INL/CON-22-67031-Revision-0

Design Features of TMIST-3 Experiments that Assist with Tritium Management

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Changing the World's Energy Future

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Idaho National Laboratory

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Irradiation Experiment Design Engineer

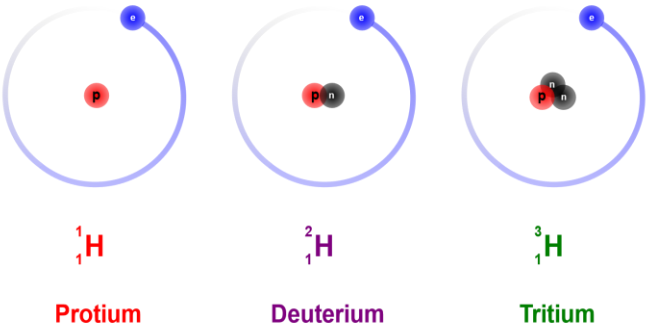
Design Features of TMIST-3 Experiments that Assist with Tritium Management

Idaho National Laboratory

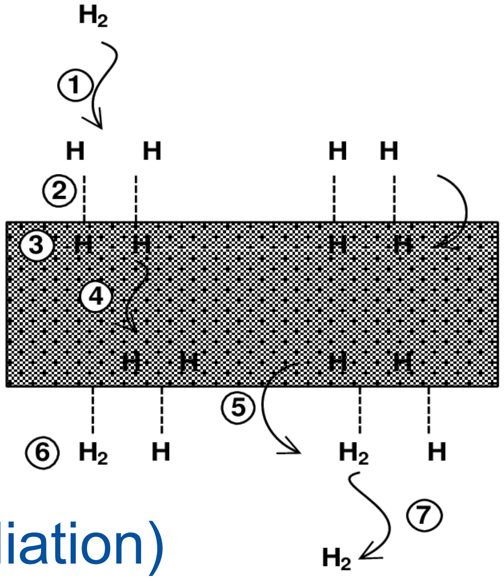
Overview

- Tritium background
- TMIST-3 experiment overview
- Permeation through components
- Leakage through connections
- Leakage to outside environment
- Radiological control measures
- Summary
- Acknowledgements

Tritium Background



- Tritium is radioactive hydrogen
  - Decays to ^3He by low energy beta radiation
  - 12.3 year half-life
  - Required for nuclear weapons stockpile
  - Potential fusion reactor fuel
- Tritium is difficult to contain
  - Leakage through connections
  - Permeation through components (exacerbated by heat & irradiation)



- Tritium management in TMIST experiments:
  - Transported into experiment from external supply (TMIST-2, TMIST-4)
  - Generated or liberated from within experiment (**TMIST-3**, TMIST-4)
  - Transported out of experiment to external monitors (TMIST-2, **TMIST-3**, TMIST-4)

TMIST-3 Experiment Overview:
***T**ritium-**P**roducing **B**urnable **A**bsorber **R**od*

Part of a series of experiments to improve understanding of TPBAR performance

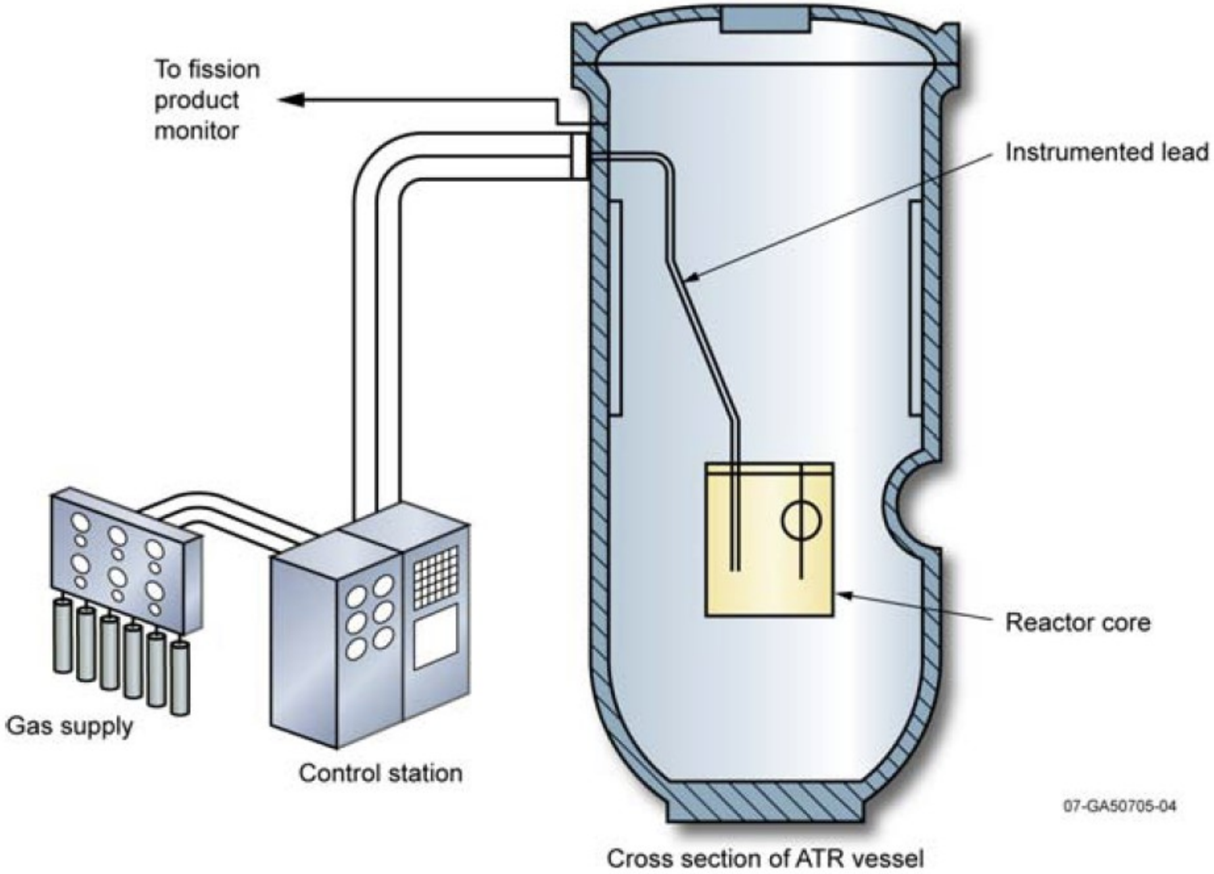
Experiment	Test	Years
Cladding Permeation	TMIST-2	2006-2012
Getter Pressure	TMIST-4	2024?
Getter Performance	TMED-4	2008-2010
Pellet Performance	**TMIST-3**	2009-2023
Advanced Pellet Mfg	TMED-3	2008-2011
Liner Oxidation	TMIST-1, TMED-1	2006-2010

TMIST-3 Experiment Overview: *TPBAR Materials Irradiation Separate Effects Test 3*

Collaboration between PNNL and INL

<u>Pellet Performance Test Objectives:</u>

- Measure tritium release as function of temperature, time, burnup, burnup rate
- Quantify speciation of tritium release (T_2O vs. T_2) as function of time, burnup, burnup rate
- Evaluate effects of pellet grain size and porosity on tritium release
- Evaluate pellet performance to burnup values exceeding current design
- Evaluate alternate pellet materials



TMIST-3 Experiment Overview: *TMIST-3A vs. TMIST-3B*

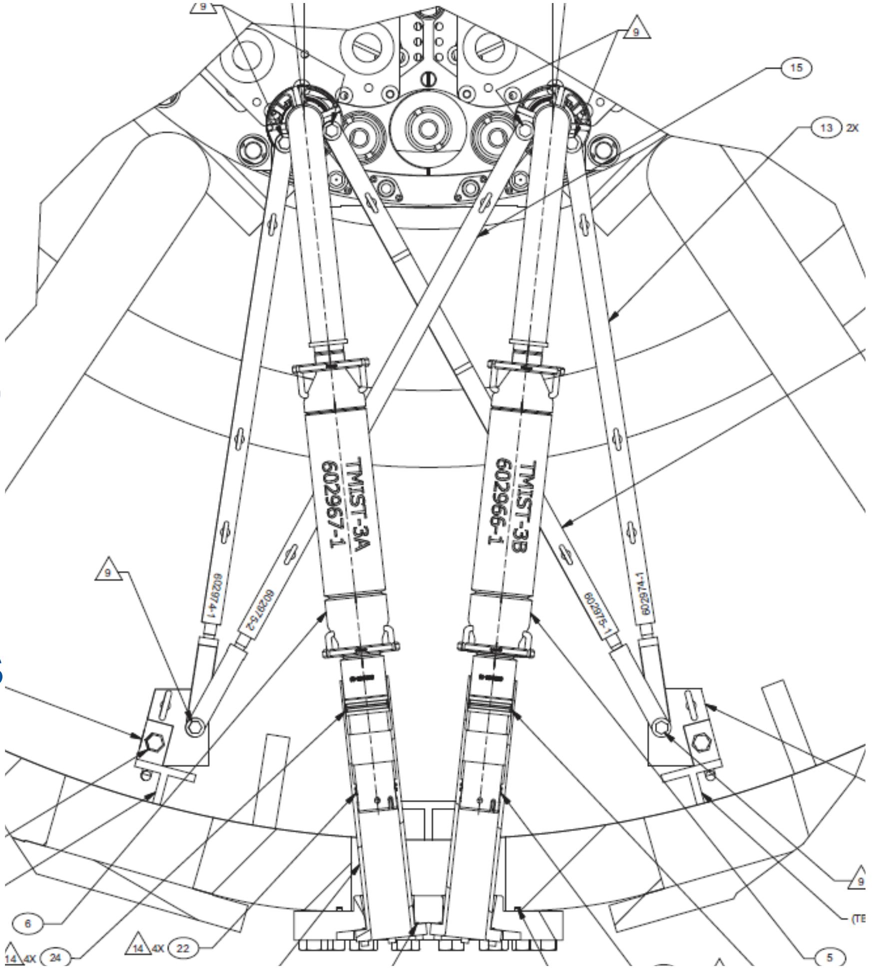
- Originally designed to be irradiated simultaneously
- Irradiated sequentially due to budget challenges

TMIST-3A

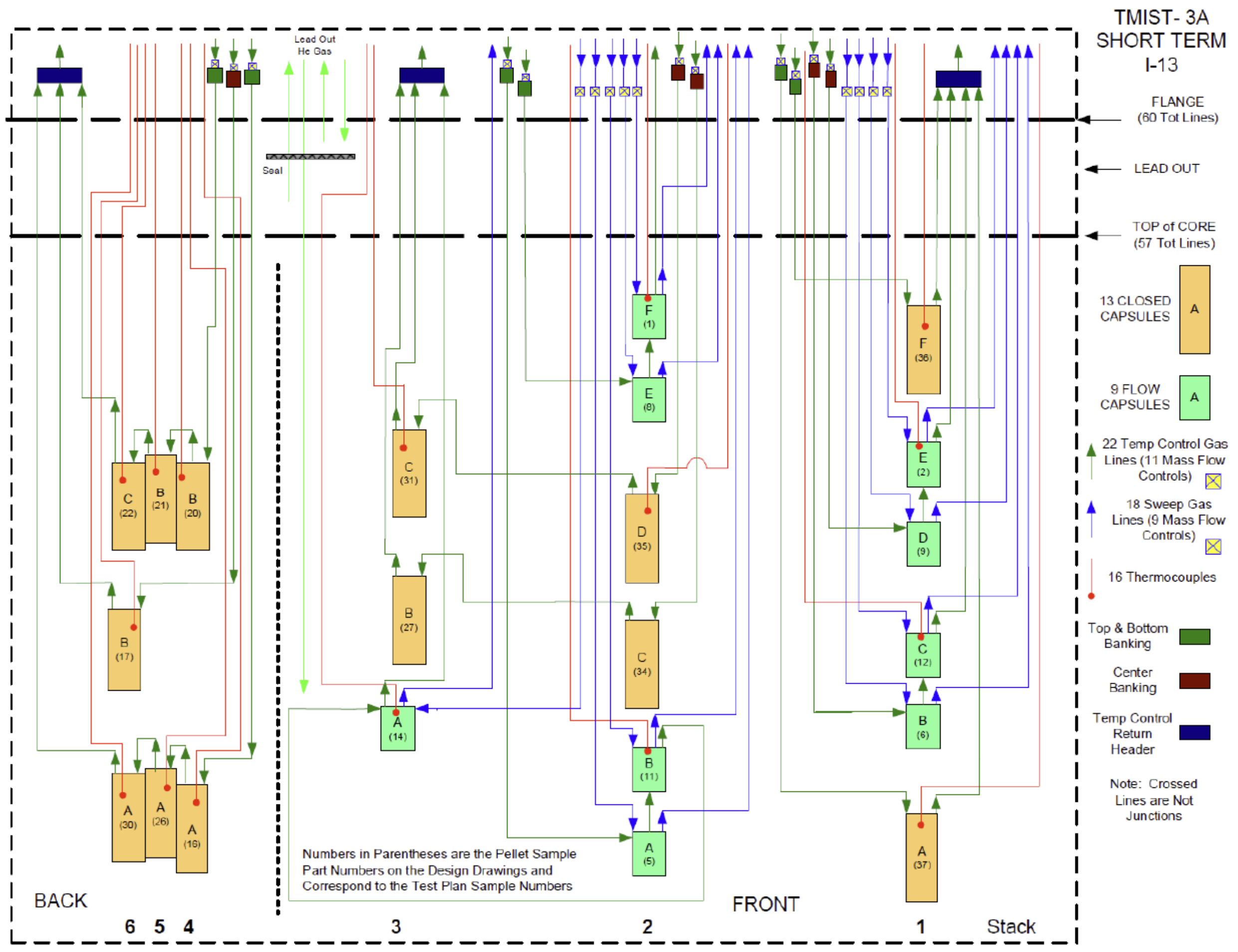
- Short-term / low burnup
- ~300 days in position I-13
- 2016-2019
- 13 Closed capsules
- 9 Flow-through capsules
- 43 Gas tubes
- 16 Thermocouples
- 7 Flux monitors

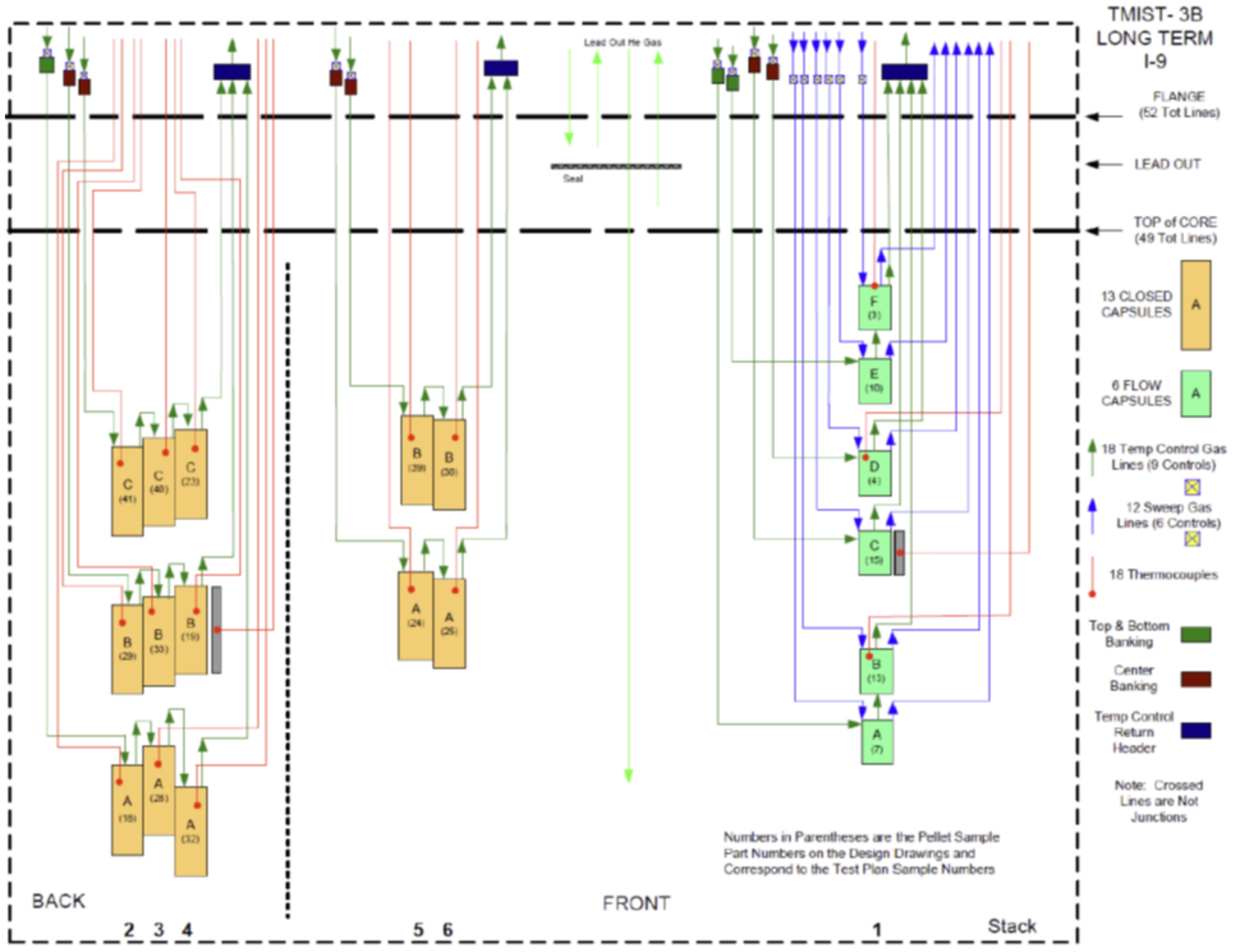
TMIST-3B

- Long-term / high burnup
- ~550 days in position I-9
- 2019-CIC-2023
- 13 Closed capsules
- 6 Flow-through capsules
- 34 Gas tubes
- 18 Thermocouples
- 7 Flux monitors



TMIST-3 Experiment Overview:
Capsule Arrangement and Instrumentation





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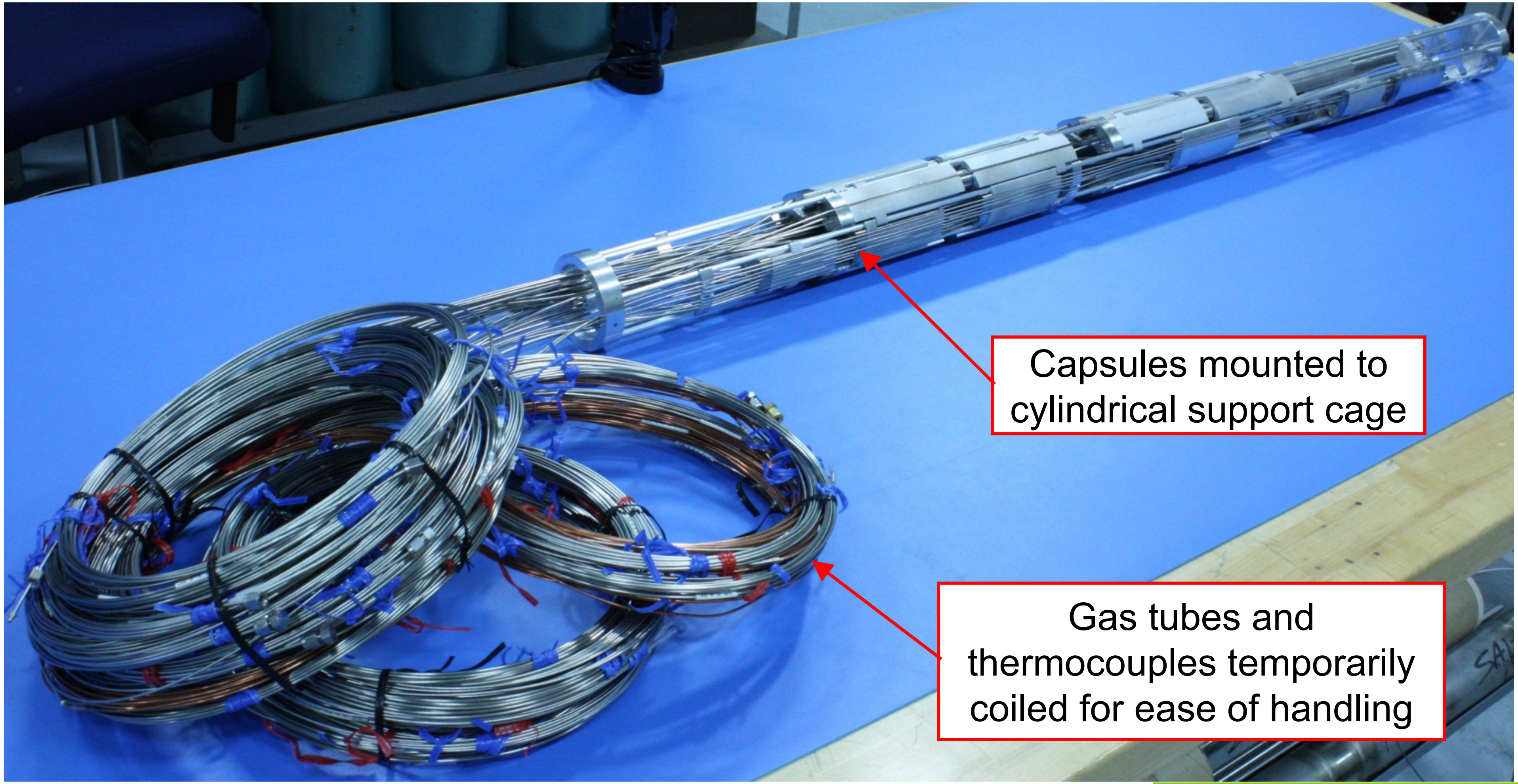
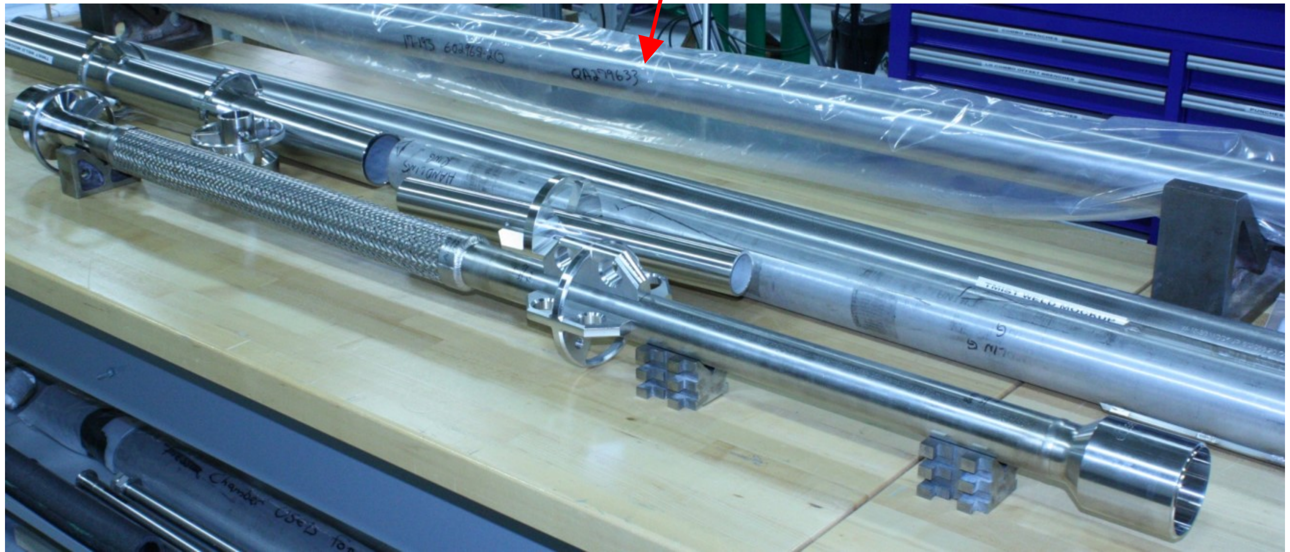
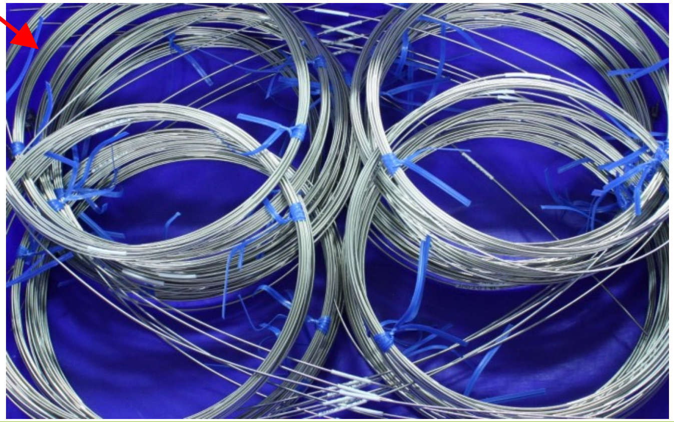
TMIST-3 Experiment Overview:
Capsule Support Cage Assembly



Permeation Through Components: *Material Selection*

- Type 304L stainless steel used in core region
  - Recommended by DOE-STD-1129
  - Good service temperature
  - Corrosion resistant
  - Common in reactor systems
  - Reactor coolant pressure boundary, capsules, gas tubing

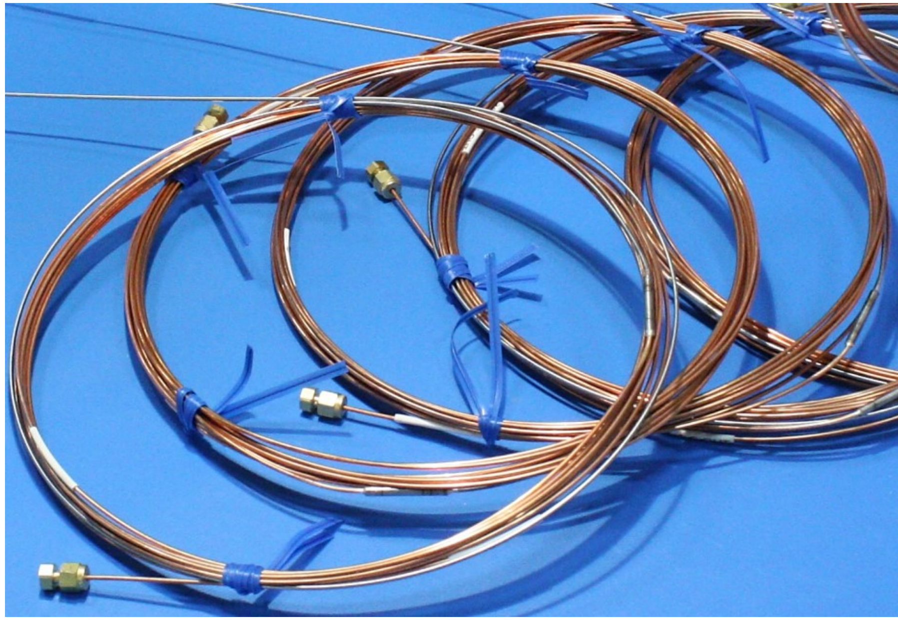




Permeation Through Components: *Material Selection*

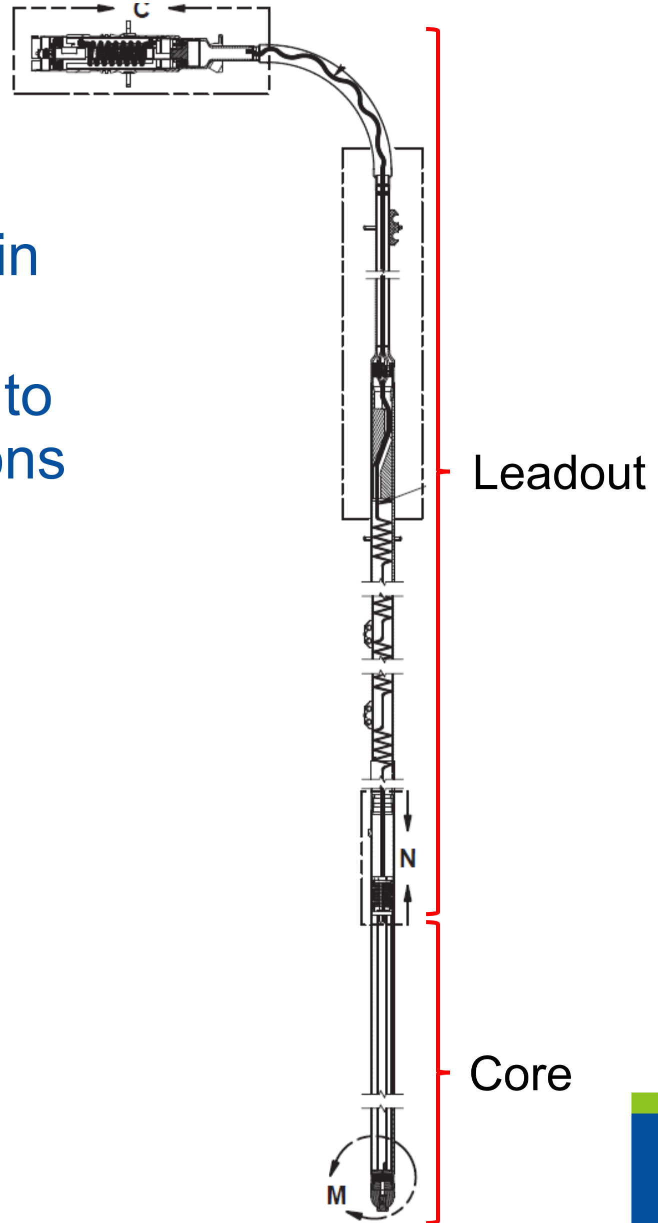
- Type 122 copper gas tubing used inside leadout above core region
  - *Lower tritium permeability* than stainless

- Copper design challenges:
  - Lower service temperature than stainless steel
  - Requires brazing (instead of welding) to join to SST
  - Lower melting point limits braze filler metal selection (and service temp.)
  - Different mechanical connections (e.g. brass vs. SST)
  - Requires isolation from reactor coolant due to PCS chemistry limits on copper (when leadout is severed during post-irradiation sizing)



Leakage Through Connections: *Minimize Connections*

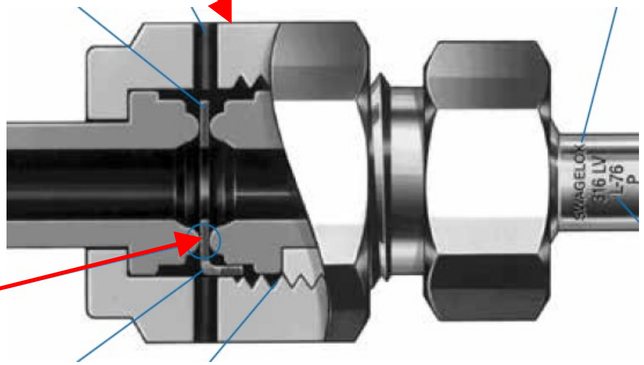
- Minimize number of connections
  - Maximum length of gas tubing in experiment ~30 feet
  - Long coils of tubing were used to avoid connecting shorter sections together

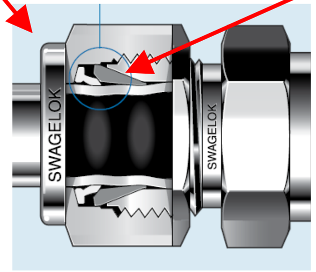


Leakage Through Connections:
Selection of Connection Type

- Metallic connections were used (tolerate higher temperature and radiation)
  - Welded or brazed connections preferred
    - More compact
    - Robust
    - More leak tight(?)
    - More difficult to repair

  - Mechanical connections (Swagelok VCR & compression) used where necessary
    - Reversible process
    - Good service history





Leakage Through Connections:
Brazing SST-to-Copper Gas Tubes

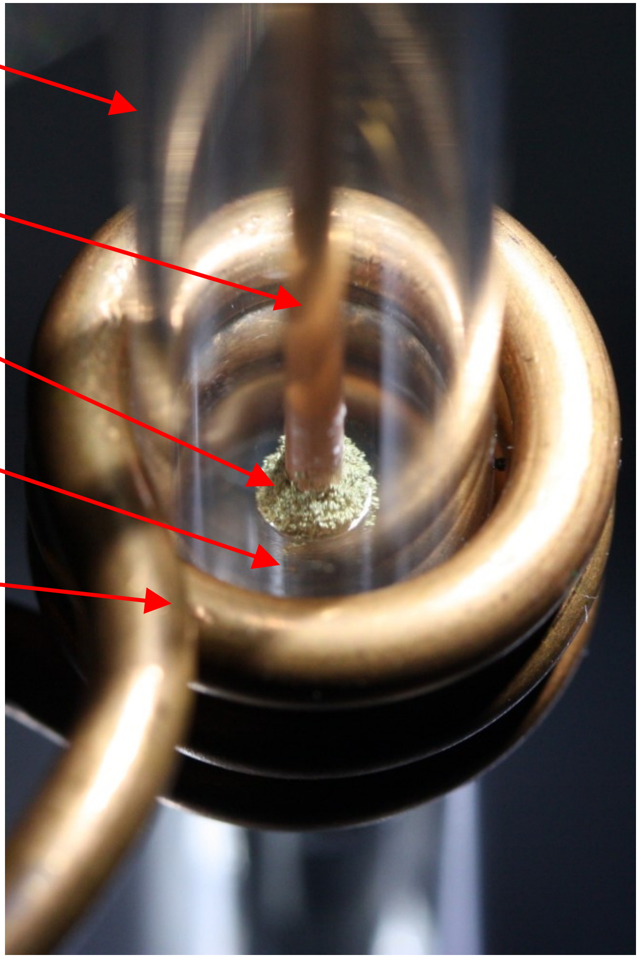
Quartz glass tube

Copper gas tube

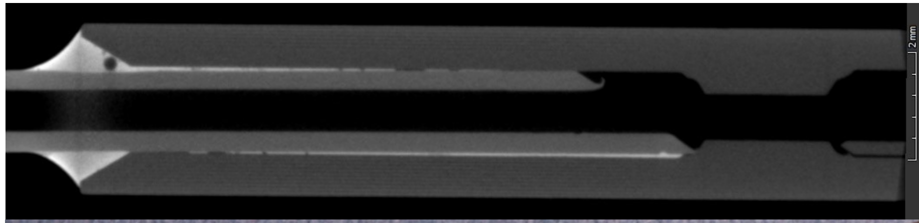
Braze filler powder

SST sleeve

Induction coil

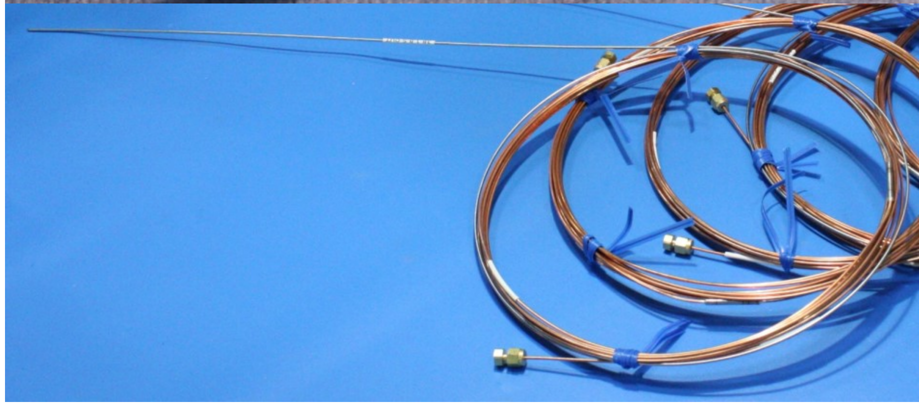


CT scan of practice braze

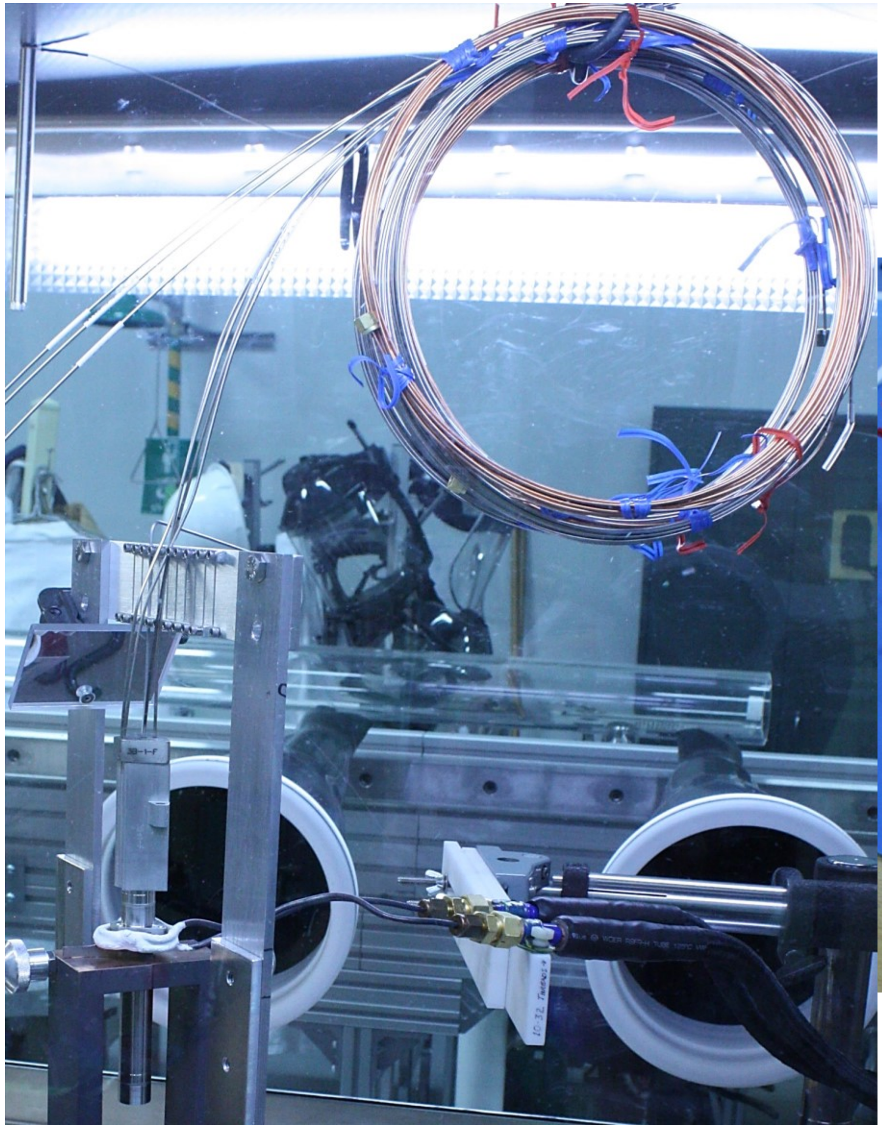


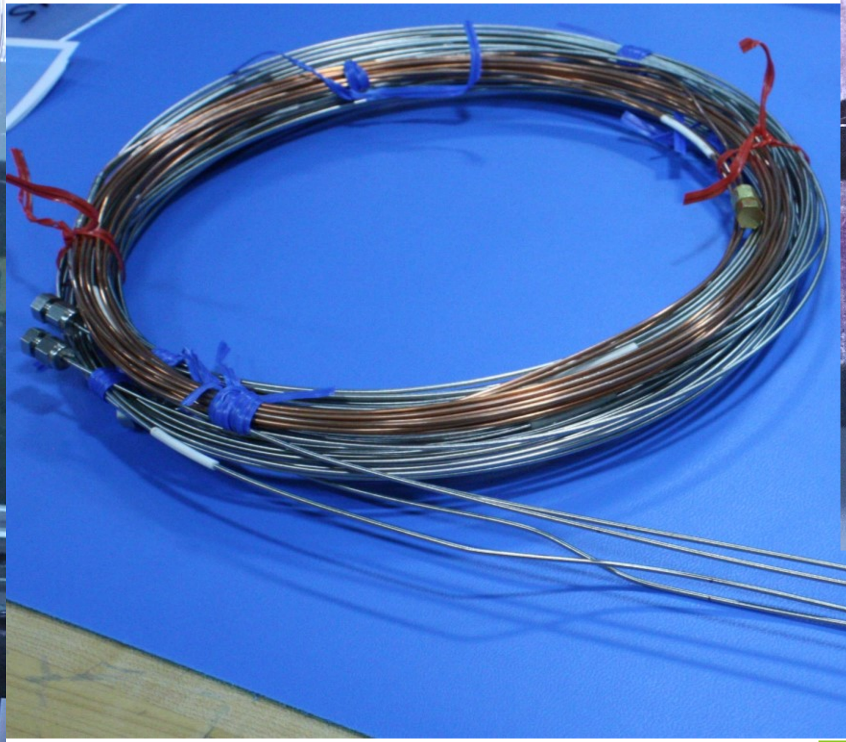
Brazed transition sleeve

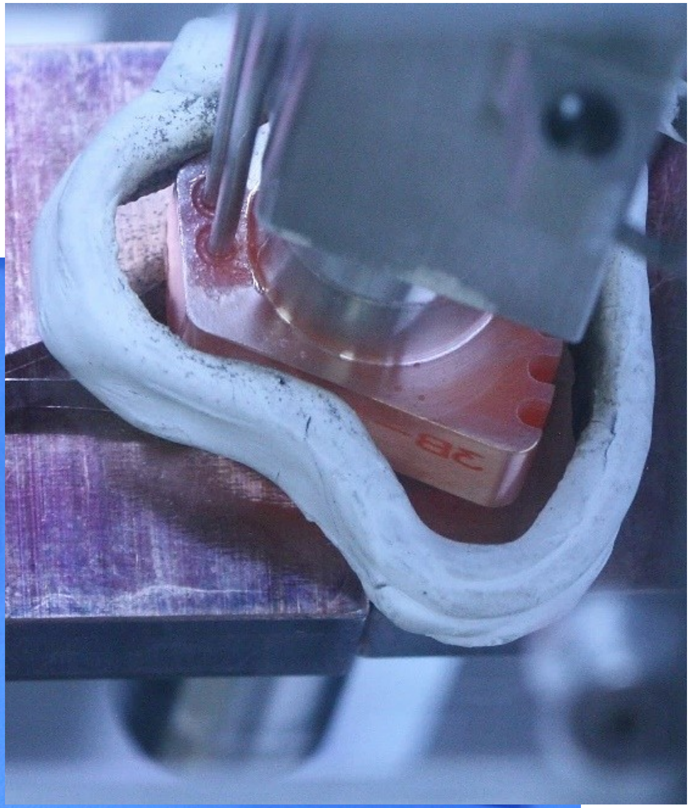
Coiled SST-Cu tube assembly



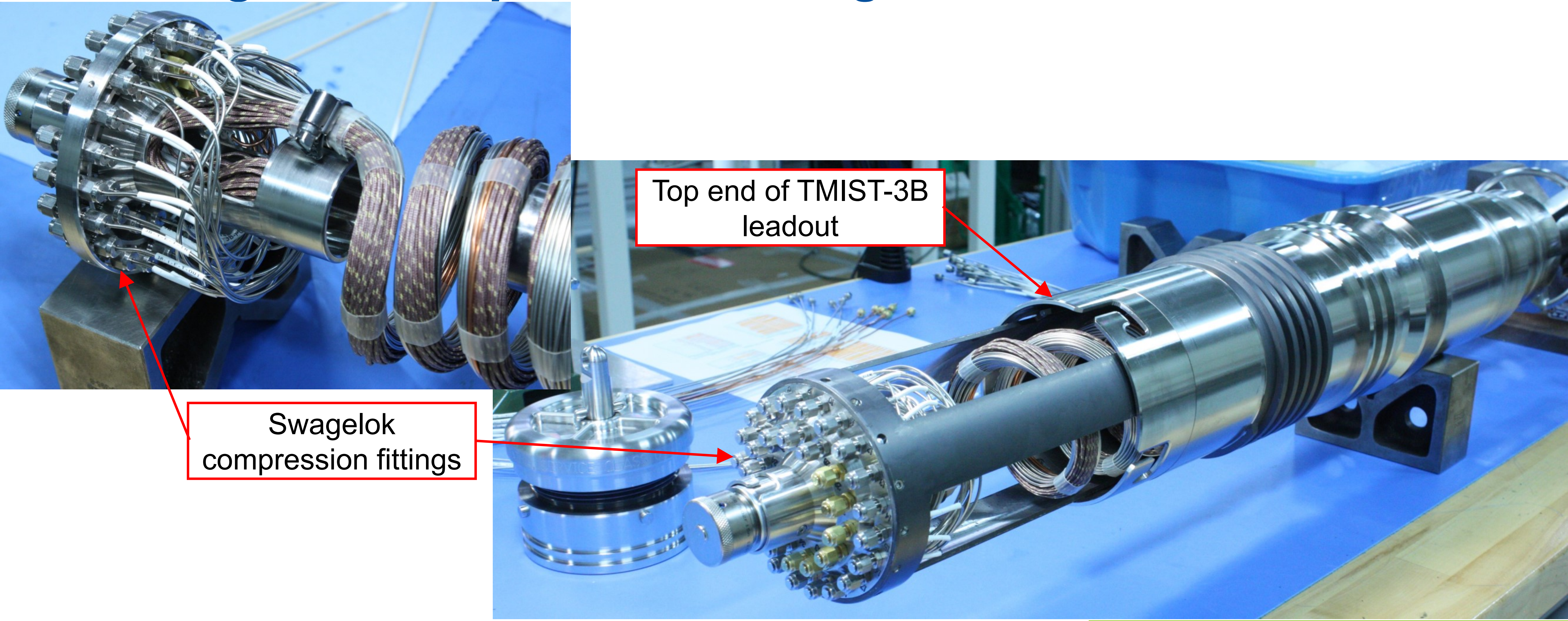
Leakage Through Connections:
Brazing SST-to-SST Capsules



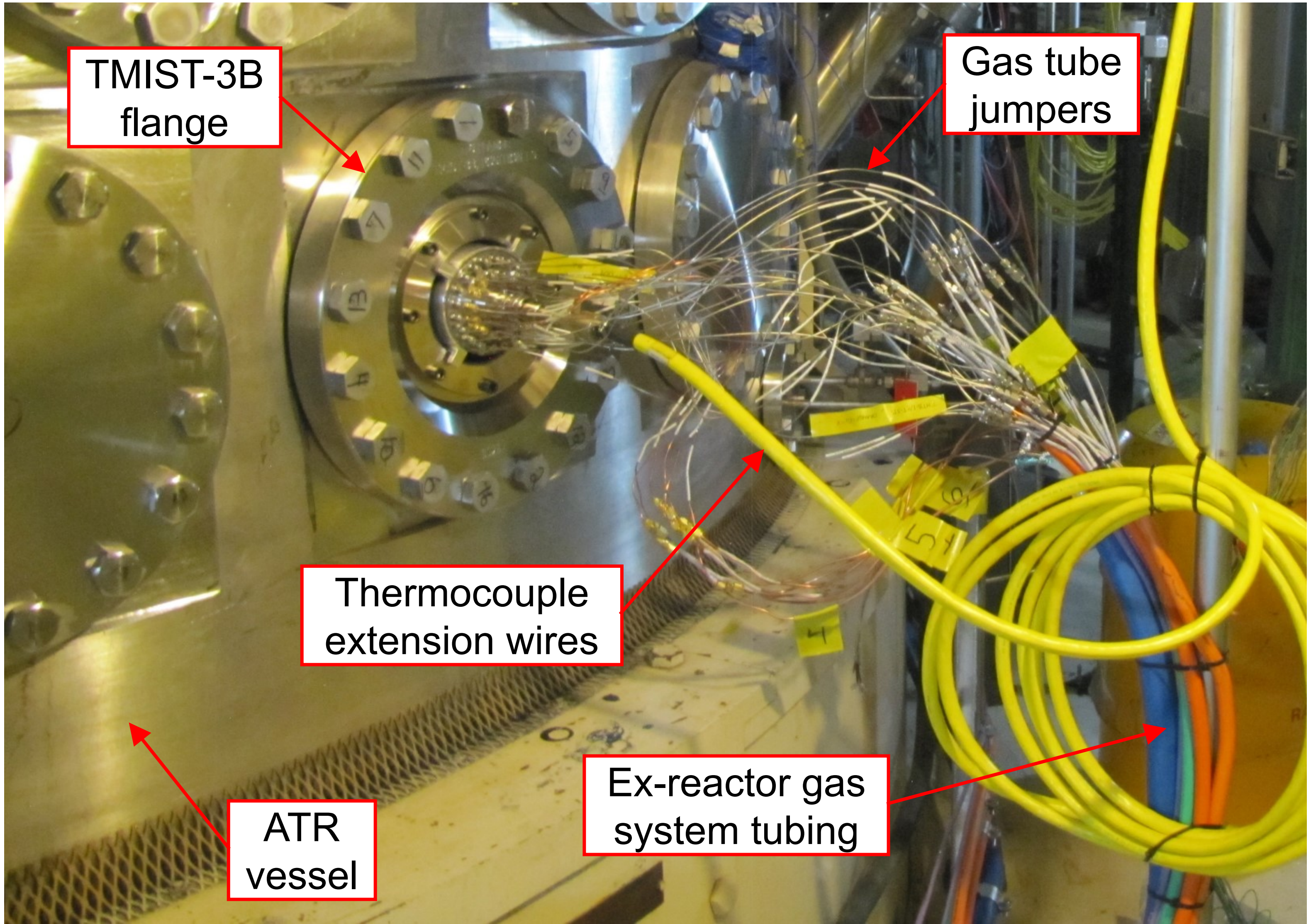


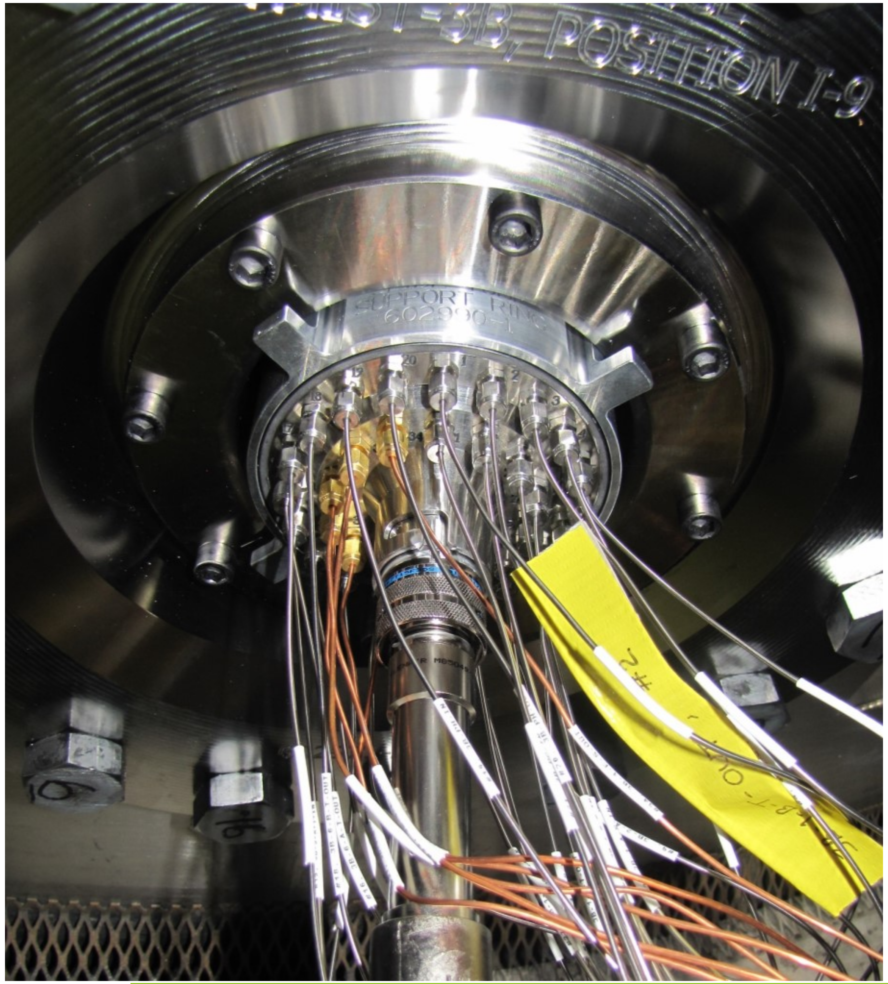


Leakage Through Connections: *Swagelok Compression Fittings*



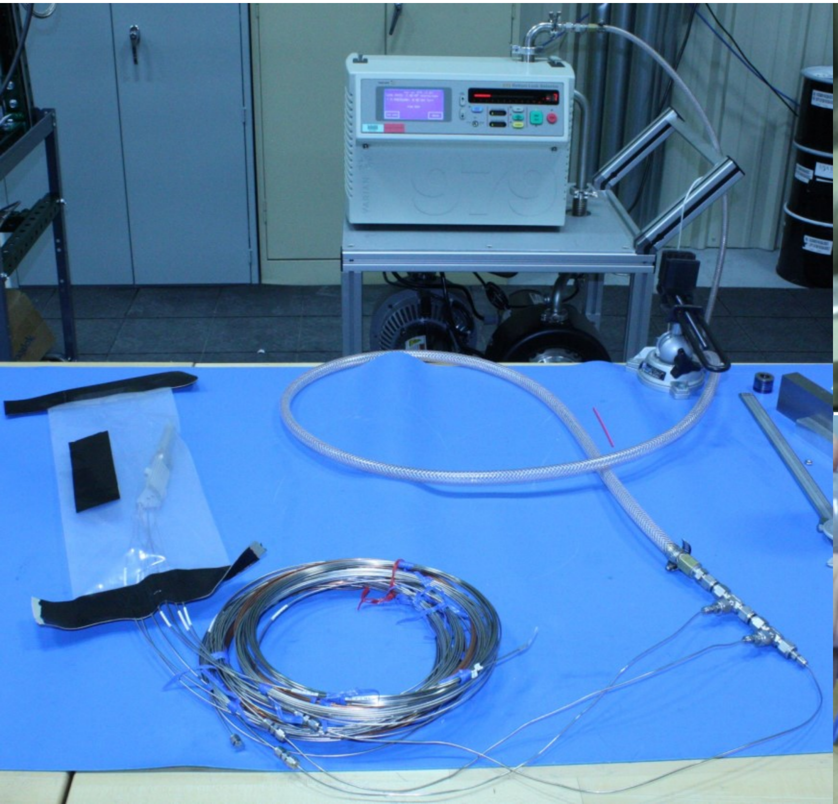
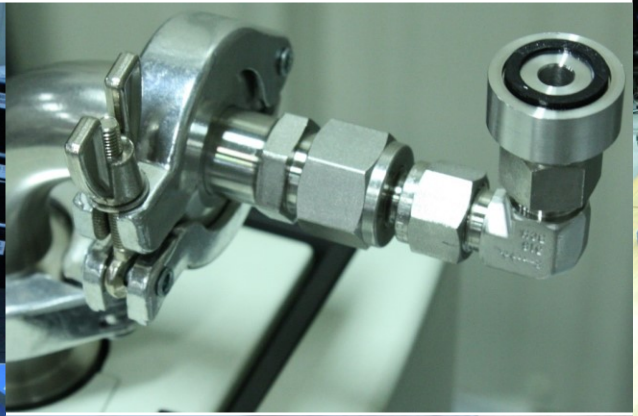
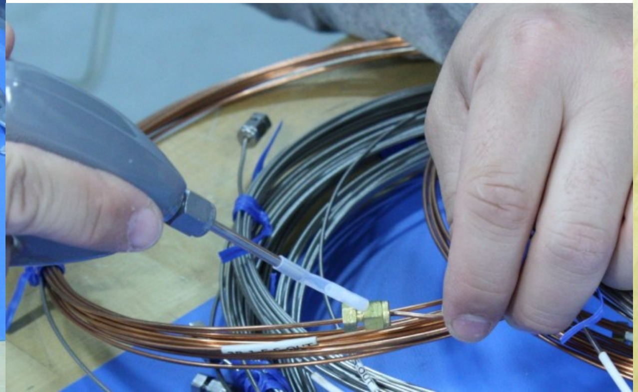
Leakage Through Connections: *Swagelok Compression Fittings*





Leakage Through Connections:
Leak Testing

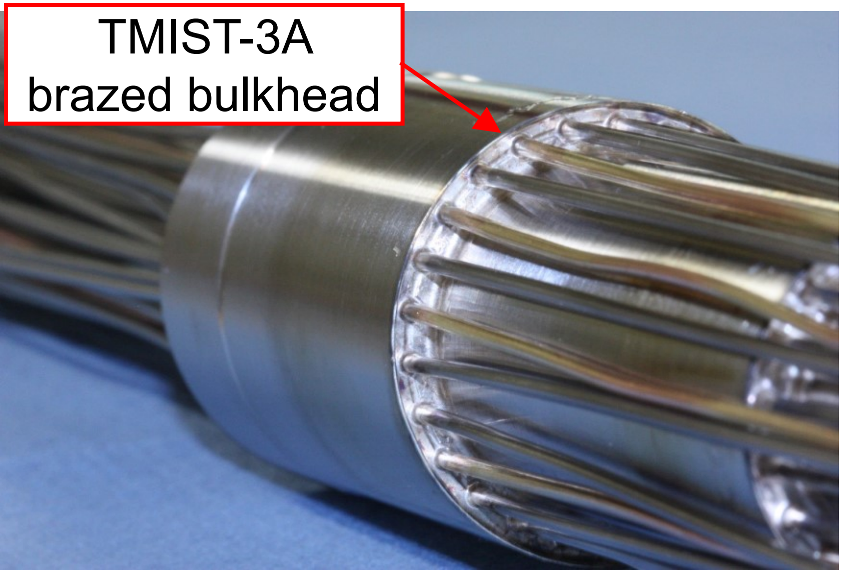
- Leak test connections during assembly after each new connection
  - Helium mass spectrometer
  - Special test fixtures, seals, "bell jars"

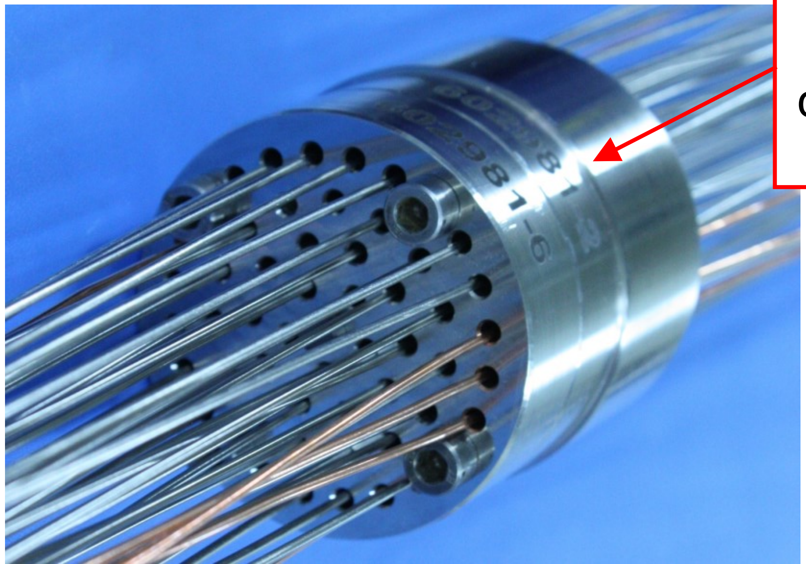




Leakage from Leadout to Outside Environment

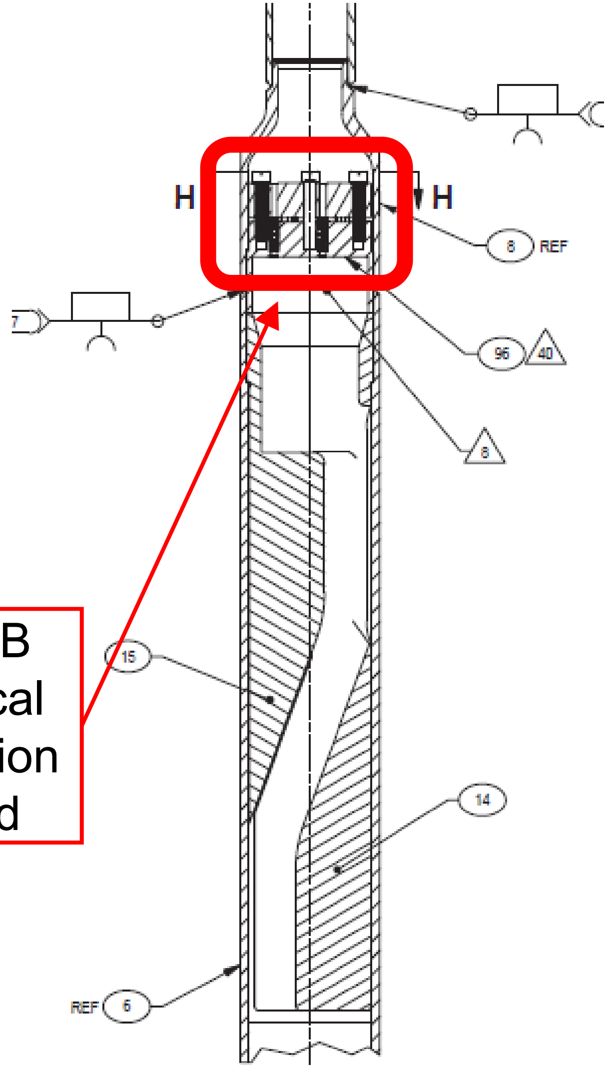
- Bulkheads in leadout isolate interior from outside environment
  - Prevent reactor coolant leakage from hypothetical failure of experiment pressure boundary
  - Enable control of atmosphere inside leadout (helium purge)
    - Control heat transfer in core section
    - Monitor for pressure boundary leaks (moisture, pressure)
    - Remove tritium that accumulates in leadout

TMIST-3A brazed bulkhead

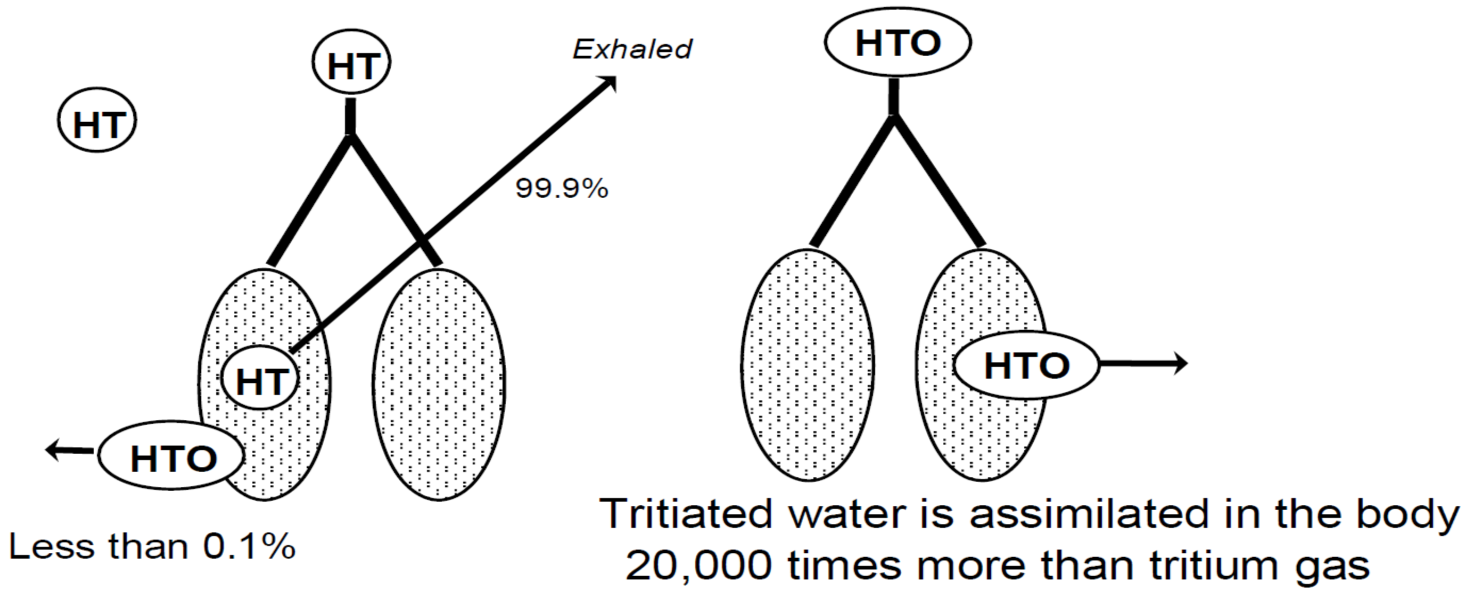




TMIST-3B mechanical compression bulkhead



Radiological Control Measures: *Biological Hazard*



- Gaseous tritium (HT, T2) is not readily absorbed by body
  - Only a small fraction retained in lungs if inhaled
- Aqueous tritium (HTO, T_2O) (liquid or vapor) is readily absorbed through skin & lungs
  - 10 day half-life inside body
  - Tritiated water/vapor is 10,000 times more hazardous than gaseous tritium

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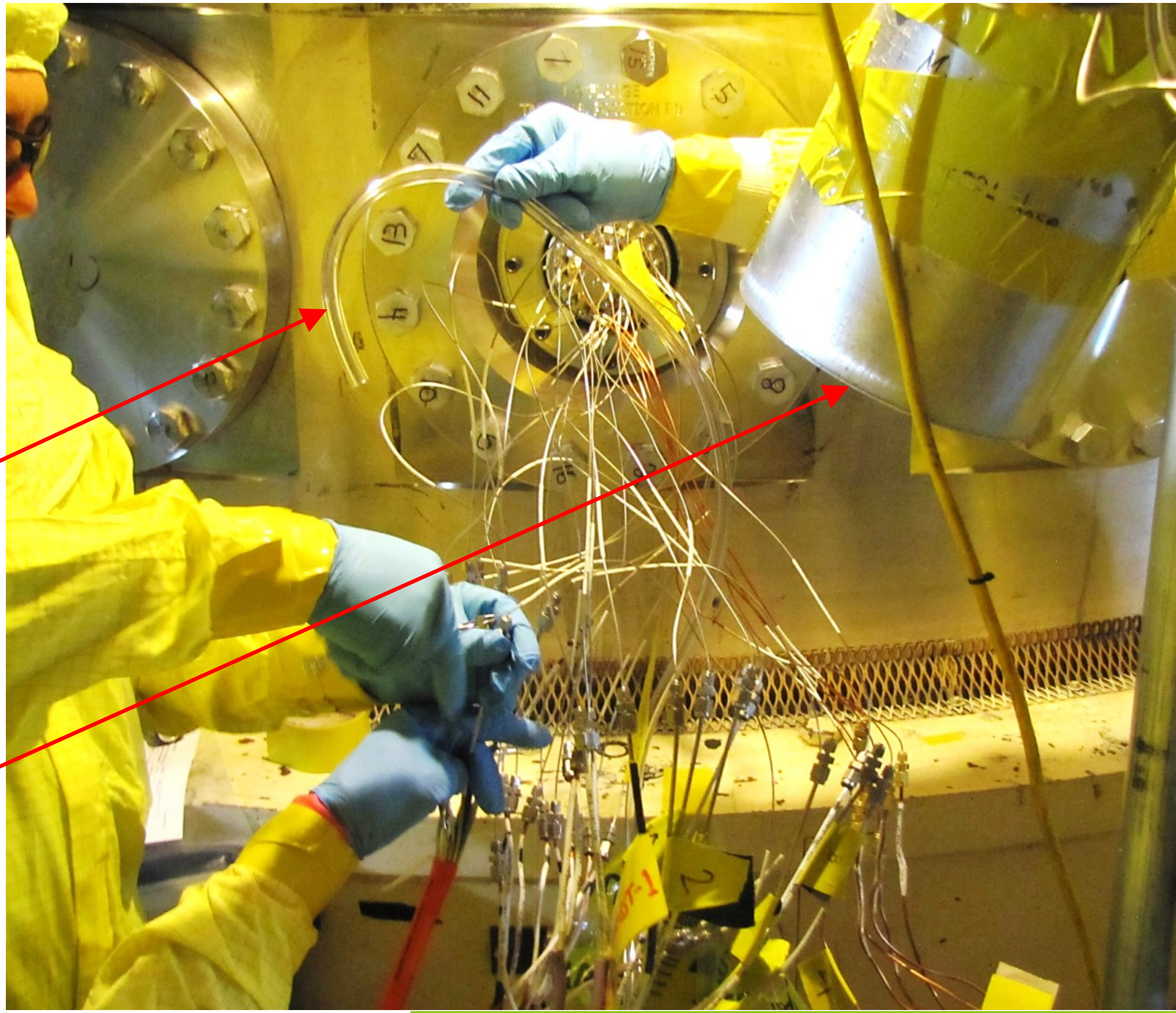
Radiological Control Measures: *Monitoring & Ventilation*

- Bioassay (urinalysis) before & after work
- Monitor airborne tritium during gas tube connections (transition from experiment to ex-reactor gas monitoring system)
  - Handheld meter with extension tube
  - Perform one connection at a time
- Use localized exhaust ventilation to draw air away from worker breathing zone
  - Exhaust trunk with air handler connected to facility ventilation system



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Summary

<u>TMIST-3 design features that assist with tritium management:</u>

- Copper gas tubing used above core region
- Number of connections minimized
- Metallic connections used
  - Welded > brazed > mechanical
- Leak tested connections during assembly
- Leadout interior purged during irradiation
- Radiological control measures during installation/removal
  - Bioassay program
  - Airborne monitoring during gas tube connections
  - Use localized exhaust ventilation

Acknowledgements

- **PNNL Tritium Technology Program team**

- DOE-STD-1129-2015, *DOE Standard for Tritium Handling and Safe Storage*
  - Publicly available: https://www.standards.doe.gov/standards-documents/1100/1129-AStd-2015

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