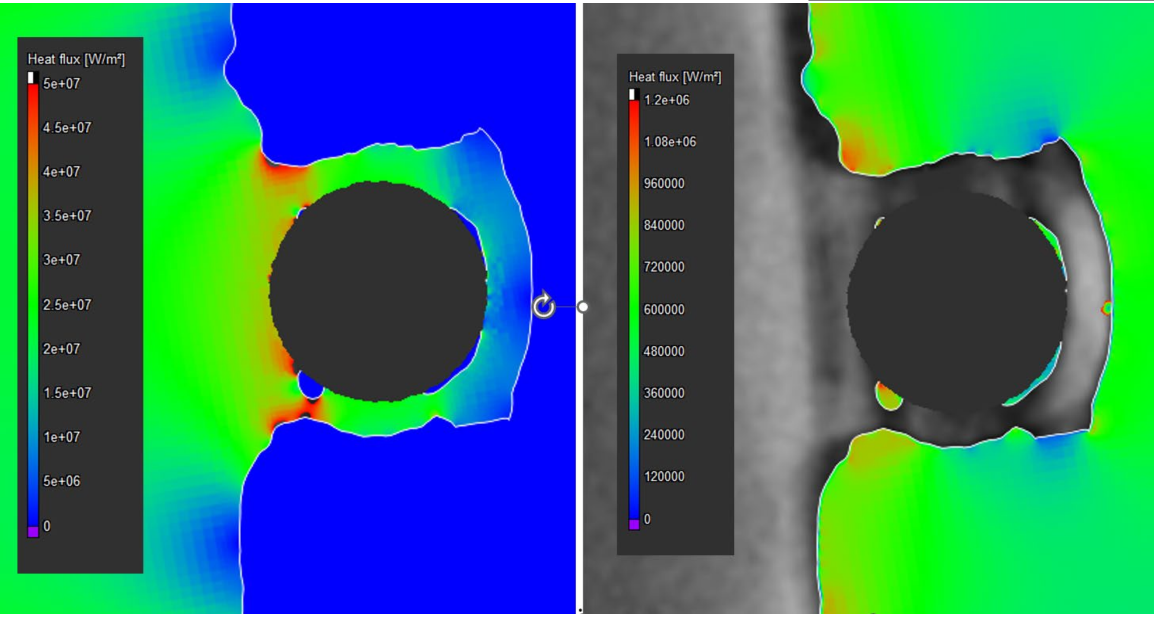
MSL intrinsic junction thermocouple in practice video: (one of many!)

https://www.energy.gov/ne/articles/national-lab-creates-new-device-test-safety-limits-nuclear-fuel

Measurement Science Laboratory Analysis

3D computed tomography of sheathed and mounted thermocouple (scan at right) at critical heat flux (simulated below)





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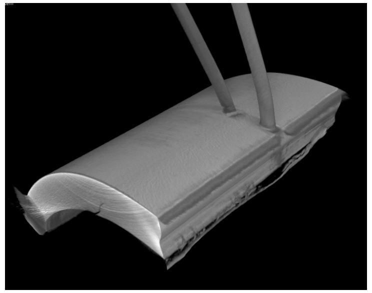
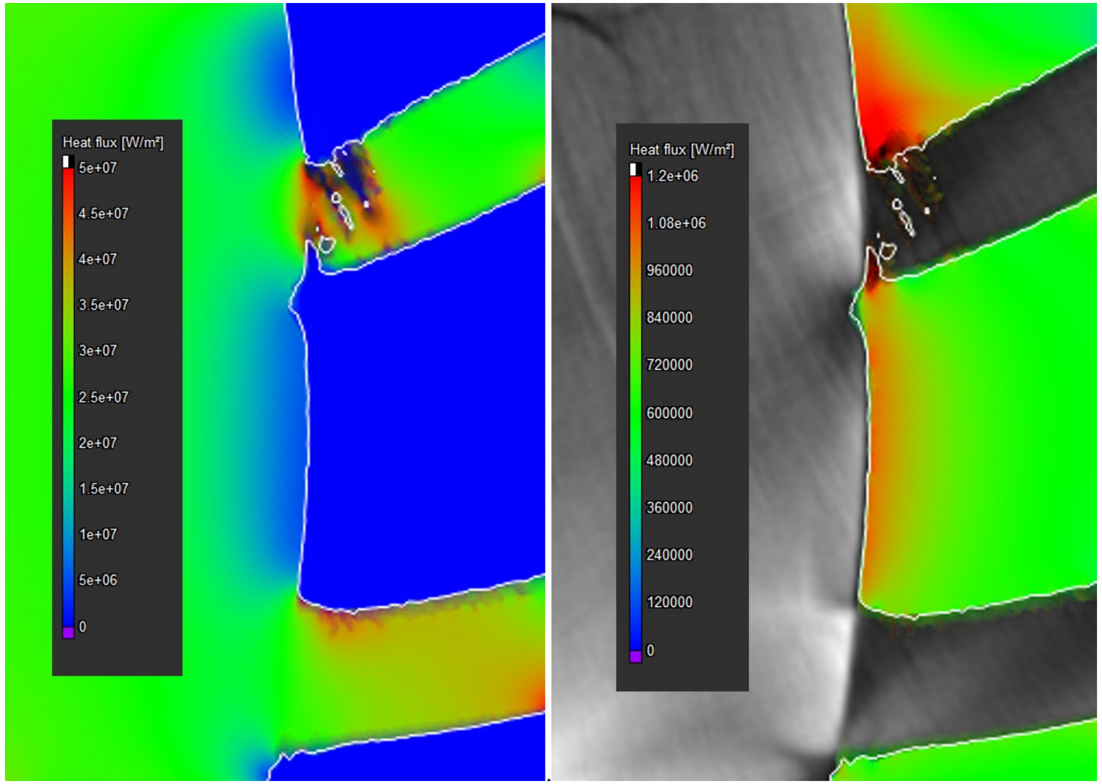
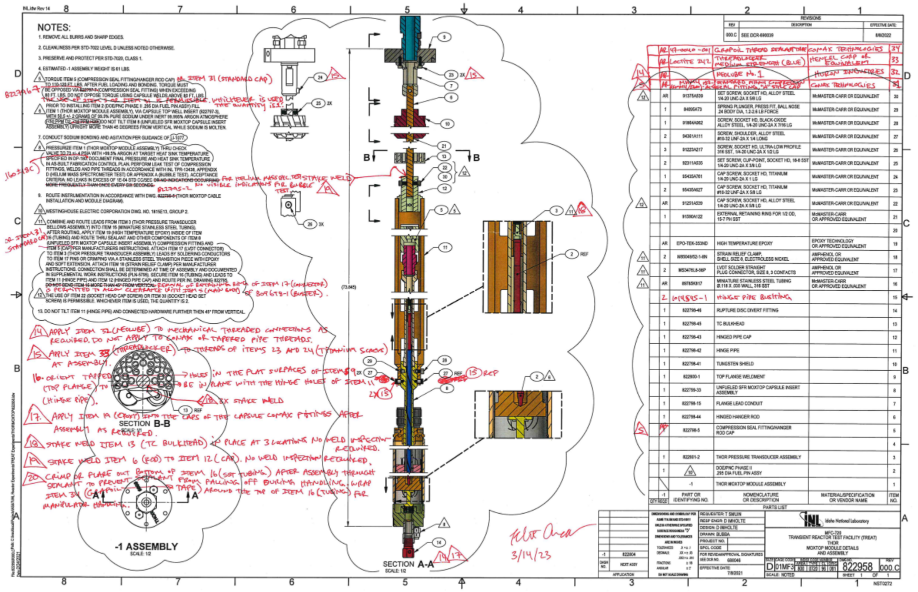


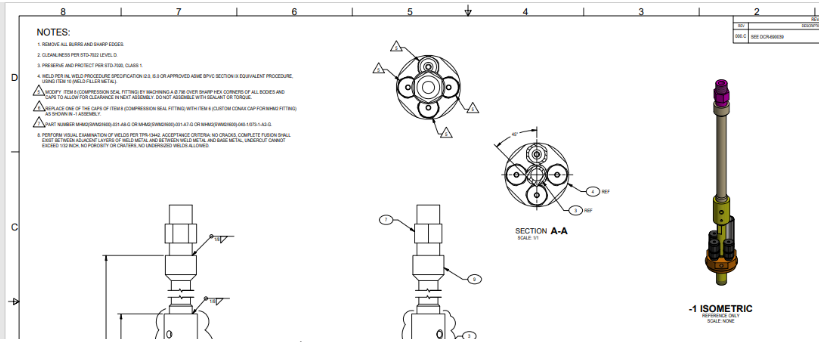
3D computed tomography of intrinsic junction thermocouple (scan at left) at critical heat flux (simulated below)

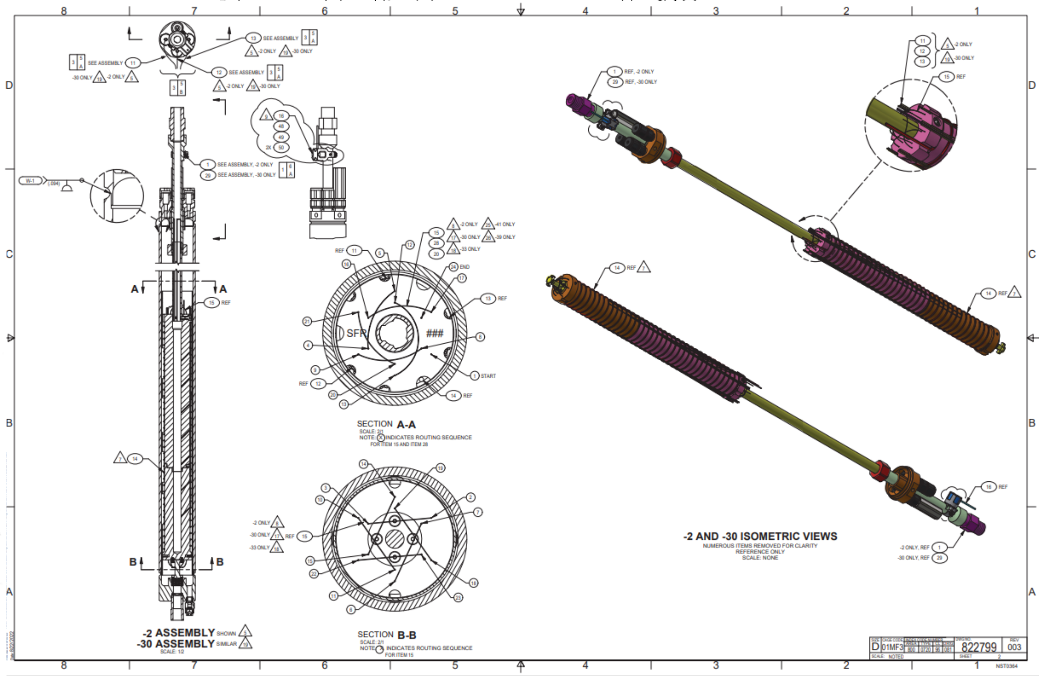


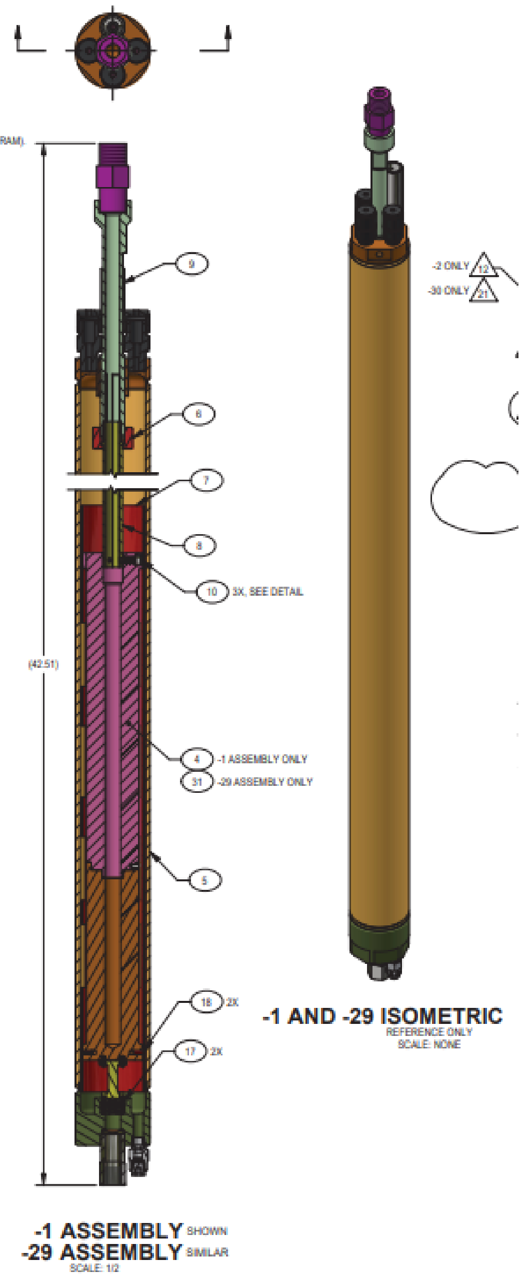
THOR MOXTOP Drawing Overview

- MSL works closely with INL Experiment Design Department
  - Guide initial design/fabrication
  - Redlines incorporated during assembly
  - As-built drawings incorporates redlines









THOR MOXTOP experiment drawings and redlines (left)

THOR MOXTOP Assembly Overview

- Supplemental Work Instruction (SWI)
  - Guide assembly and instrumentation fabrication/assembly
  - Step-by-step sequence
  - Document As-built conditions
  - Performs quality assurance

44. Route Type K thermocouple soft extensions through internals in P1 flange Conax in configuration shown in Figure 2. Configuration can vary as long as AES leads are spaced as far radially from the LVDT Primary and Secondary leads

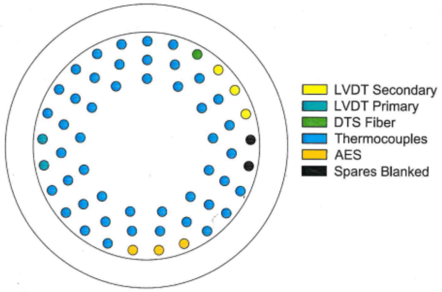


Figure 2. P1 Flange Conax Instrumentation Configuration

45. Connectors T1 and T2 need to be located at least **8"** above flange to allow mate up to HFEF top hat. Attach chromel and alumel pins to leads above flange per 822795 note 16 and THOR-M Thermocouple Pin Out Table. Apply Strain relief and connectors in accordance with 822958 and THOR-MOXTOP Thermocouple Pin Out Table. Use PEEK tape on leads for applying Strain Relief.

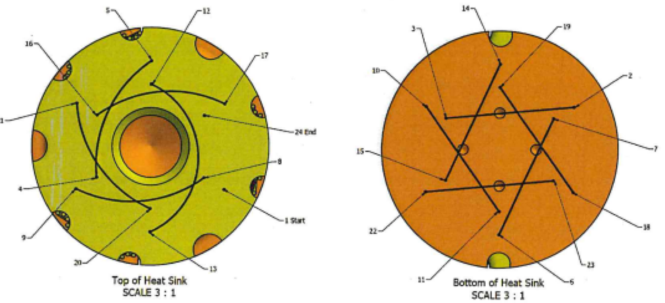
Performer initials/employee#: 132291 Date 2/9/23

Document as-built dimensions for furcation, capillary, and polyimide fiber below.

Capillary Tubing Length for Flange Conax: 7"
Capillary Tubing Length for Capsule Conax: 10"
Furcation Tubing Length : 38"
Polyimide Fiber Length : 48"

Performer initials/employee#: TB 116218 Date 2-3-23

15. Route DTS fiber through heat sink assembly in accordance with the number scheme below and per 822799-2 Assembly Sections A and B and note 8. In event that routing sequence and orientation details differ, the record drawing detailed routing sequence and orientation shall be used.



Note: Pedestal not shown

This SWI Cover Sheet, upon completion, complies with the requirements of LWP-21220 and LWP-20000. The SWI herein was developed using the guidance provided in PLN-5795 and in accordance with LI-764.

SWI Information	
SWI Number	SWI-12082022-1-TB
QLD Number or Equivalent	MFC-001512
Drawing/Sketch Number(s)	DWG 822798, 822799, 822800, 822958, & 822795 822796
Activity Primary Location	Measurement Sciences Laboratory (EIL)
Scope Description	The scope includes fabricating drawing 822958-1 THOR-MOXTOP-1 Module assembly without fuel.

SWI Release for Work		
	Signature	Date
Design Engineer	KLINT ANDERSON (Affiliate) Digitally signed by KLINT ANDERSON (Affiliate) Date: 2023.02.28 12:04:03 -07'00'	
Responsible Engineer		2/28/23
Program Quality Engineer	Reed C. Ashby	1/12/2023
Fabrication Lead		2-28-23

Activity Performer List	
Name	S #
Ashley Lambson	116563

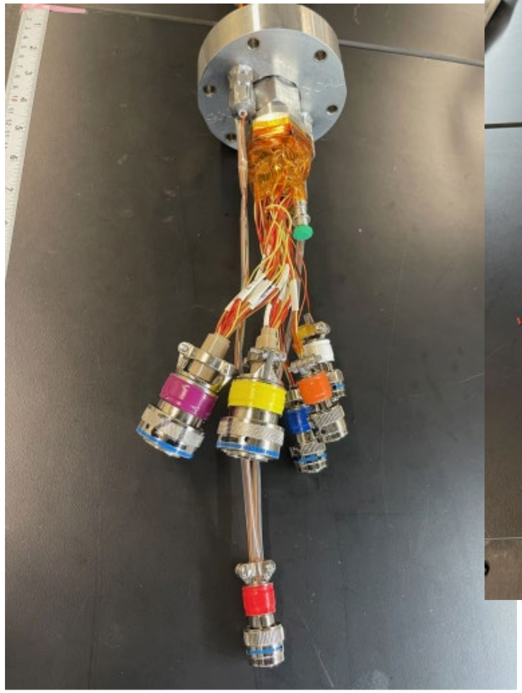
SWI Number: SWI-12082022-1-TB Page # 1 of 31

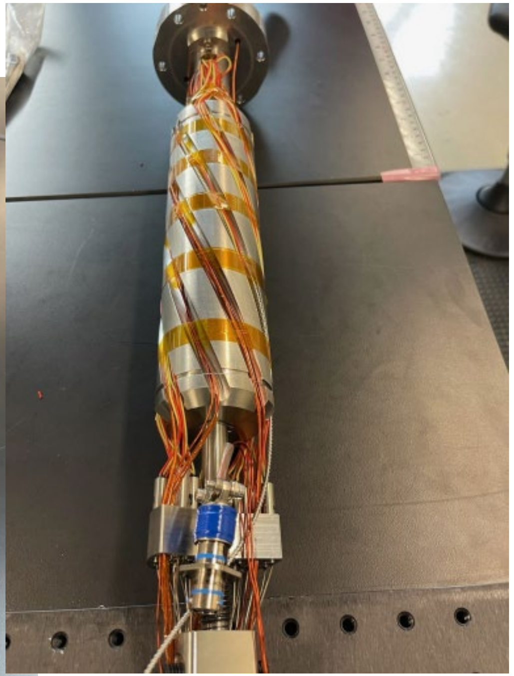
Drawing Item	Description	Quantity	QA/PO/WR Number	Performer Initials
DWG 822799, Item 5	Capsule Bottom Assembly	1	WR ~~21-219~~ 22-318	AL TB 4/19/23
DWG 822799, Item 6	Well Collar	1	WR 21-83	AL
DWG 822799, Item 10	Modified Cap Screw	3	WR 21-83	AL
DWG 822799, Item 15	DTS Gold Fiber	AR	QA 321240	TB
DWG 822799, Item 16	Acoustic Electric Sensor	AR	QA 312981	AL
DWG 822799, Item 17	Wave Spring	2	QA 314240 from WR 21-83	AL
DWG 822799, Item 18	Spring Pin	2	WR 21-83	AL
DWG 822799, Item 20	Miniature SS Tubing 0.042" OD	AR	QA 341911	AL
DWG 822799, Item 21	EPO-TEK-353ND	AR	QA 350590	AL
DWG 822799, Item 22	Foil, Aluminum	AR	QA 348564	AL
DWG 822799, Item 28	DTS Coreless Fiber	AR	QA 290114	TB
DWG 822799, Item 34	Heat Sink Assembly	1	WR 21-256	AL
DWG 822799, Item 35	Well Short	1	WR 21-256	AL
DWG 822799, Item 36	Heat Sink Sleeve Long	1	WR 21-256	AL
DWG 822799, Item 37	MOXTOP Capsule Top Assembly	1	WR 22-279	AL
DWG 822799, Item 43	Hot Cell TC Probe Assembly HP1	2	QA 347642	AL

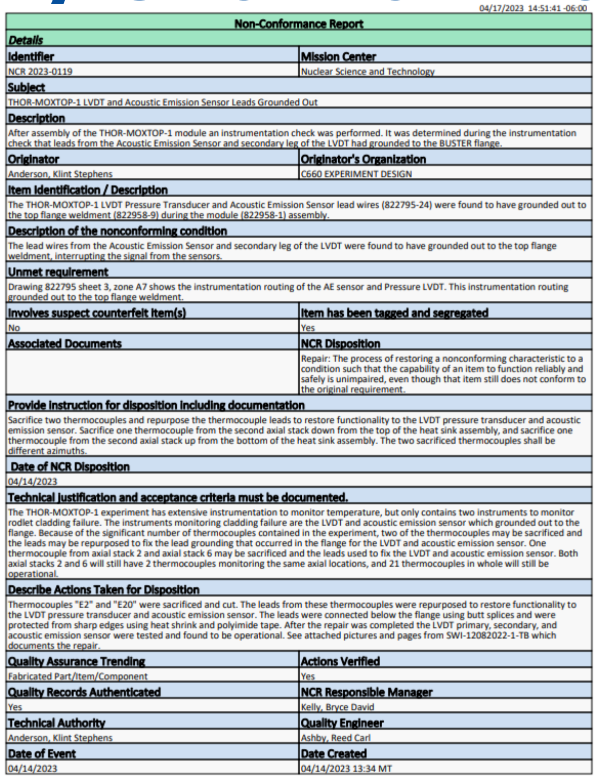
THOR MOXTOP Supplemental Work Instructions

THOR MOXTOP Assembly Overview - continued

- Supplemental Work Instruction (SWI)
  - Leak Testing Examination Reports
  - External Cable Layout
  - Non-Conformance Reports

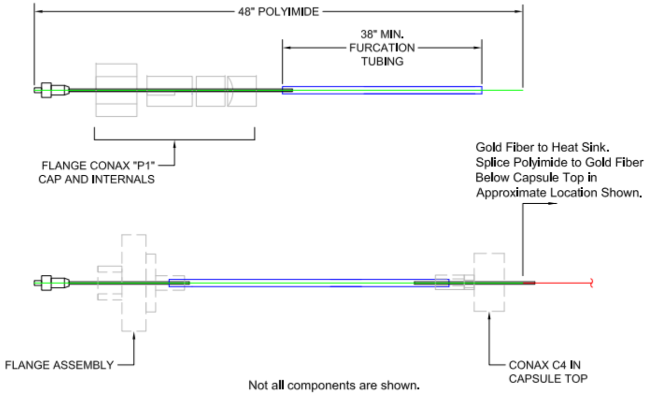


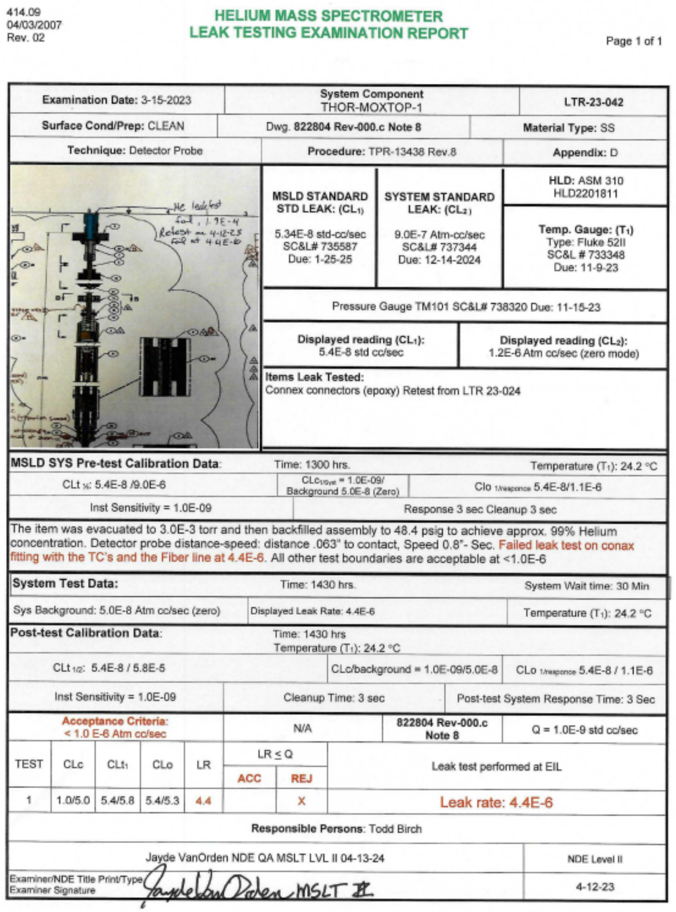




04/17/2023 14:51:41 -06:00

Non-Conformance Report	
Details	
Identifier	**Mission Center**
NCR 2023-0119	Nuclear Science and Technology
Subject	
THOR-MOXTOP-1 LVDT and Acoustic Emission Sensor Leads Grounded Out	
Description	
After assembly of the THOR-MOXTOP-1 module an instrumentation check was performed. It was determined during the instrumentation check that leads from the Acoustic Emission Sensor and secondary leg of the LVDT had grounded to the BUSTER flange.	
Originator	**Originator's Organization**
Anderson, Klint Stephens	C660 EXPERIMENT DESIGN
Item Identification / Description	
The THOR-MOXTOP-1 LVDT Pressure Transducer and Acoustic Emission Sensor lead wires (822795-24) were found to have grounded out to the top flange weldment (822958-9) during the module (822958-1) assembly.	
Description of the nonconforming condition	
The lead wires from the Acoustic Emission Sensor and secondary leg of the LVDT were found to have grounded out to the top flange weldment, interrupting the signal from the sensors.	
Unmet requirement	
Drawing 822795 sheet 3, zone A7 shows the instrumentation routing of the AE sensor and Pressure LVDT. This instrumentation routing grounded out to the top flange weldment.	
Involves suspect counterfeit item(s)	**Item has been tagged and segregated**
No	Yes
Associated Documents	**NCR Disposition**
	Repair: The process of restoring a nonconforming characteristic to a condition such that the capability of an item to function reliably and safely is unimpaired, even though that item still does not conform to the original requirement.
Provide instruction for disposition including documentation	
Sacrifice two thermocouples and repurpose the thermocouple leads to restore functionality to the LVDT pressure transducer and acoustic emission sensor. Sacrifice one thermocouple from the second axial stack down from the top of the heat sink assembly, and sacrifice one thermocouple from the second axial stack up from the bottom of the heat sink assembly. The two sacrificed thermocouples shall be different azimuths.	
Date of NCR Disposition	
04/14/2023	
Technical justification and acceptance criteria must be documented.	
The THOR-MOXTOP-1 experiment has extensive instrumentation to monitor temperature, but only contains two instruments to monitor rodlet cladding failure. The instruments monitoring cladding failure are the LVDT and acoustic emission sensor which grounded out to the flange. Because of the significant number of thermocouples contained in the experiment, two of the thermocouples may be sacrificed and the leads may be repurposed to fix the lead grounding that occurred in the flange for the LVDT and acoustic emission sensor. One thermocouple from axial stack 2 and axial stack 6 may be sacrificed and the leads used to fix the LVDT and acoustic emission sensor. Both axial stacks 2 and 6 will still have 2 thermocouples monitoring the same axial locations, and 21 thermocouples in whole will still be operational.	
Describe Actions Taken for Disposition	
Thermocouples "E2" and "E20" were sacrificed and cut. The leads from these thermocouples were repurposed to restore functionality to the LVDT pressure transducer and acoustic emission sensor. The leads were connected below the flange using butt splices and were protected from sharp edges using heat shrink and polyimide tape. After the repair was completed the LVDT primary, secondary, and acoustic emission sensor were tested and found to be operational. See attached pictures and pages from SWI-12082022-1-TB which documents the repair.	
Quality Assurance Trending	**Actions Verified**
Fabricated Part/Item/Component	Yes
Quality Records Authenticated	**NCR Responsible Manager**
Yes	Kelly, Bryce David
Technical Authority	**Quality Engineer**
Anderson, Klint Stephens	Ashby, Reed Carl
Date of Event	**Date Created**
04/14/2023	04/14/2023 13:34 MT





414.09
04/03/2007
Rev. 02

HELIUM MASS SPECTROMETER LEAK TESTING EXAMINATION REPORT

Page 1 of 1

Examination Date: 3-15-2023	**System Component** THOR-MOXTOP-1	**LTR-23-042**
Surface Cond/Prep: CLEAN	Dwg. **822804 Rev-000.c Note 8**	**Material Type:** SS
Technique: Detector Probe	**Procedure:** TPR-13438 Rev.8	**Appendix:** D

MSLD STANDARD STD LEAK: (CL_1) 5.34E-8 std-cc/sec SC&L# 735587 Due: 1-25-25	**SYSTEM STANDARD LEAK: (CL_2)** 9.0E-7 Atm-cc/sec SC&L# 737344 Due: 12-14-2024	**HLD:** ASM 310 HLD2201811 **Temp. Gauge: (T_1)** Type: Fluke 52II SC&L # 733348 Due: 11-9-23
Pressure Gauge TM101 SC&L# 738320 Due: 11-15-23		
Displayed reading (CL_1): 5.4E-8 std cc/sec	**Displayed reading (CL_2):** 1.2E-6 Atm cc/sec (zero mode)	
Items Leak Tested: Connex connectors (epoxy) Retest from LTR 23-024		

MSLD SYS Pre-test Calibration Data:	Time: 1300 hrs.	Temperature (T_1): 24.2 °C
$CLt_{½}$: 5.4E-8 /9.0E-6	$CLc_{1/Syst}$ = 1.0E-09/ Background 5.0E-8 (Zero)	Clo $_{1/response}$ 5.4E-8/1.1E-6
Inst Sensitivity = 1.0E-09	Response 3 sec Cleanup 3 sec	

The item was evacuated to 3.0E-3 torr and then backfilled assembly to 48.4 psig to achieve approx. 99% Helium concentration. Detector probe distance-speed: distance .063" to contact, Speed 0.8"- Sec. Failed leak test on conax fitting with the TC's and the Fiber line at 4.4E-6. All other test boundaries are acceptable at <1.0E-6

System Test Data:	Time: 1430 hrs.	System Wait time: 30 Min
Sys Background: 5.0E-8 Atm cc/sec (zero)	Displayed Leak Rate: 4.4E-6	Temperature (T_1): 24.2 °C
Post-test Calibration Data:	Time: 1430 hrs Temperature (T_1): 24.2 °C	
$CLt_{1/2}$: 5.4E-8 / 5.8E-5	CLc/background = 1.0E-09/5.0E-8	CLo $_{1/response}$ 5.4E-8 / 1.1E-6
Inst Sensitivity = 1.0E-09	Cleanup Time: 3 sec	Post-test System Response Time: 3 Sec

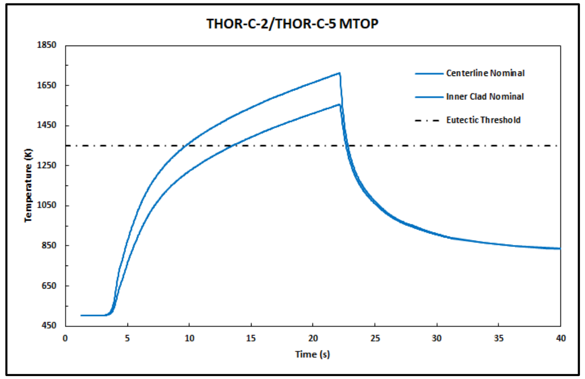
Acceptance Criteria: < 1.0 E-6 Atm cc/sec					N/A		822804 Rev-000.c Note 8	Q = 1.0E-9 std cc/sec
TEST	CLc	CLt_1	CLo	LR	LR ≤ Q ACC	REJ	Leak test performed at EIL	
1	1.0/5.0	5.4/5.8	5.4/5.3	4.4		X	Leak rate: 4.4E-6	

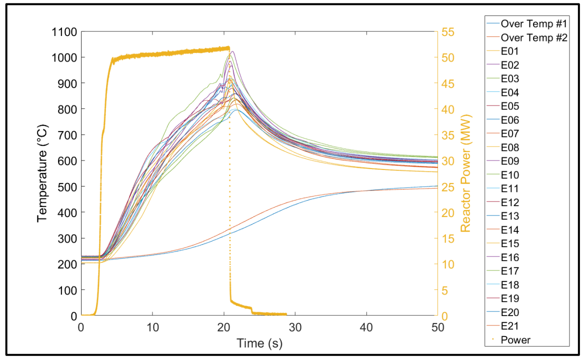
Responsible Persons: Todd Birch

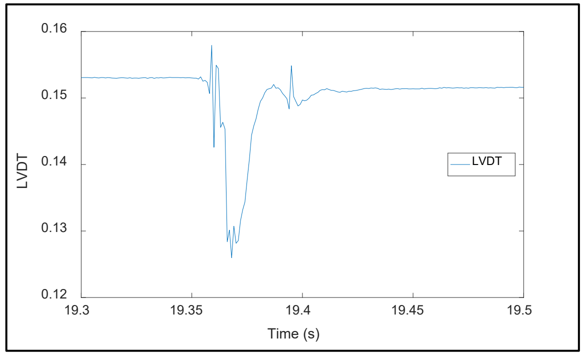
Jayde VanOrden NDE QA MSLT LVL II 04-13-24	NDE Level II
Examiner/NDE Title Print/Type Examiner Signature: Jayde VanOrden MSLT II	4-12-23

THOR MOXTOP Supplemental Work Instructions

3-Month-Long THOR MOXTOP (Mixed Oxide Fuel) Video of Assembly & 60 seconds of Data from TREAT







Advanced Test Reactor (ATR) and Critical (ATRC) Facility Gamma Tube, Radiation Measurements Laboratory (RML), Test Train Assembly Facility (TTAF)

<u>**Reactor Type**</u>

Pressurized, light-water moderated and cooled; beryllium reflector

250 MWt design

<u>**Reactor Vessel**</u>

3.65 meter diameter cylinder, 10.67 meter high stainless steel

<u>**Maximum Flux, at 250 MW**</u>

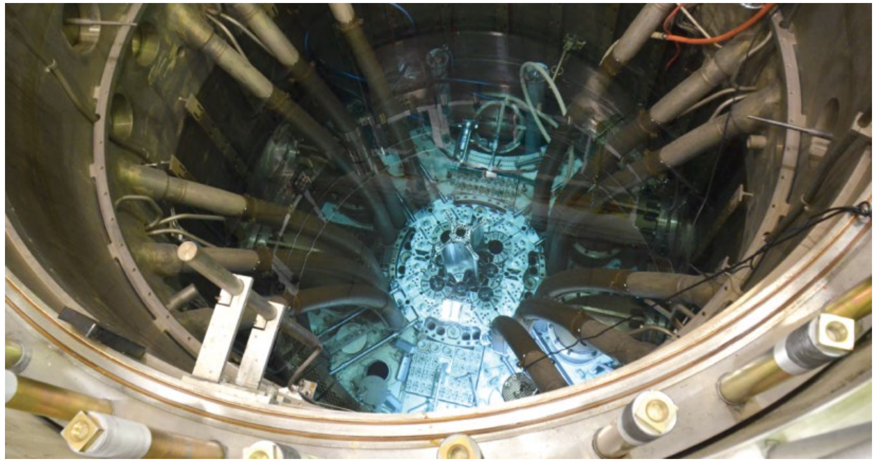
1 x 10^{15} n/cm^2-sec thermal

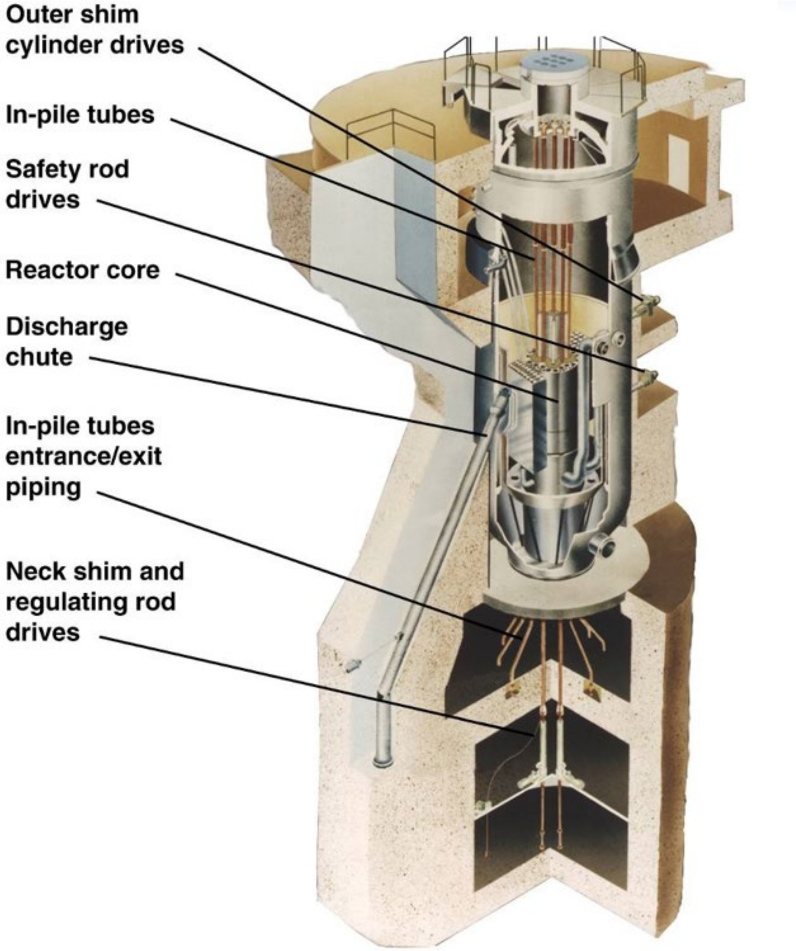
5 x 10^{14} n/cm^2-sec fast

<u>**Reactor Core**</u>

40 fuel assemblies

U-Al plates – 19/assembly



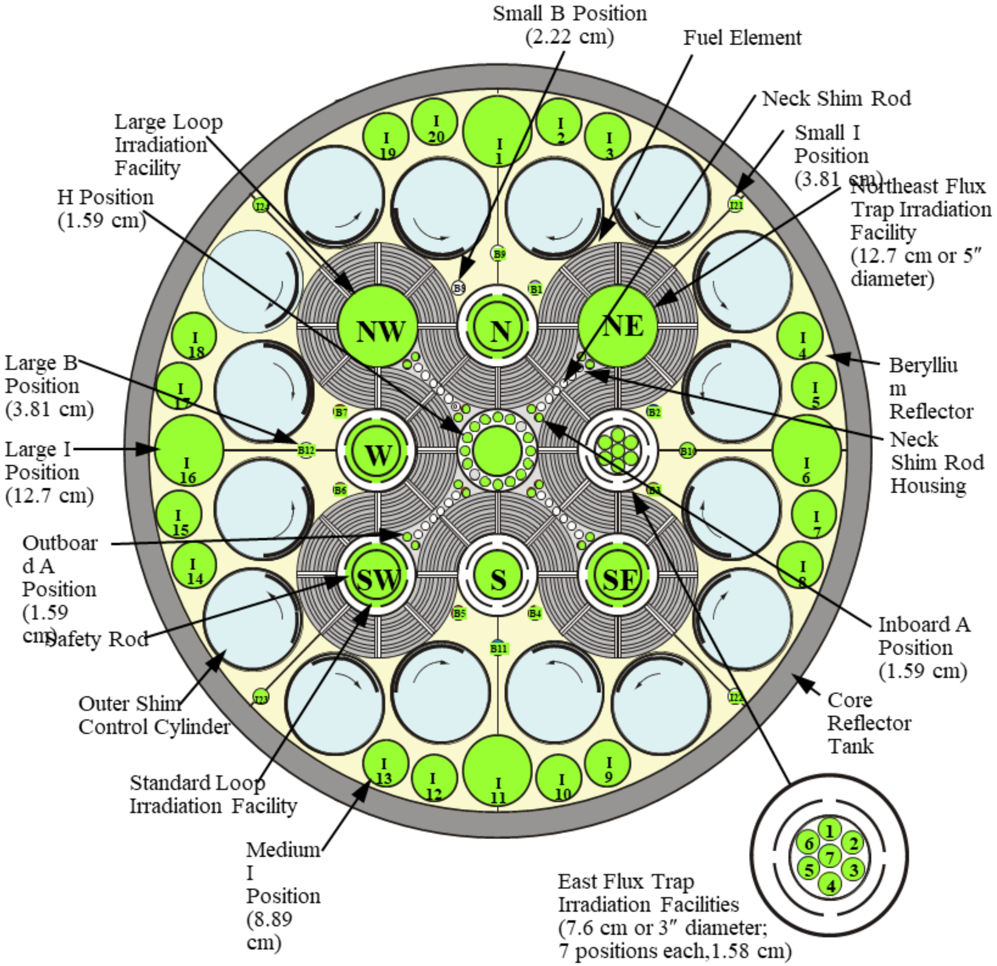


https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_53406.pdf

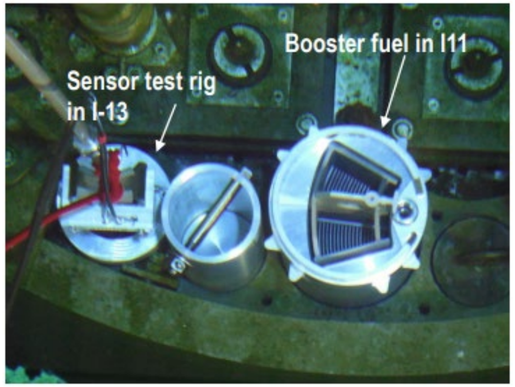
ATR / ATRC* Test Positions

- Test size – 1.22 m length, 1.27 to 12.7 cm diameter
- 77 Irradiation Positions
- Rotating Hafnium Control Cylinders – symmetrical axial flux
- Power/Flux Adjustments ("Tilt") across the Core - ≤ 3:1 ratio

- Power in the four lobes of the "clover leaf" can be adjusted independently – almost like four separate reactors



ATR core (left) & ATRC core (right)

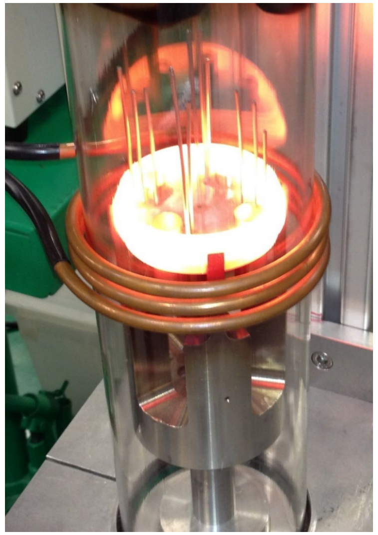


Neutron Detector Testing in ATRC

https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_54644.pdf

*all test positions not available in ATRC

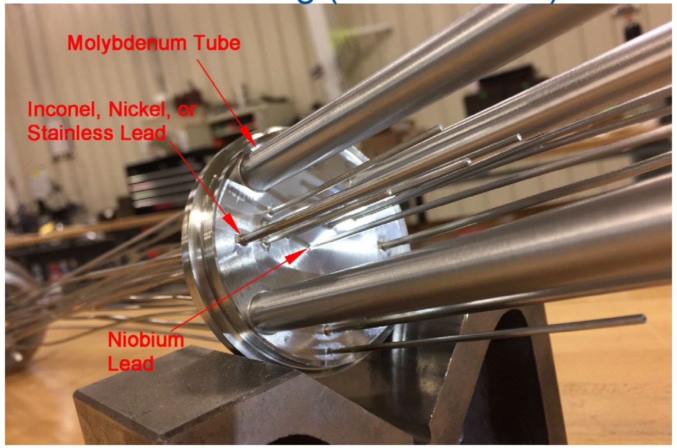
Instrumented Test Assembly and installation example: Advanced Gas-cooled Reactor 5/6/7

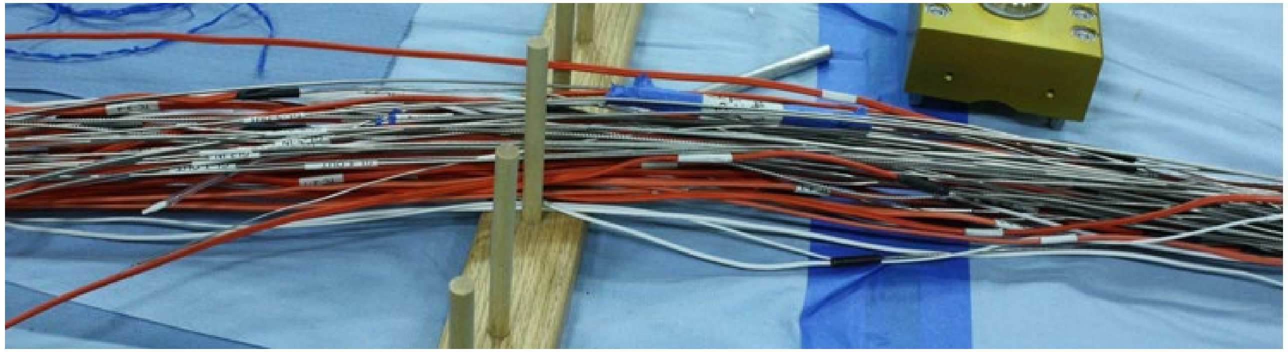


Sensor and Gas Line Brazing (above/below)

Assembly in Test Train Assembly Facility (above/below)

Installation into ATR



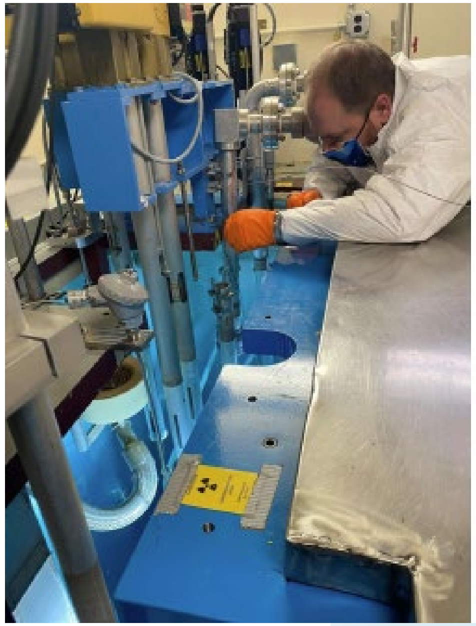


https://gain.inl.gov/SiteAssets/2020SensorTechnologiesWorkshop/Presentations_SensorTechnologiesForAdvancedReactorsVirtualWorkshop_13Oct2020/05-Palmer_AGR-567InstrumentationDevelopment_13Oct2020.pdf

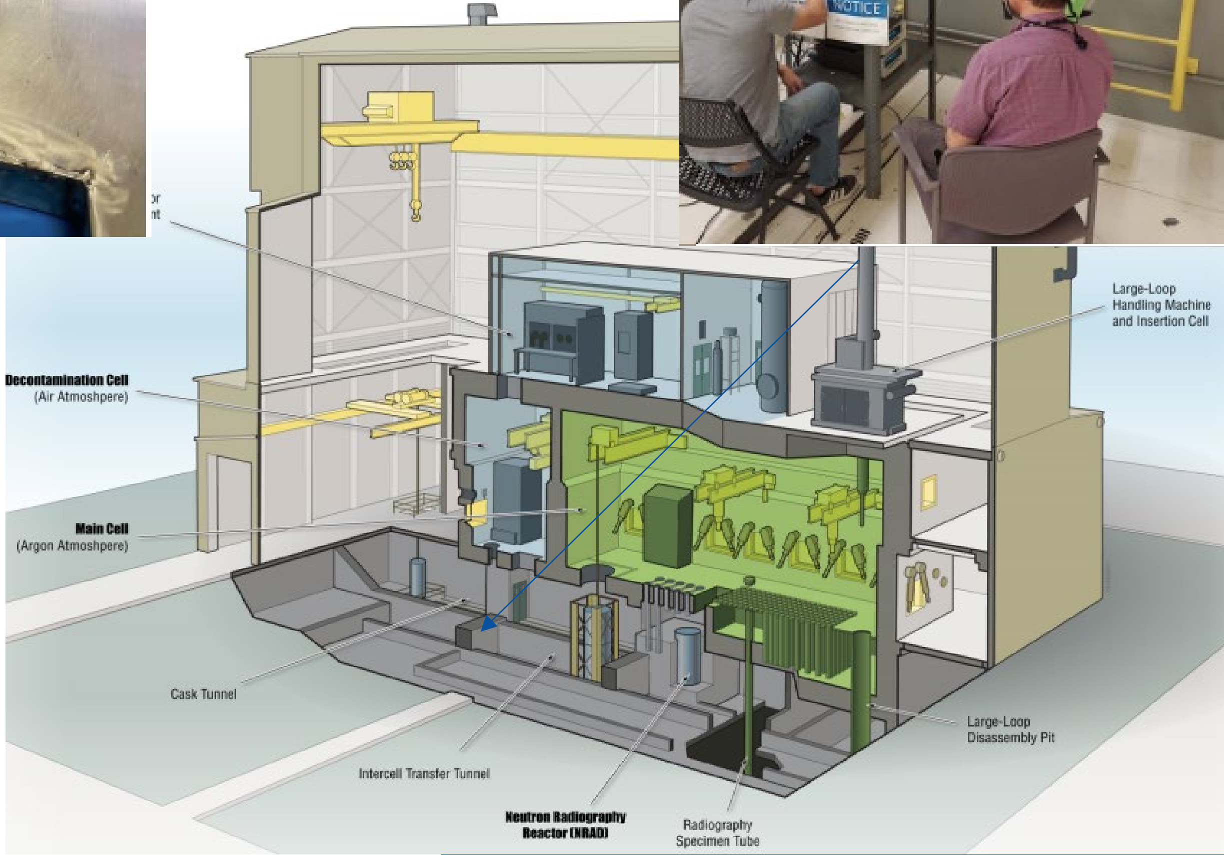
Neutron RADiography Reactor (NRAD) Facility

NRAD Reactor Attributes

- 250kW TRIGA® Reactor (Conversion Type)
- Shallow Open Pool (Atmospheric Pressure)
- Radiation levels (~2.5R/hr) prevent pool-top access during full power operation.
- Direct Access to HFEF hot cell



Neutron flux sensor installation in NRAD (left) and testing outside NRAD in transfer tunnel (right)

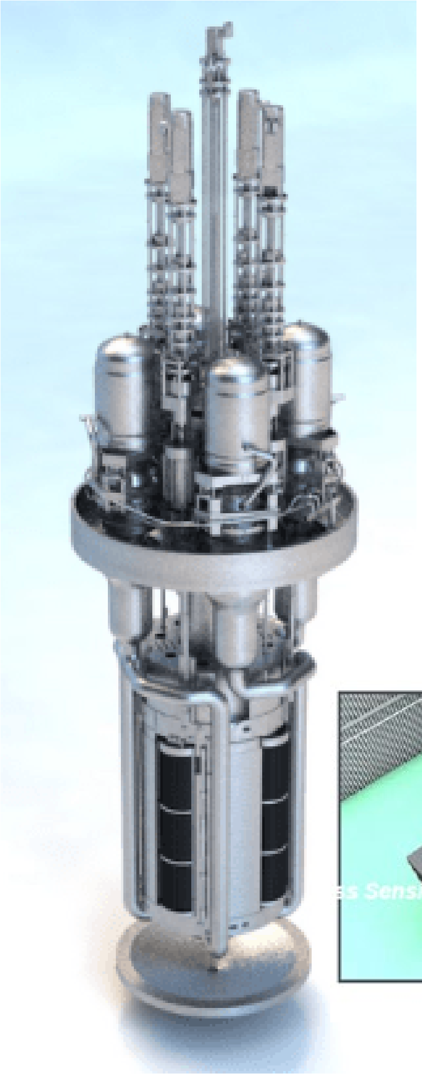


Molten Salt Research Temperature-Controlled Irradiation (MRTI) designed for instrumentation, not installed

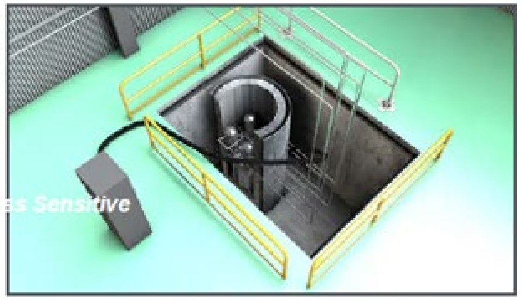
https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_29038.pdf

https://inl.gov/nuclear-energy/researchers-irradiate-chloride-based-molten-salt-in-first-of-a-kind-experiment/

90% design completed for MARVEL microreactor



MARVEL microreactor



Reactor in TREAT storage pit

MARVEL Reactor Attributes

- Sodium-potassium cooled reactor with natural circulation cooling
- Operating temperature of 500 - 500ºC
- Stirling engines convert 85-100 kW of thermal energy to ~20 kW electrical power
- 2 year mission may include:
  - Test, demonstrate, and address issues related to installation, startup, and operation
  - Enable Autonomous Operation Technologies
  - Enable Seamless Application Integration
  - **Demonstrate radiation and temperature-hardened sensors and instrumentation to enable remote monitoring, advanced sensor reliability tests, and online calibration**

MARVEL will be available to researchers once it is operational. Please contact the National Technical Director or Technical Lead for more information.

https://www.energy.gov/ne/articles/marvel-microreactor-reaches-final-design-step

https://gain.inl.gov/SiteAssets/MicroreactorProgram/MARVEL_Fact_Sheet_R15.pdf

Final Notes & Recruitment

- INL has unique capabilities for sensor design, development, fabrication, assembly, characterization, deployment in both non-nuclear and irradiation experiments while also fostering a variety of commercialization activities
- MSL welcomes instrumentation-focused collaborations with visiting researchers, students, vendors, etc.
- MSL is growing, join the team! Please watch https://inl.gov/careers/

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