In-Reactor Measurement of Tritium Permeation through Stainless Steel Cladding

Presented by

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Presentation Outline

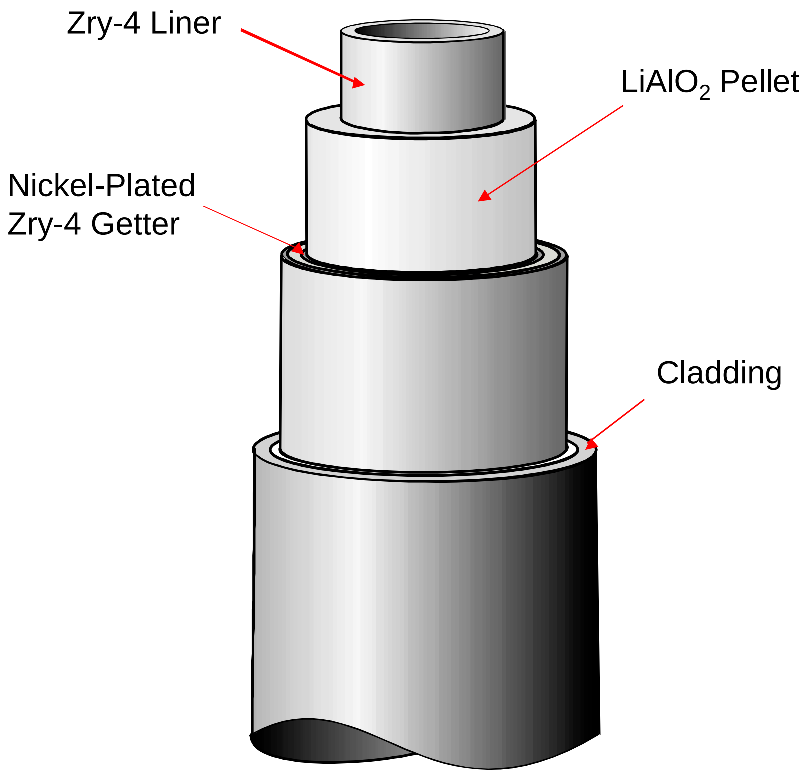
- Motivation
  - Characterize in-reactor tritium permeation performance
    - Observe temperature and pressure dependence
    - Support predictive modeling and design efforts
    - Mitigate environmental release
- In-Reactor Permeation Test: *TMIST-2*
  - Experimental description
    - ATR test position and irradiation environment
    - TMIST-2 capsule and measurement system
  - In-reactor permeation measurements
- Summary and Conclusions

Motivation

- Characterize in-reactor tritium permeation through Type 316 stainless steel
  - Fission Reactor
    - Secondary Source Rods
  - Fusion Reactor
    - Containment Materials
  - Isotope-Producing Targets
    - Tritium Producing Burnable Absorber Rods (TPBARS)
- Support predictive modeling capabilities
  - Assess current estimates
  - Develop new correlations
- Mitigate tritium release to environment
  - Compliance with Regulatory Authority
  - Environmental Stewardship

Motivation

- TPBARs
  - Support NNSA tritium readiness campaign
  - Cladding exposed to low tritium partial pressures under commercial light water reactor conditions
  - Must mitigate tritium permeation at low pressure



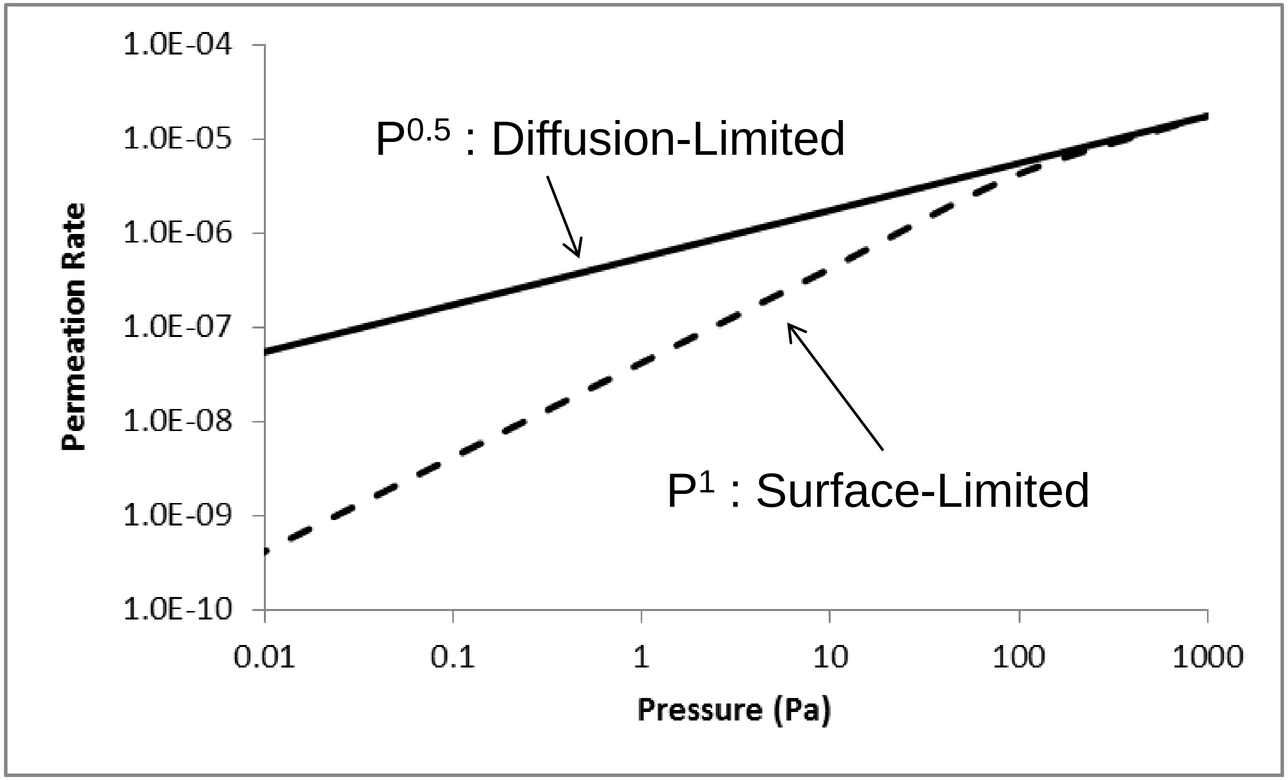
Not to Scale

Permeation Discussion

- Ex-reactor permeation measurements
  - > 100 Pa → Diffusion-limited → $P^{0.5}$
  - < 100 Pa → Surface-limited → P^{1}
- In-reactor permeation mechanism uncertain
  - Direct dissociative chemisorption
    - Molecules adsorb and readily dissociate upon contact
    - Disrupted ex-reactor at low pressure by:
      - Surface impurities / oxide films
  - Radiation-enhanced dissociation
    - Radiolysis of T_2 in gas phase
    - Physical or chemical changes in surface in-reactor

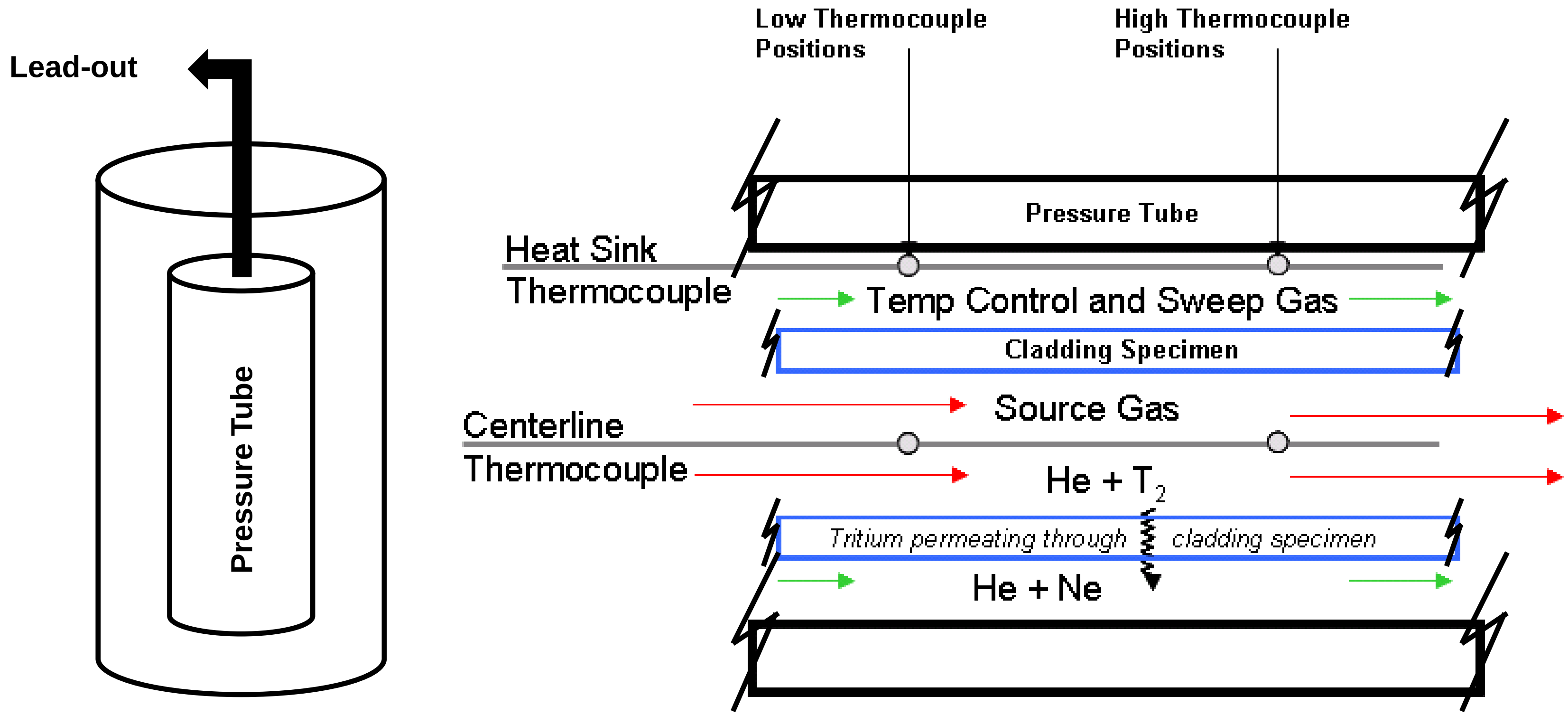
Permeation Discussion

- Pressure-dependent permeation
  - Limiting mechanism changes
  - Significantly impacts low pressure permeation rate



TMIST-2: In-Reactor Permeation Measurement

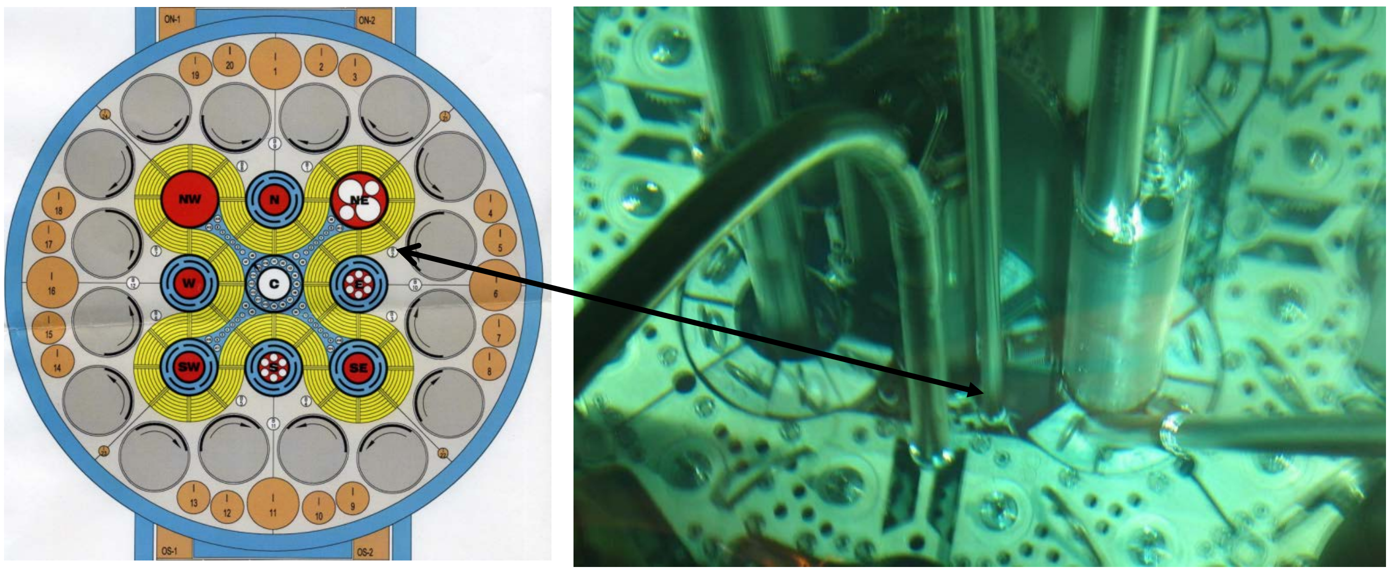
- Evaluate permeation performance for 316 Stainless Steel



  - Temperature dependence (292°and 330°C)
  - Pressure dependence (0.1, 5, 50 Pa)

Experimental Description (1/2)

- Experimental lead-out test assembly
  - Irradiated in Advance Test Reactor (ATR) at Idaho National Laboratory (INL)

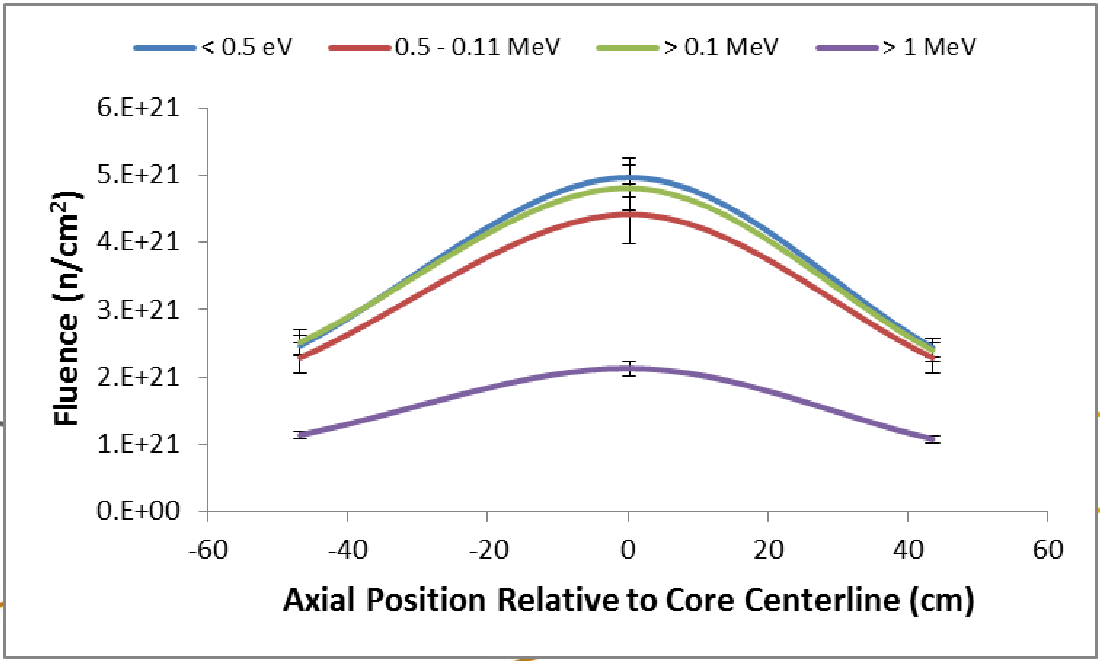


Test Assembly located in small B2 position

Experimental Description (2/2)

- Test Irradiation March 2009 - April 2010
  - 5 ATR Reactor Cycles
  - Simulate WBN1 fast flux

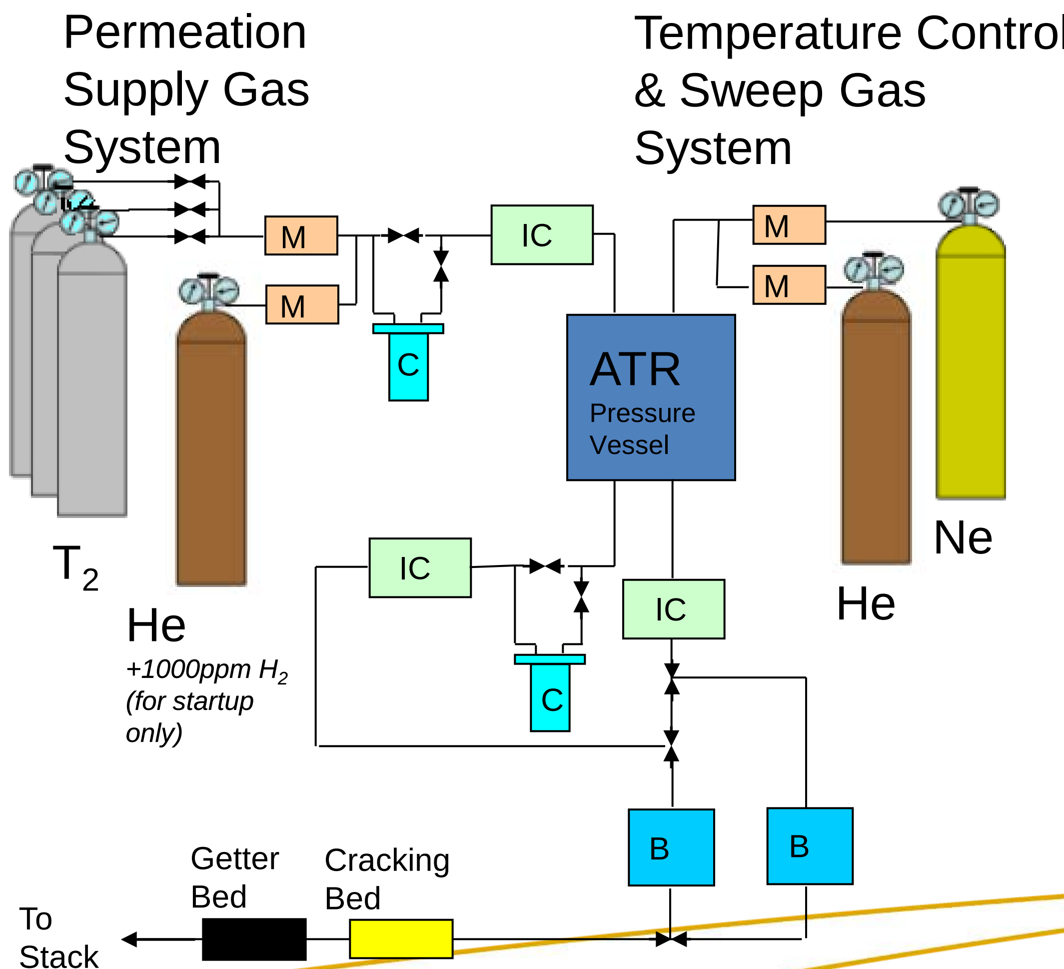
Flux (n/cm^2-s)	ATR B-2	± %	WBN	± %
Thermal (< 0.5 eV)	1.67E14	13	2.95E13	10
Epithermal (0.5eV – 0.1 MeV)	1.51E14	16	1.19E14	10
Fast 2 (0.1 – 1MeV)	9.06E13	24	6.70E13	14
Fast 1 (>1 MeV)	7.28E13	8	6.00E13	10



- Flux wire analysis
  - 258 EFPD at 18MW
  - 1.63 dpa

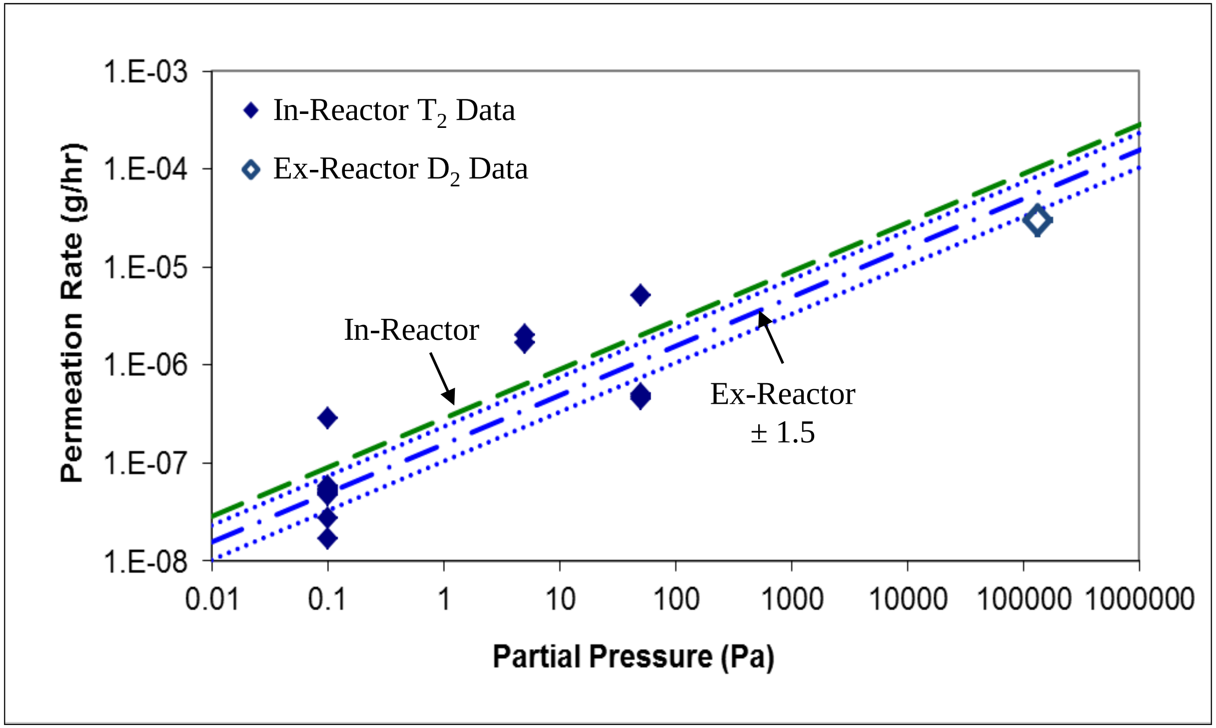
Measurement System

- Ex-reactor measurement
  - Pre-mixed source gas
  - Sweep gas monitored by ion chamber
  - Permeated tritium captured in bubbler column and measured via liquid scintillation counting



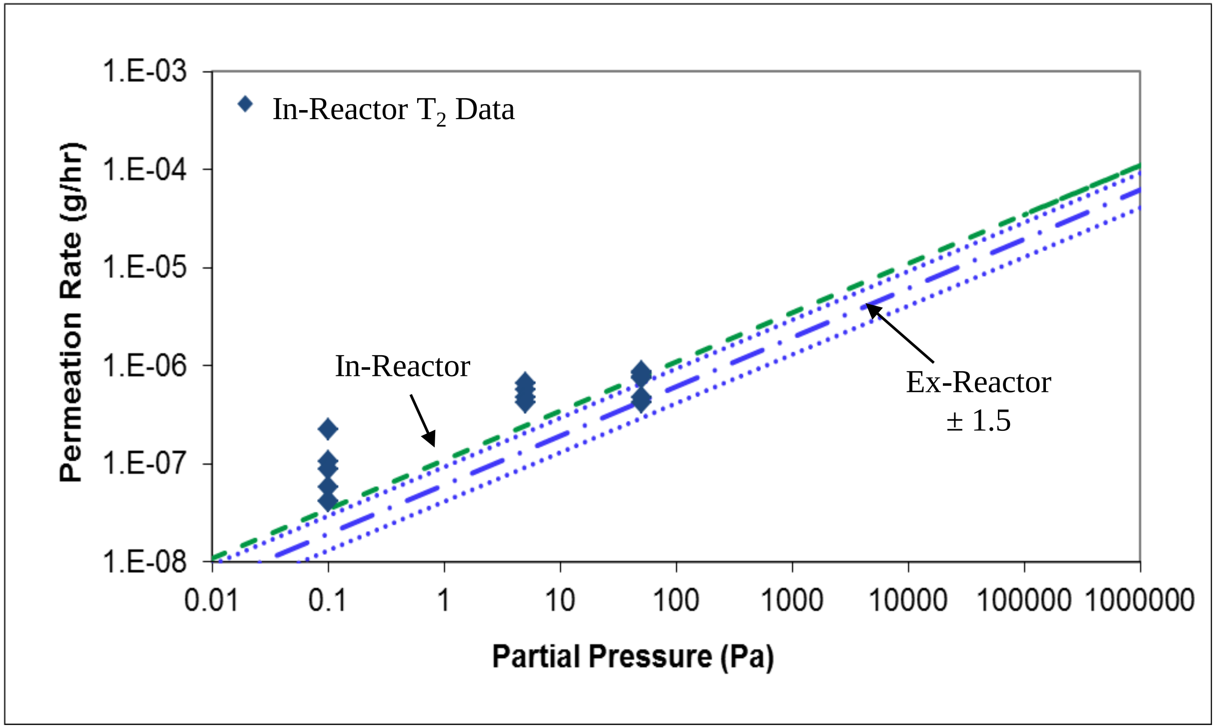
Results of Permeation Measurements

- 330°C Permeation Measurements
  - Observed $P^{0.5}$ dependence
  - Enhanced relative to predictions based on Le Claire correlation and ex-reactor tests with D_2



Results of Permeation Measurements

- 290°C Permeation Measurements
  - Observed $P^{0.5}$ dependence
  - Enhanced relative to predictions based on Le Claire correlation



Tritium Permeation Summary

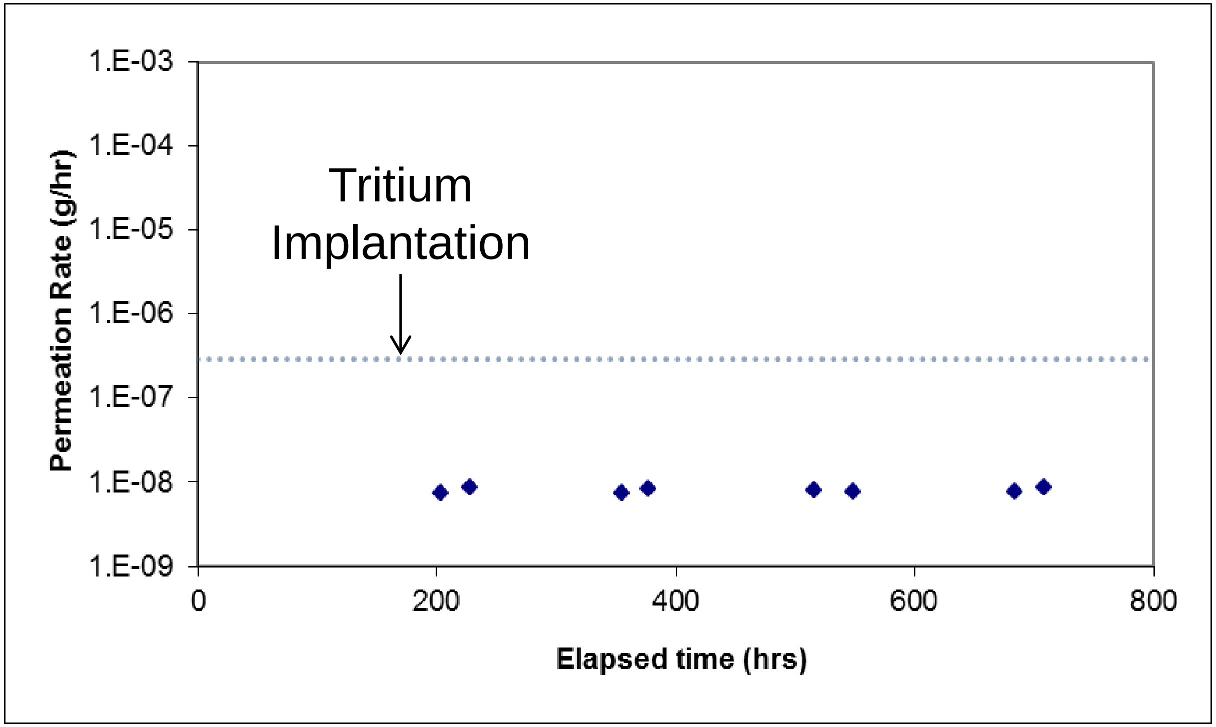
- In-reactor measurements reveal $P^{0.5}$ pressure dependence
  - Indicates in-reactor permeation is diffusion-limited under test conditions
- In-reactor permeation enhanced relative to predictions based on Le Claire's ex-reactor permeability correlation
  - Permeation enhanced by a factor of ~ 2 - 5
- In-reactor measurements suggest permeation rates increase with temperature as expected
  - Data scatter precludes Arrhenius analysis of the temperature dependence
  - Consistent with weak temperature dependence noted in literature

^{3}He Analyses

- ^{3}He found in tritium-containing environments
  - Decay product of tritium
- Impact on tritium permeation uncertain
  - Tritium formation via neutron capture
  - Implanted tritium may contribute to permeation
- Evaluate contribution by supplying ^{3}He instead of tritium to cladding permeation experiment
  - 1013 Pa ^{3}He in 124 kPa ^{4}He at 330°C

^{3}He Results

- Comparison
  - Estimate transmutation /reaction rate based on local thermal flux
  - Assume all implanted tritium permeates



- Less than 3% of the implanted tritium permeates
  - Not a significant contribution to overall permeation

Summary and Conclusions

- In-reactor measurements
  - Diffusion-limited permeation under test conditions
    - $P^{0.5}$ dependence at both temperatures
  - Weak temperature dependence over studied range
  - Enhanced permeation relative to predictions based on ex-reactor data
    - Significantly greater than predictions based on ex-reactor D_2 permeation data at > 100 Pa and P^1 dependence
    - Nominally a factor of ~2-5 greater than extrapolation of Le Claire correlation
  - ^{3}He contribution to permeation is small (< 3%)

Selected References

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