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Tritium Transport within the TMIST-3 In-Reactor Experiment

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Tritium Focus Group Meeting, Princeton, NJ

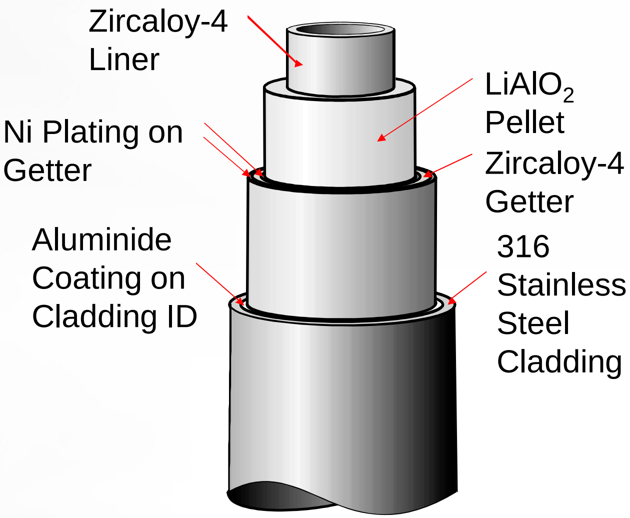
Overview:

- Tritium Technology Program
- Motivation for TMIST-3
    - Modeling Needs
- ATR Environment
- TMIST-3 Description
- Tritium Transport
- Initial Transport Model
- Initial Transport Test
- Summary & Future Work

Tritium Technology Program

- Supports the Tritium Readiness Subprogram for the National Nuclear Security Administration (NNSA)
  - Tritium production achieved by irradiating tritium-producing burnable absorber rods (TPBARs) in Watts Bar Nuclear Unit-1 (WBN-1)
  - TPBAR performance evaluated by
    - Post-Irradiation Examination (PIE) of select TPBARs
    - Monitoring tritium concentration in the reactor coolant system (RCS)
      - Observe regulatory requirements for environmental release

Watts Bar Nuclear Plant
Spring City, TN



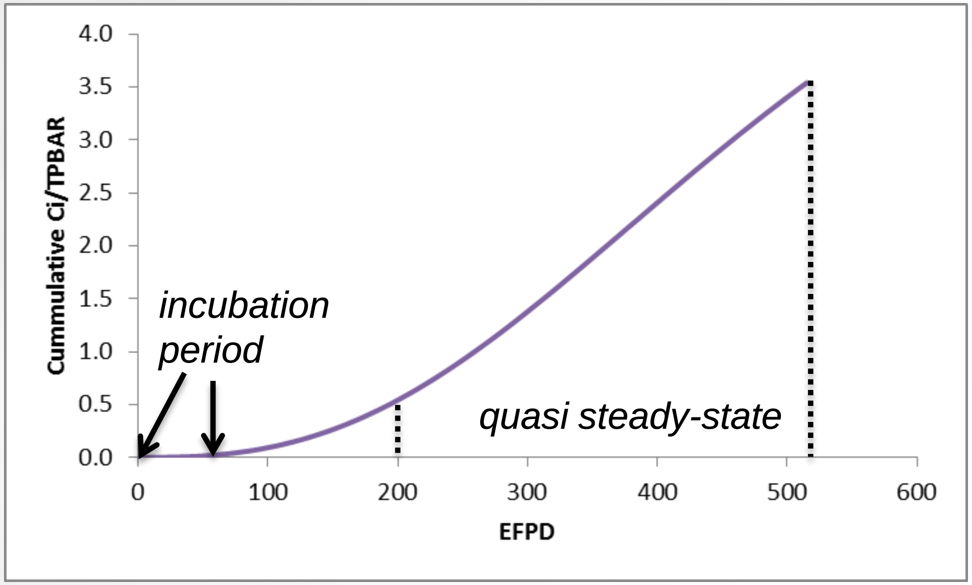
Not to scale

Motivation for TMIST-3

- Supports TTP Science and Technology (S&T) program
  - Evaluate underlying mechanisms driving TPBAR performance
    - Past TMIST/TMED experiments have evaluated:
      - Liner oxidation
      - Cladding permeation
      - Hydrogen absorption behavior
    - Provide data to improve TPBAR modeling capability
    - Estimate changes in performance due to changes in:
      - Plant operation
      - Component manufacture / vendors
      - TPBAR design
- Provides in-reactor data for the release and speciation of tritium from γ-lithium aluminate (γ-$LiAlO_2$) and cermet (γ-$LiAlO_2$ in Zr) pellets
  - Data collected as a function of time, burnup, and burnup rate
  - Establish an upper limit for pellet burnup
  - Assess release characteristics in context of TPBAR permeation

Modeling Needs

- Tritium speciation (i.e., T_2 or T_2O)
  - Interaction with adjacent components
- Kinetics of release
  - Does the apparent incubation period in RCS data result from:
    - Establishment of a driving equilibrium vapor pressure?
    - Tritium retention in pellet?

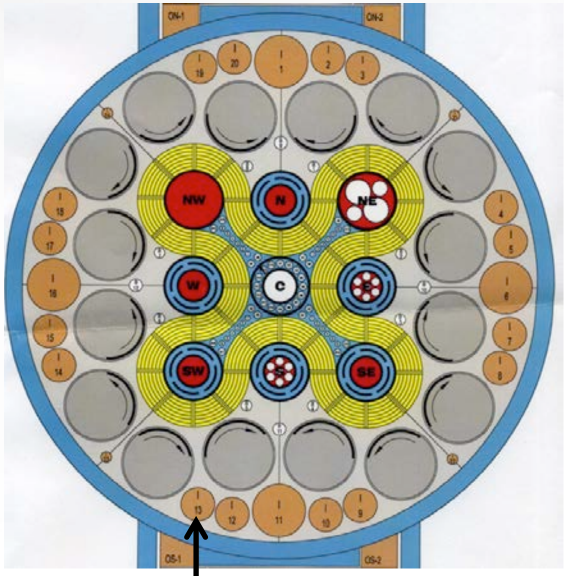


Cycle 9 RCS data

ATR Environment

- Tritium production achieved by ^{6}Li(n,α) reaction
  - Test position selection based on thermal neutron flux
  - Test matrix requires two test trains
    - Mirrored neutronic and thermal hydraulic conditions desirable
    - Enables data on burnup rate to be acquired
- Medium I-Hole locations selected
  - I-9 for TMIST-3B
  - I-13 for TMIST-3A

ATR Position	Diameter (cm)	Thermal Flux (n/cm^2-s)	Fast Flux (E>1MeV) (n/cm^2-s)
Small B-Hole	2.22	2.5×10^{14}	8.1×10^{13}
Small I-Hole	3.81	8.4×10^{13}	3.2×10^{12}
Medium I-Hole	8.89	3.4×10^{13}	1.3×10^{12}
Large I-Hole	12.7	1.7×10^{13}	1.3×10^{12}
WBN-1	**NA**	**5.4×10^{13}**	**2.1×10^{13}**

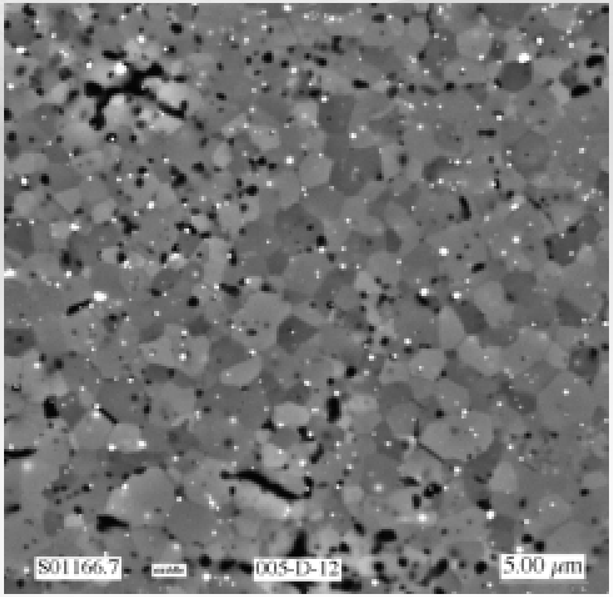


ATR Core Map

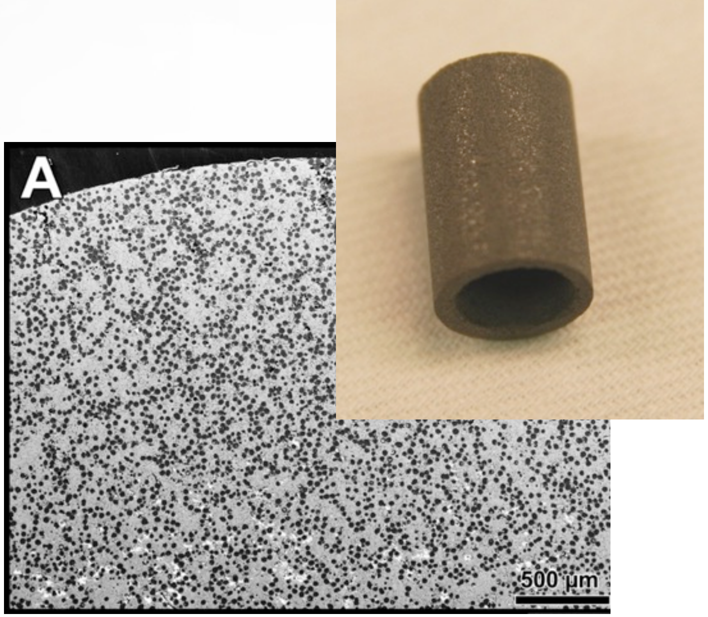
Location for the TMIST-3A
low-burnup test train (I-13)

TMIST-3 Description: Test Samples

- Test specimens
  - Standard TPBAR $LiAlO_2$ pellets
    - 2 µm grain size
    - 97-98% TD
    - 1 mm wall thickness
  - Large grain $LiAlO_2$ pellets
    - 10 µm grain size
  - Porous $LiAlO_2$ pellets
    - Small pores (~90% TD)
    - Large pores (~85% TD)
  - Thin-wall $LiAlO_2$ pellets
    - 0.76 mm wall
  - Cermet pellets
    - $LiAlO_2$ particles in Zr matrix
    - Four ceramic particle loadings from 10-40 v/o



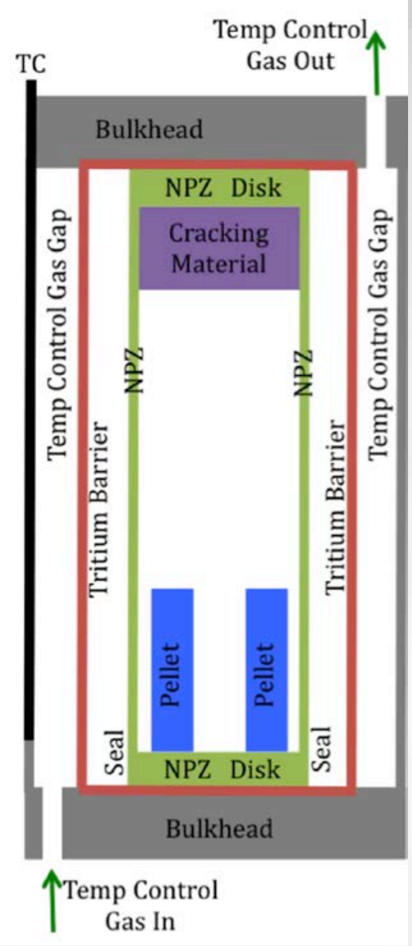
Standard $LiAlO_2$ pellet microstructure



Cermet pellet with 40 v/o LiAlO2

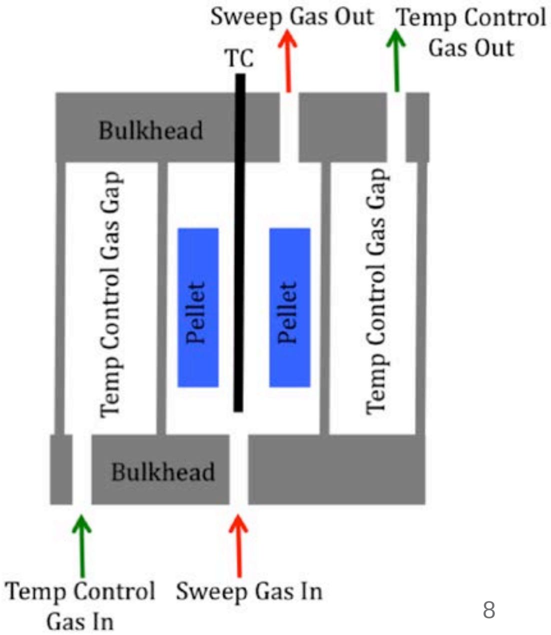
TMIST-3 Description: Capsule Design

Closed Capsule



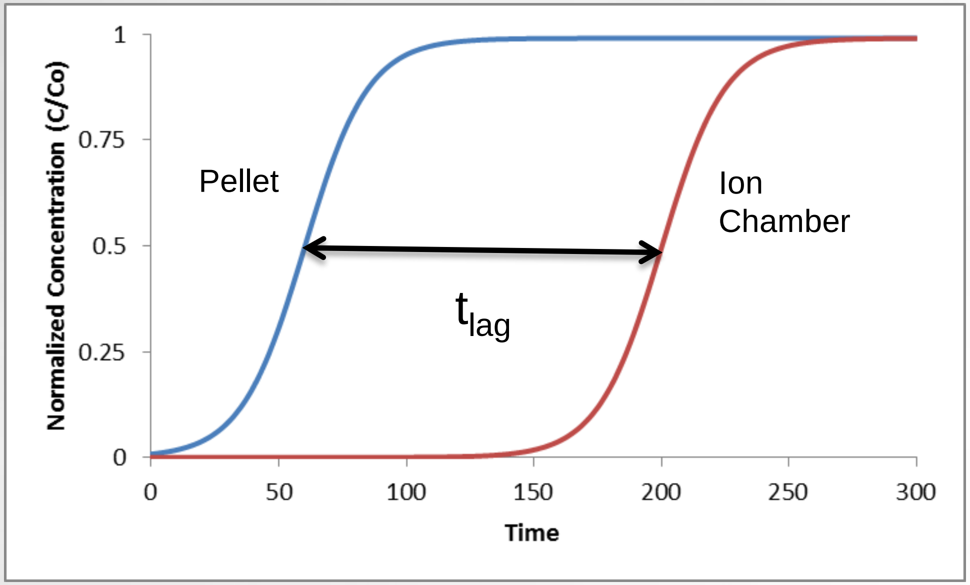
- Closed capsules
  - Used for speciation measurements and pellet integrity/retention tests
  - Tritium released from pellets as T_2 and T_2O is spatially segregated and gettered in-situ
  - Speciation data inferred from post-irradiation examination tritium assays
- Flow-through capsules
  - Used for time, burnup, burnup rate, and temperature dependent tritium release measurements
  - Tritium released from pellets is carried to ex-reactor measurement system for analysis
  - Total tritium measurement only

Flow-Through Capsule



Tritium Transport

- Sweep gas from flow-through capsules transports tritium to measurement system outside of reactor (ex-reactor)
  - Ion chambers continuously monitor tritium concentration
  - Sweep gas proceeds from ion chambers to oxidizer columns bubblers prior to getter beds and exhaust
  - Results from ion chamber will be used to reveal tritium release kinetics



Ideal IC response relative to step change in pellet release

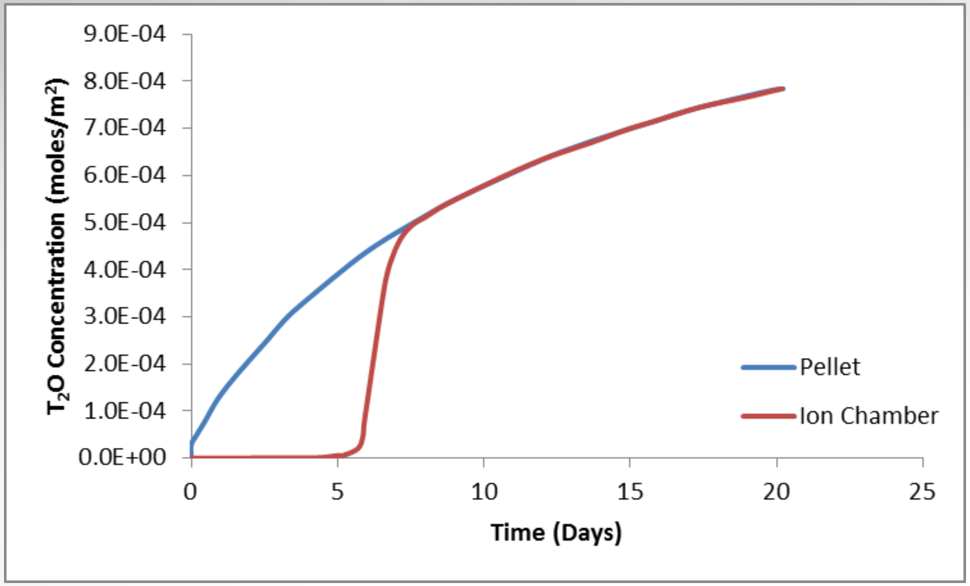
- A time lag, t_{lag}, is expected between pellet release and ion chamber measurement
  - Ideally, t_{lag} results only from the transit time between pellet and ion chamber
  - In reality, tube wall interactions can significantly impact ion chamber response

Initial Transport Model

- Tube wall interactions with T_2/T_2O laden gas were modeled to estimate ion chamber response time
  - Majority of pellet release is expected to be T_2O
- Multiple processes can act concurrently to impact tritium transport
  - Adsorption
    - Physisorption
      - Gas atoms or molecules are loosely bound on surface
      - Sensitive to partial pressure and to temperature
    - Chemisorption
      - Gas atoms or molecules are strongly bonded to surface
      - Sensitive to temperature and insensitive to pressure below threshold value
  - Isotopic exchange
    - Tritium and protium can “swap” or freely exchange with one another
    - Assumed to occur between physisorbed and chemisorbed inventories

Initial Transport Model

- Model assumptions
  - 100’ of 1/8” Cu tubing at 150°F
  - T_2O introduced at inlet at 30 sccm
  - Mass transfer coefficient taken from T. Shiraishi et al. for water adsoprtion/desorption on surface
  - Output generated by WATER code developed at INL



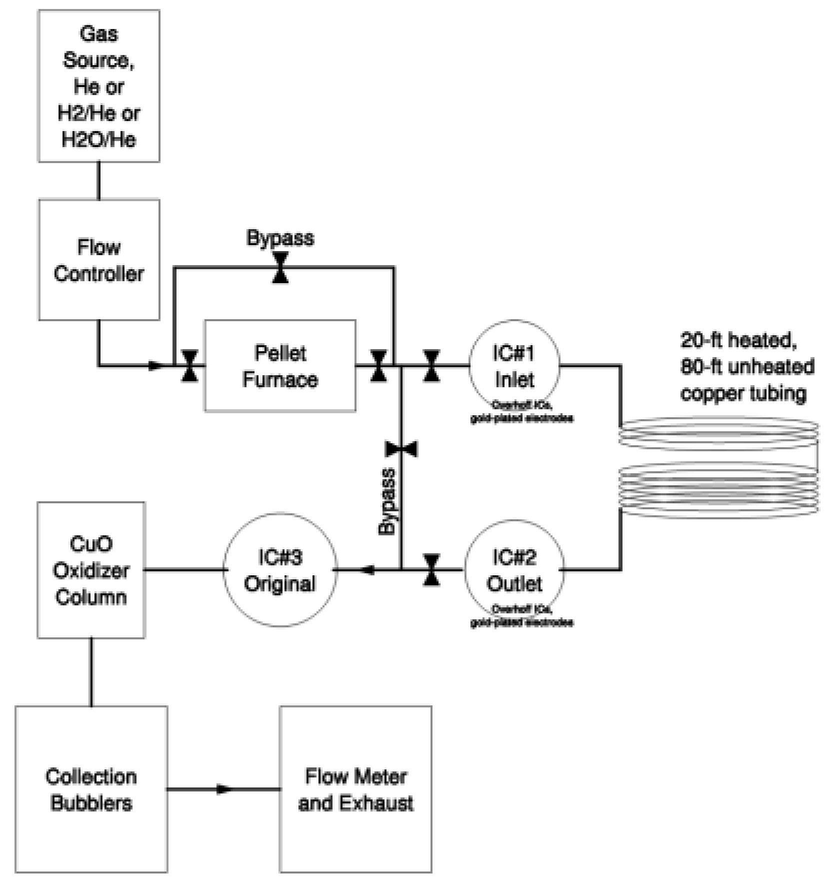
- Predictions indicate slow ion chamber response times
  - t_{lag} of 1 week or more can be expected, depending on release rate estimates
  - Slow response times expected to mask details of pellet release behavior
- Recommend filling physisorbed and chemisorbed inventories with a pre-test T_2O flush prior to test

T. Shiraishi, S. Odoi, M. Nishikawa,Adsorption and Desorption Behavior of Tritiated Water on the Piping Materials,” Journal of Nuclear Science and Technology v.34 [7] p.687-694 (1997)

M. Nishikawa, T. Takeishi, Y. Kawamura, Y. Takagi, Y. Matsumoto, “Tritium Balance in the Piping System of a Fusion Reactor,” Fusion Technology v.21 p. 878-882 (1992)

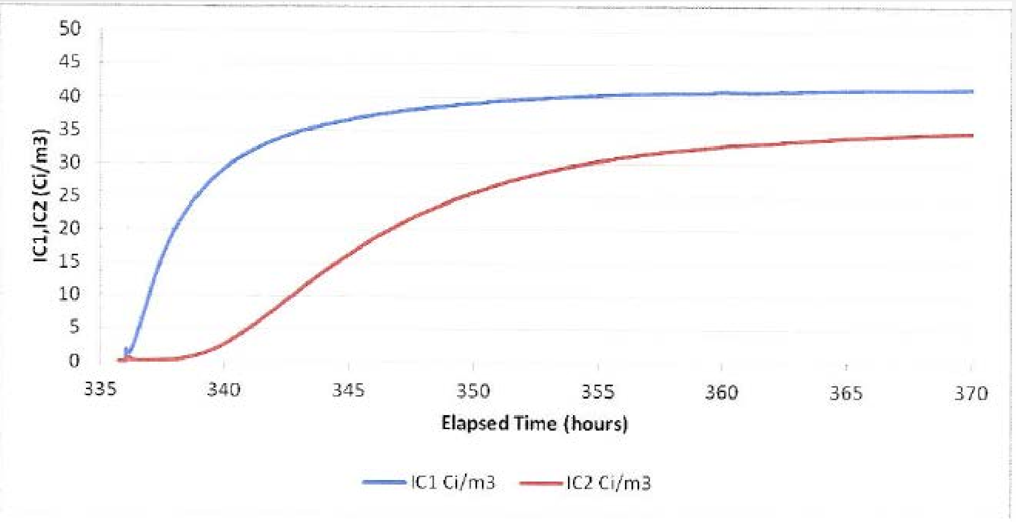
Initial Transport Experiment

- Loop test setup in laboratory to generate data for model comparison
  - Irradiated γ-$LiAlO_2$ pellet used as source (T_2O)
  - 30 sccm UHP He
  - 100’ 1/8” Cu tubing (20’ at 150°F)
- Tests conducted to compare ion chamber performance and cleanup method
  - Ion chambers 1 & 2 use wire electrode design to minimize moisture retention
  - Ion chamber 3 is an older design with perforated stainless steel electrodes susceptible to moisture retention
  - Cleaning methods included
    - Dry He purge
    - Heating
    - Isotopic swamping (H_2, H_2O)



Initial Transport Experiment

- Ion chamber response (IC1 vs IC2) after source (T_2O) is released
  - IC2 is shifted and modified relative to IC1
  - t_{lag} is greater than time required for gas transit only
    - Consistent with tube wall interaction
    - Shape of IC2 response suggests slower mass transfer coefficient and smaller inventory
    - Final difference attributed to calibration uncertainty



- Response time is on the order of hours (< 1day) as opposed to a week or longer
  - Suggests TMIST-3 pellet release events can be resolved reasonably well without a need for T_2O pre-flush

Initial Transport Experiment

- Overhoff Ion Chamber
  - Designed to minimize T_2O retention
  - Electrodes gold-plated
  - Wire electrode design, virtual wall
  - Triple electrode design
  - Bakeable to at least 150C
  - Used at PNNL and JET

Initial Transport Experiment

- Summary of cleaning operations

Ion Chamber Clean-up Method #	Method Description	Order of Effectiveness
1	Dry He Purge	Least Effective
2	Dry He purge with heat (80-130°C)	Slightly more effective
3	Isotopic Swamping with H_2	More effective
4	Isotopic Swamping with H_2O	Most effective
5	Isotopic swamping with heat	No difference from 4

- Isotopic swamping with H_2O was easily the most effective clean-up method evaluated during this test
  - Rapid return to baseline observed on all three ion chambers

Summary and Future Work

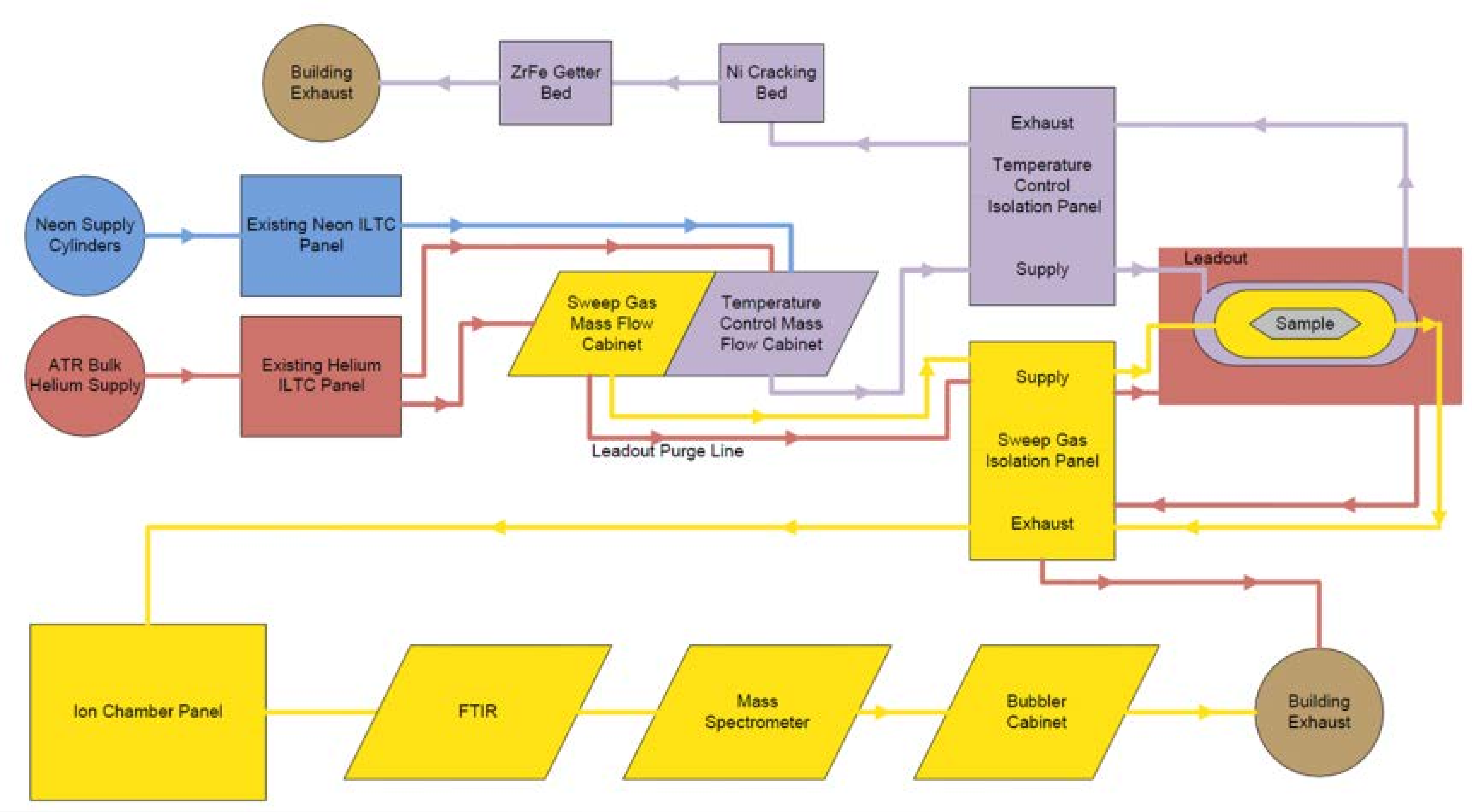
- Tube wall interactions impact transport from source to ion chamber
  - Initial model indicated significant modifications to the lag time (several days to several weeks) and shape of the detector response
  - Test results indicate shorter lag times (< 24 hours) can be expected
    - Indicates TMIST-3 pellet release characteristics can be satisfactorily resolved
    - Eliminates need for pre-test flush with T_2O
- Ion chamber clean-up can be readily achieved by flushing with water vapor (H_2O)
  - Rapid return to baseline by removing absorbed tritium from ion chamber
  - Improved ion chamber designs exhibit less tritium build-up through absorption, but still benefit from periodic cleanup during long tests
- Additional work required to reconcile modeling efforts with test results
  - Evaluate assumptions and mass transfer coefficients in existing model
  - Implement new code developed to evaluate transport in TMIST-3

Acknowledgments

- Glen R. Longhurst
  - Idaho National Laboratory/ Southern Utah University
  - Model development and WATER code simulation
- David L. Baldwin
  - Pacific Northwest National Laboratory
  - Test loop design and testing at Radiological Processing Laboratory

BACKUP SLIDES

Layout of TMIST-3 gas flow system



Components within TMIST-3 gas flow system

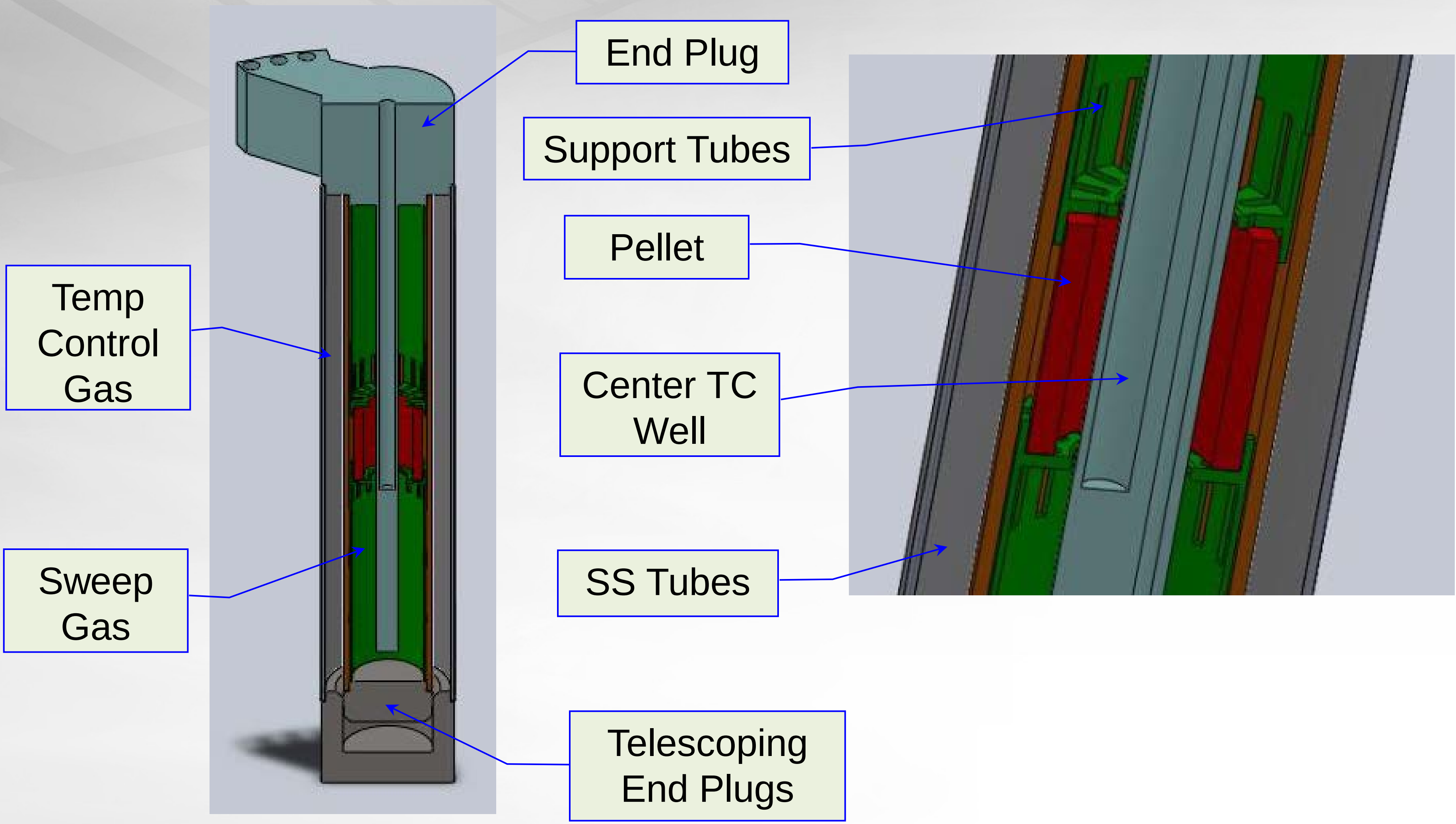
Ametek ProLine Quadrupole Mass Spec

Tyne 10cc Ion Chambers

Getter Bed Cabinet

Temperature Control Gas Mass Flow Controller Cabinet

Flow Through Capsule - Overview



End Plug

Support Tubes

Pellet

Temp Control Gas

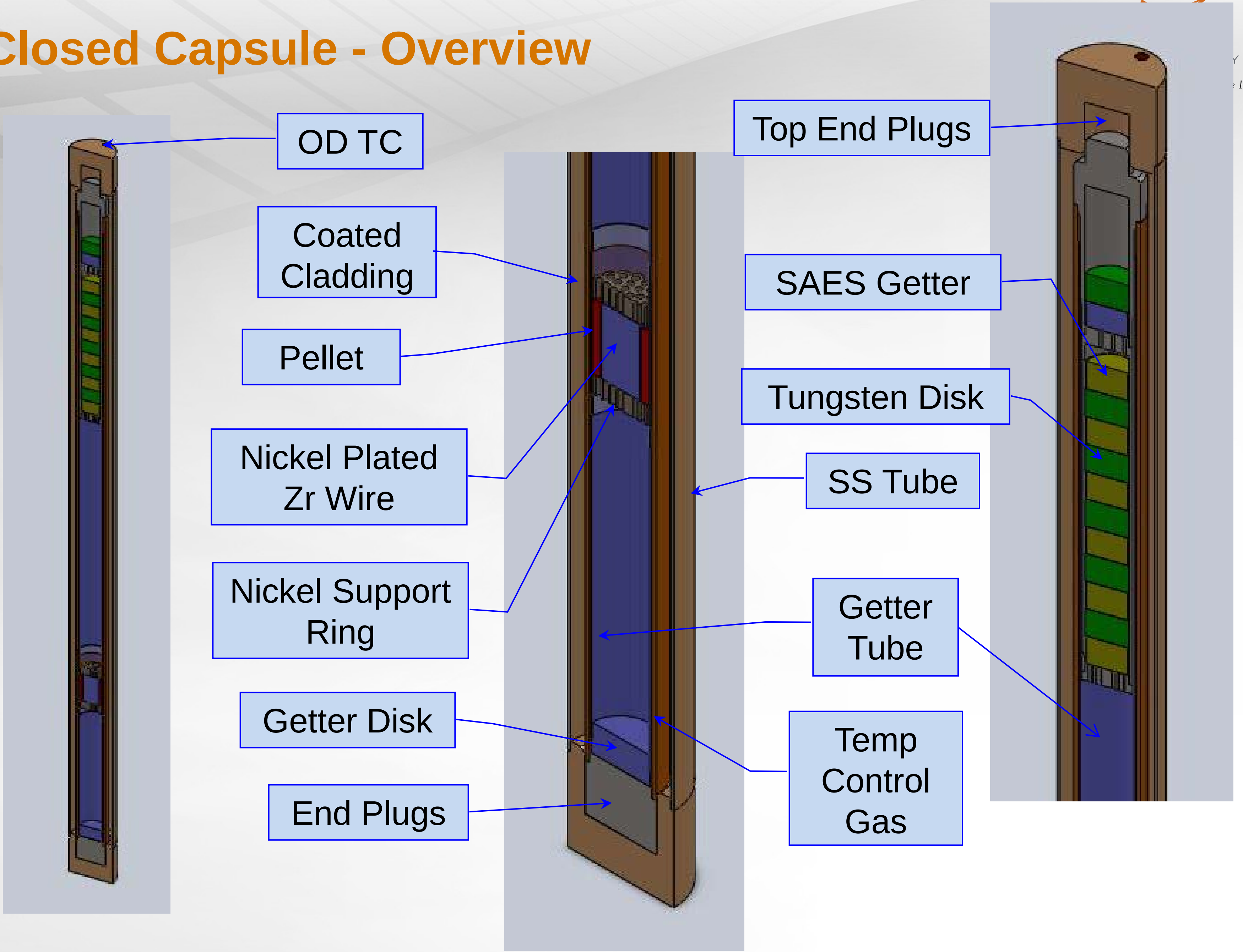
Center TC Well

Sweep Gas

SS Tubes

Telescoping End Plugs

Closed Capsule - Overview



OD TC

Coated Cladding

Pellet

Nickel Plated Zr Wire

Nickel Support Ring

Getter Disk

End Plugs

Top End Plugs

SAES Getter

Tungsten Disk

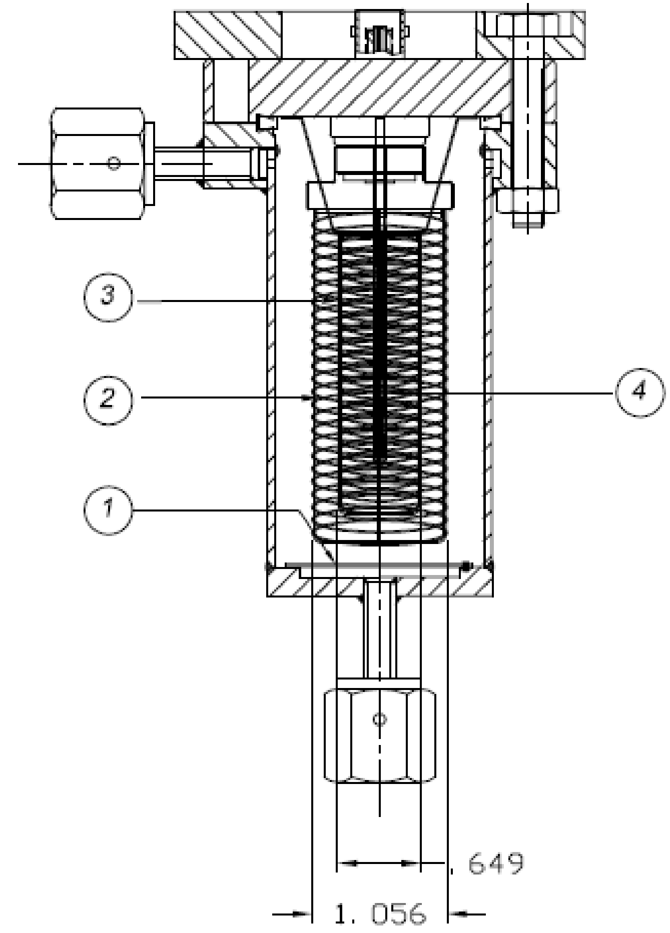
SS Tube

Getter Tube

Temp Control Gas

Initial Transport Experiment

- Tyne Ion Chamber



1. DIFFUSER, mesh, electropolished, guide the gas flow evenly;
2. PRECIPITATOR, wire, -100V to the chassis ground, creat electrical field;
3. GROUND CASE, wire, 0V to the chassis ground;
4. COLLECTOR, stainless rod, -100V+offset created by the ion.