Tritium Focus Group meeting
September 23-25, 2014 at Idaho National Laboratory, Idaho Falls, ID

Tritium Permeation Activity at Safety and Tritium Applied Research (STAR) facility

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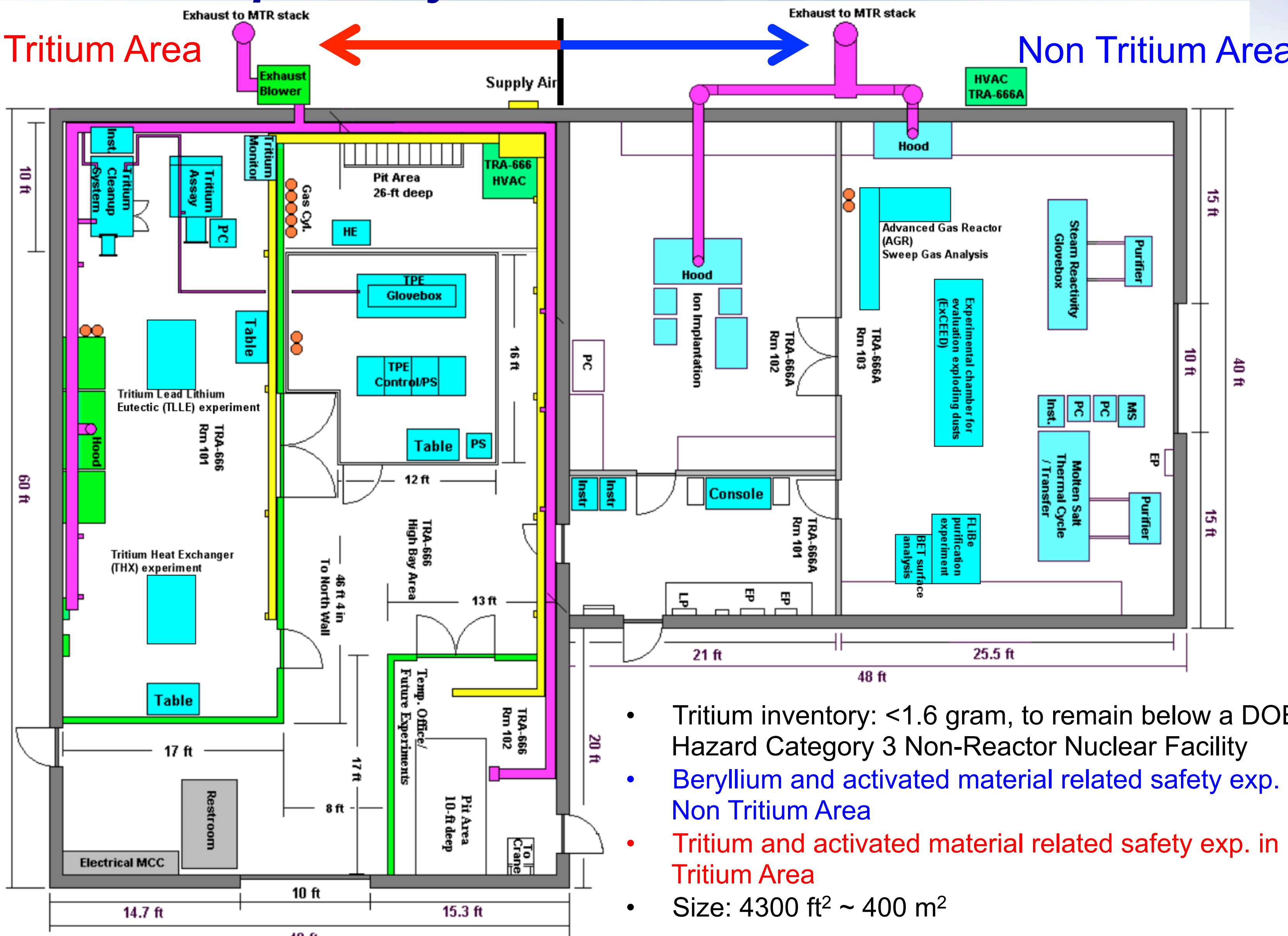
Outline:

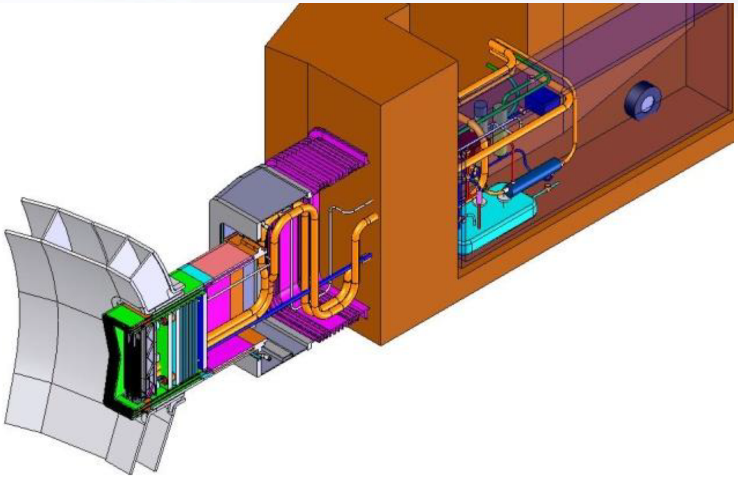
1. Motivation of low tritium partial pressure permeation
2. Tritium permeation for fission application
3. Tritium permeation for fusion application

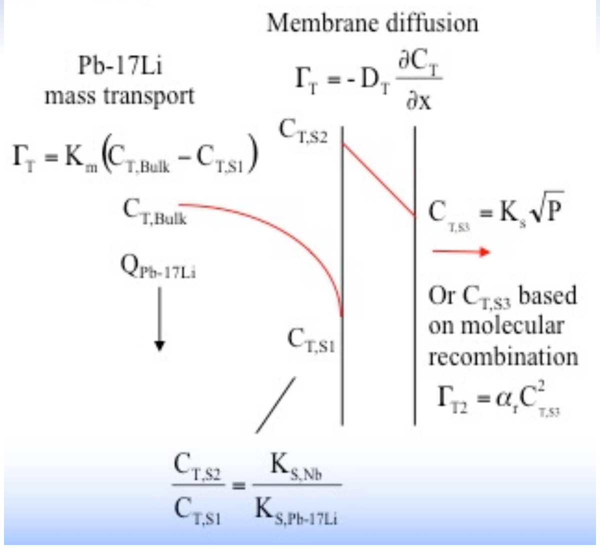
STAR Floorplan Layout



- Tritium inventory: <1.6 gram, to remain below a DOE Hazard Category 3 Non-Reactor Nuclear Facility
- Beryllium and activated material related safety exp. in Non Tritium Area
- Tritium and activated material related safety exp. in Tritium Area
- Size: 4300 ft^2 ~ 400 m^2

Safety concern: ex-vessel release source term





- Challenges in blanket development
  - Tritium permeation leads to the operation safety.
  - Mass transport properties (e.g. diffusivity, solubility, and permeability) of tritium at realistic blanket conditions (e.g. low tritium partial pressure << 100 Pa) is important for tritium blanket system design, but the data is very limited.
  - Tritium permeation barrier materials can reduce the release to the environment, however, the performance of tritium permeation barrier materials (e.g. ceramics) is unknown under fusion nuclear environments due to strong radiation field and displacement damage.
  - Tritium behavior in blanket/structural/barrier materials at realistic blanket conditions (e.g. low tritium partial pressure << 100 Pa) is not fully understood

➔ There exists large uncertainty in tritium permeation/extraction in blanket design

Motivation for low tritium partial pressure permeation

Reference: "Tritium permeation through 304 stainless steel…"A.S. Zarchy, and R.C. Axtmann, *Journal of Nuclear Materials* **79** (1979) 110

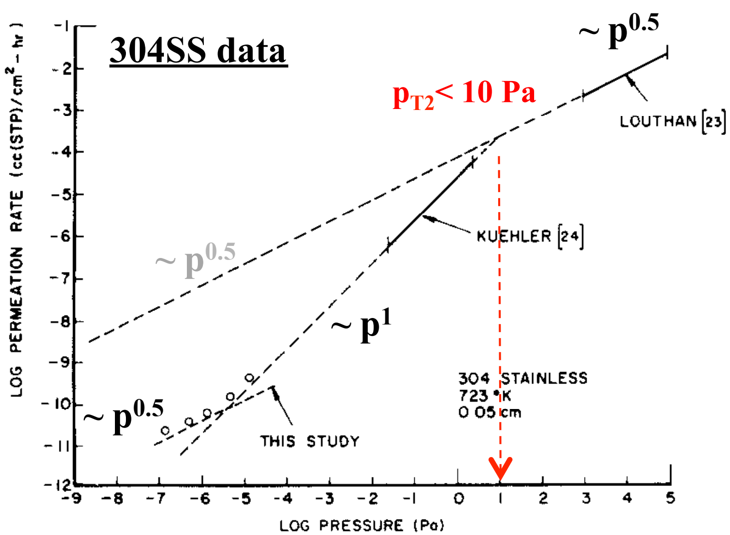


Fig. 4. Permeation rates of hydrogenic gases through 304 stainless steel as measured in three different studies. Results have been normalized for isotopic effects and differences in sample thicknesses.

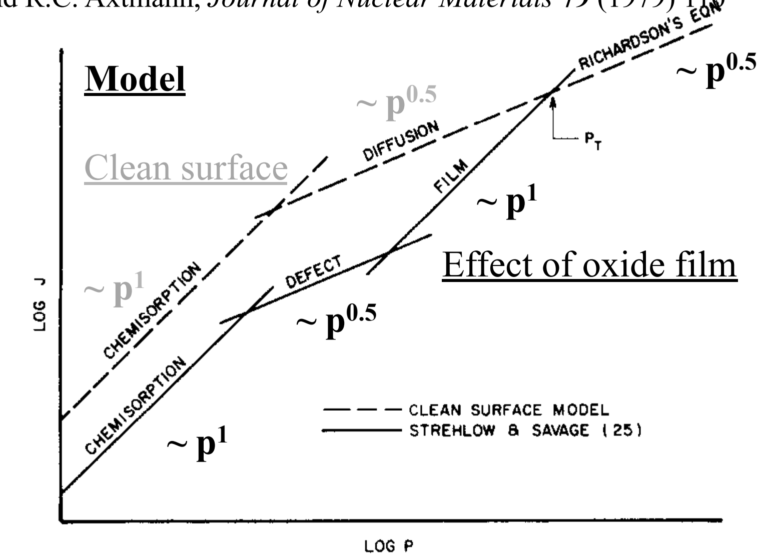


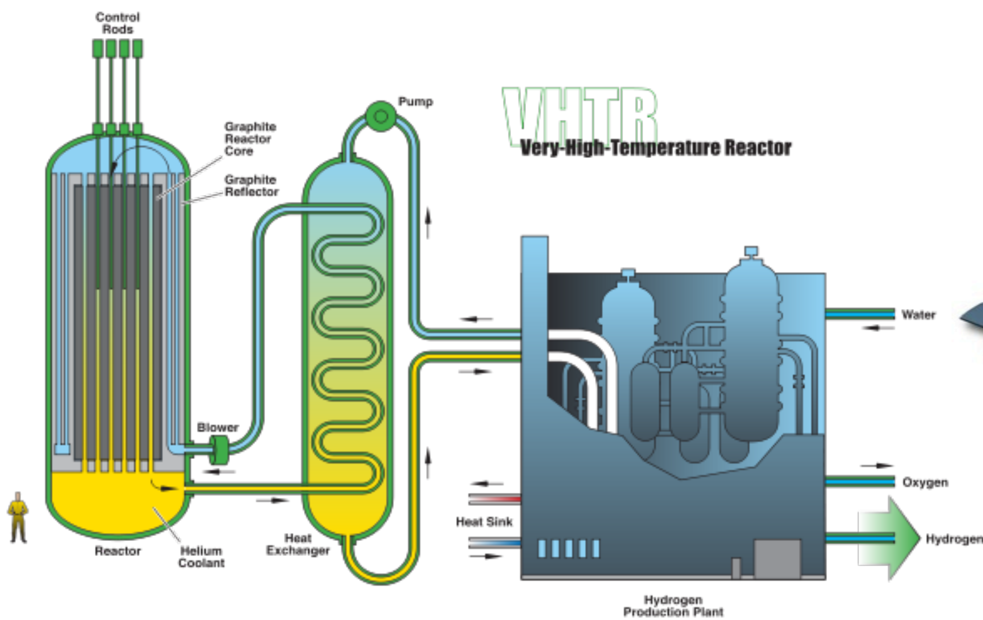
Fig. 6. Overall permeation behavior of hydrogenic gases through metals. P_T is the transition pressure between metal-limited and film-limited permeation.

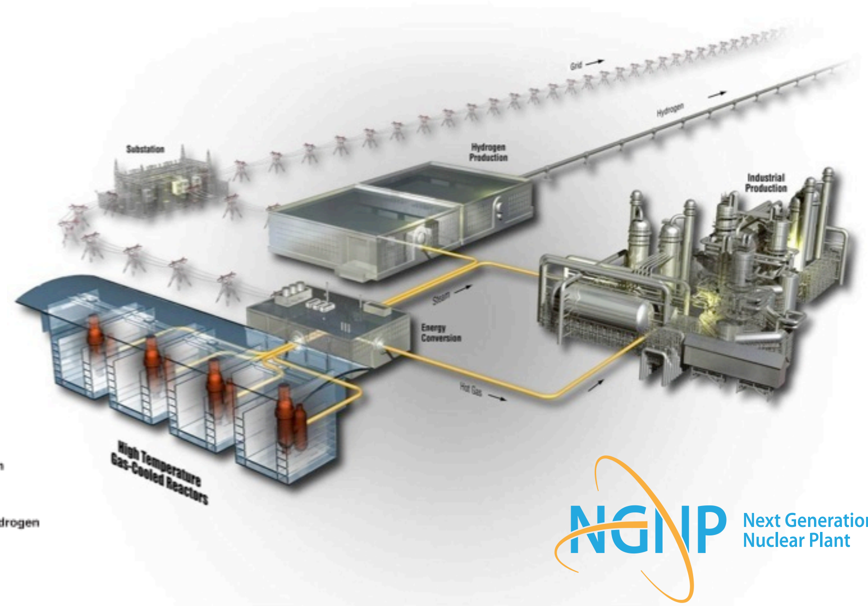
- Importance of tritium permeation at low tritium partial pressure:
  - Tritium permeation rate is lower at low tritium partial pressure (p_{T2}< 10 Pa for 304 SS)
  - Tritium permeation to the environment can be significantly reduced
  - Data from low tritium partial pressure is limited

➔ STAR facility operates two experiments (THX and TLLE) designed to measure tritium permeation rate at low tritium partial pressure ($10^{-3} < p_{T2}$ [Pa]< 100)

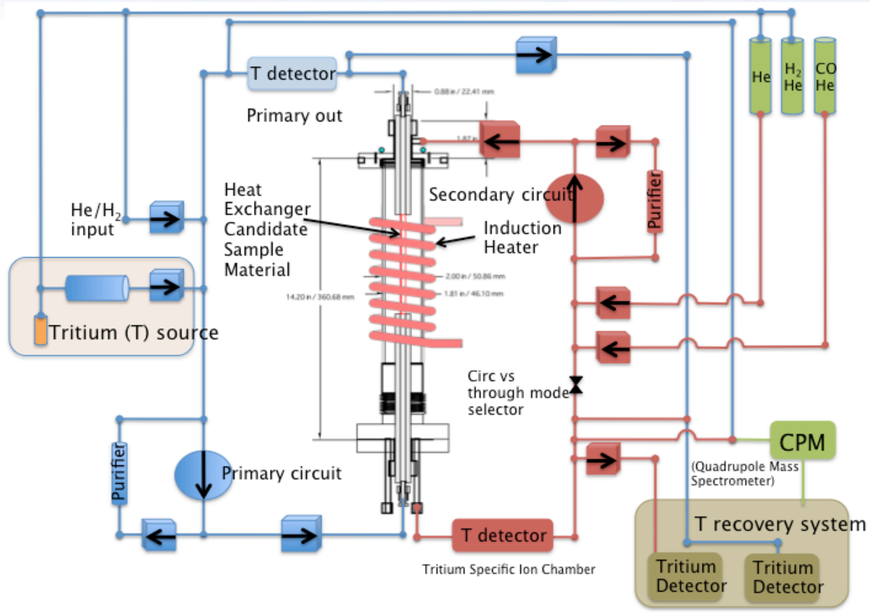
Tritium Heat Exchanger (THX) Experiment

- Tritium permeation apparatus was built in support for DOE NE NGNP/VHTR design
- Designed to measure tritium permeation rate through the candidate materials for VHTR IHX at low tritium partial pressure conditions (ppb – ppm) in the primary loop.
- Underlying physics for tritium permeation in the transition regime between diffusion limited and surface limited regimes is complex and there exists surface oxide effect on permeation
- Designed to test a tubular shaped specimen up to 1000 C
- Available to measure tritium permeability in fusion material as well.





Tritium Heat Exchanger (THX) Experiment



F82H sample

Test section and induction heater

THX glovebox

2012 US-PRC WS

Results from THX (1/2)

Incoloy 800H

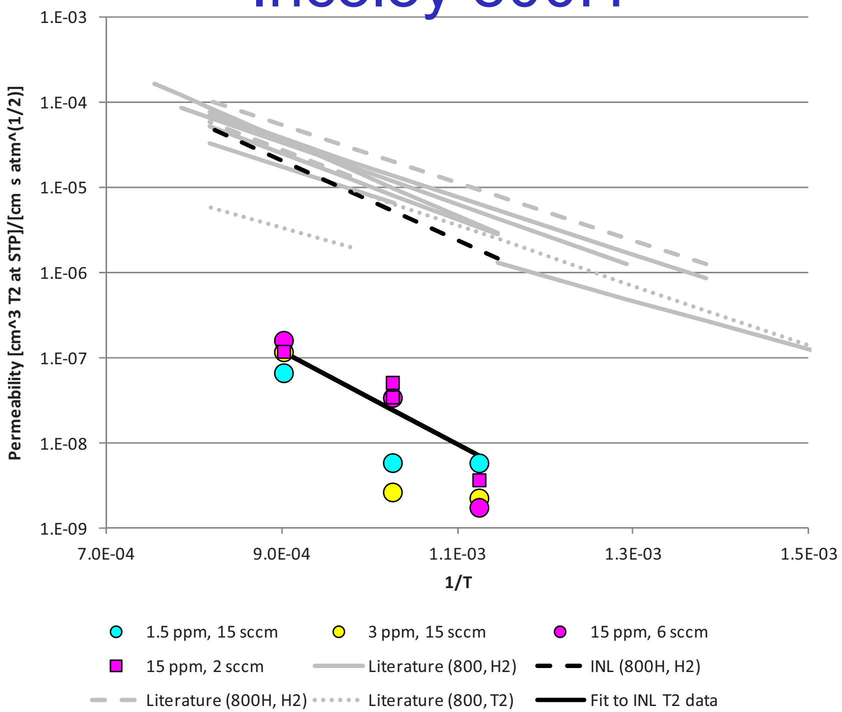


Figure 12. Arrhenius plot of Incoloy 800H tritium permeability (FY 11) with literature data.

Inconel 617

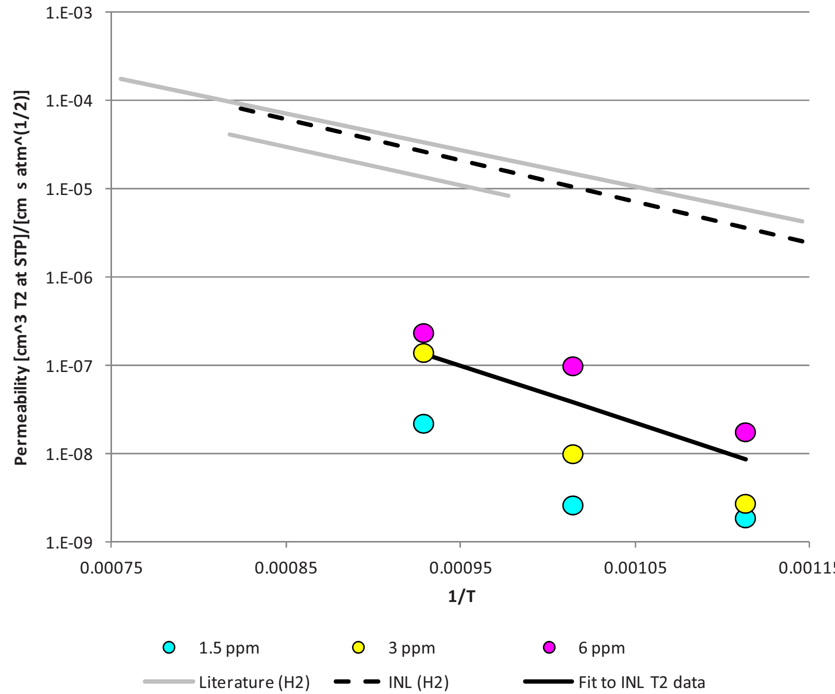


Figure 14. Arrhenius plot of Inconel 617 tritium permeability (FY 11) with literature data.

At high partial pressures (most of literature data), diffusion-limited permeation, in which the permeation flux is proportional to the square root of pressure, is expected.

Reference: "Tritium Permeability of Incoloy 800H and Inconel 617" INL/EXT-11-23265 and INL/EXT-11-23265 rev1

2012 US-PRC WS

Results from THX (2/2)

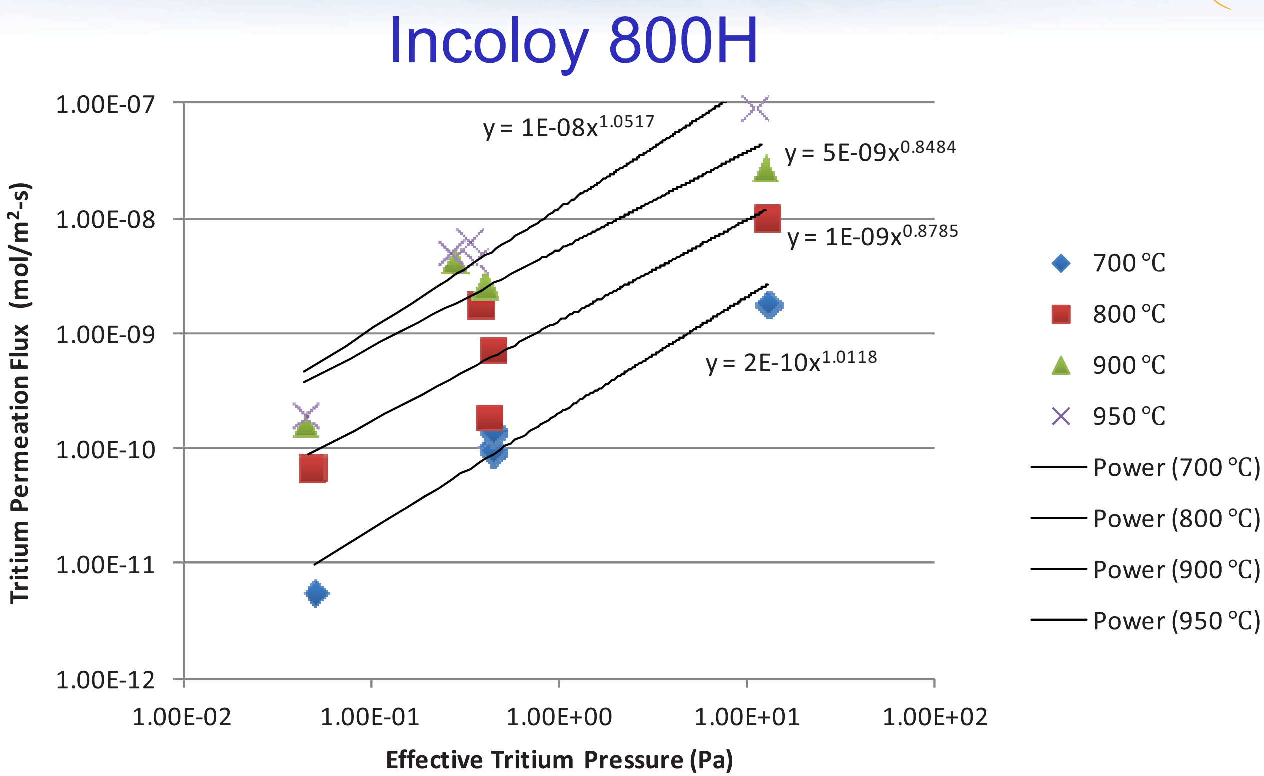


Figure 16. Tritium permeation flux versus effective tritium pressure (FY 12) at four different (peak) temperatures.

At low pressures, surface-limited permeation is expected, the flux is proportional to the pressure (the relationship is linear).

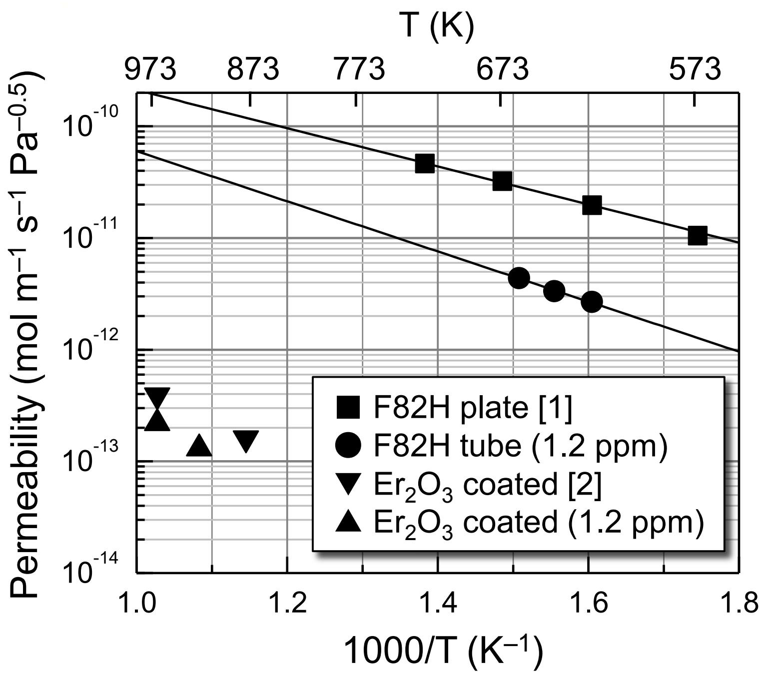
Reference: "Tritium Permeability of Incoloy 800H and Inconel 617" INL/EXT-11-23265 and INL/EXT-11-23265 rev1

2012 US-PRC WS

Tritium permeability measurement in tritium permeation barrier materials

- Utilize high detection sensitivity of tritium for low tritium permeation rate through low permeable erbium oxide (Er_2O_3) coated F82H (reduced activation ferritic steel) at 500–700 ºC with 1.2 ppm tritium
- Low partial pressure data showed linear dependence on tritium partial pressure, indicating the surface limited permeation or effect of oxide on permeation

- The coated sample indicated 3 orders of magnitude lower permeability than that of F82H substrate at 600-700 C.
  ➔ very promising tritium permeation barrier



Conditions:
- Temperature: 300 to 700°C
- Primary concentrations of 0.1 to 100 (atom) parts per million tritium in helium (partial pressures of <10^{-7} atm)
- Apparatus: THX

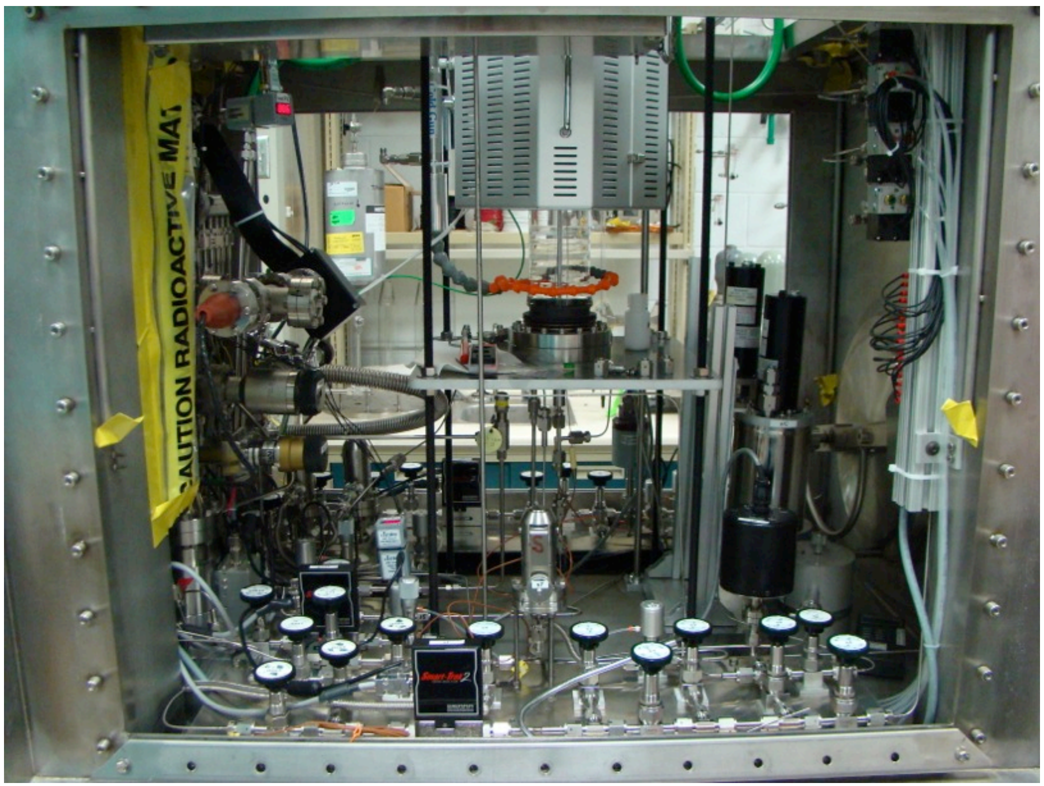
[2] T. Chikada, *et al.*, Fusion Eng. Des. 85 (2010) 1537–1541.

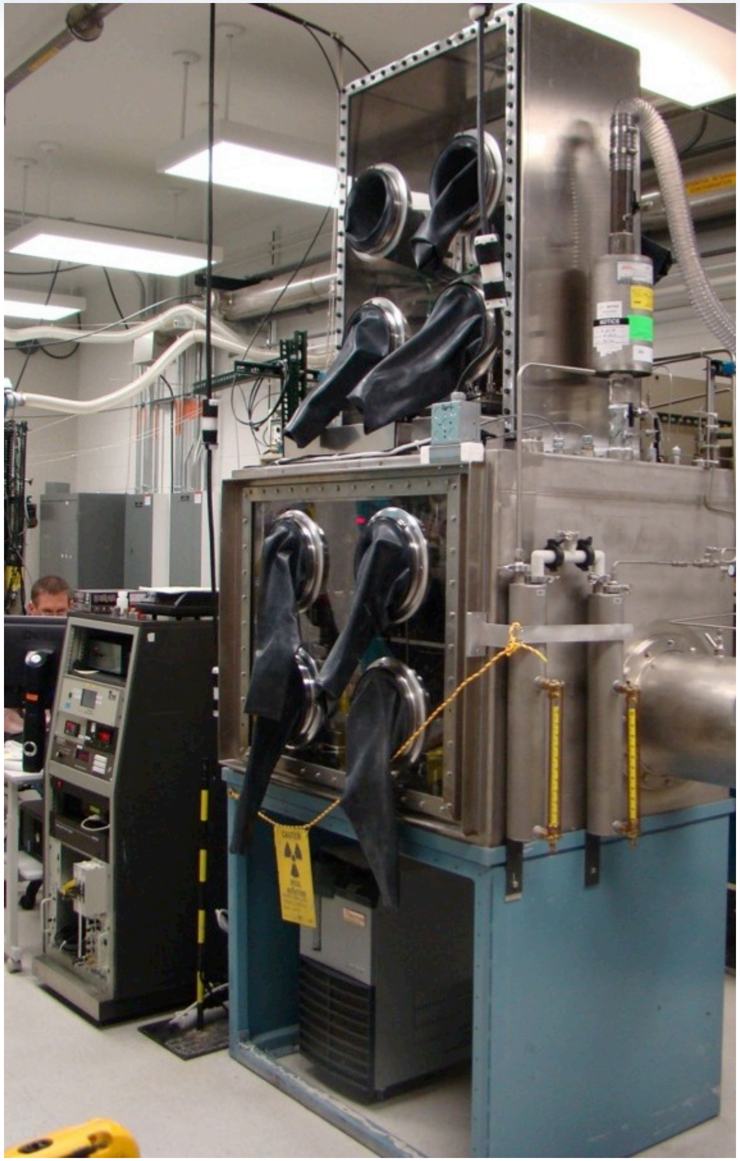
Outlines

1. Overview of tritium research in Safety and Tritium Research (STAR) facility
    - Motivation of tritium research program
2. Tritium research at STAR:
    - Tritium permeation in Tritium Heat eXchanger (THX) exp.
    - Tritium mass transport in Tritium Lead Lithium Eutectic (TLLE) experiment
    - Tritium Migration Analysis Program (TMAP) modeling
3. Possible collaborative research with NFRI/KAERI
    - Proposed experiments

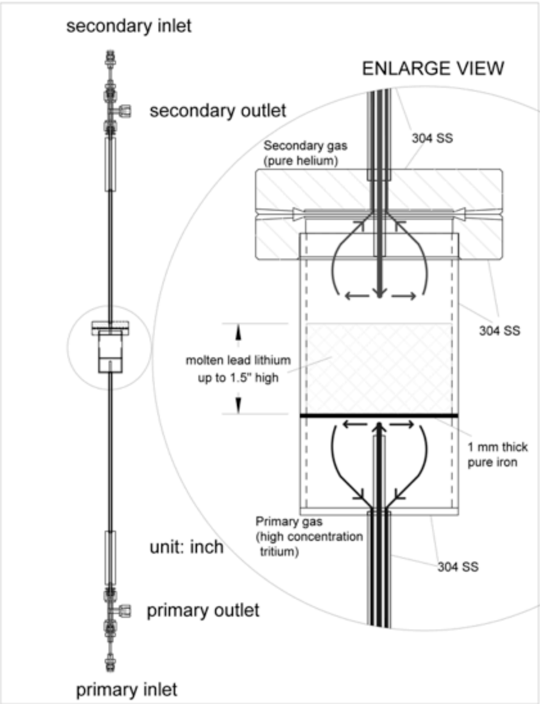
Tritium Gas Absorption Permeation (TGAP) experiment

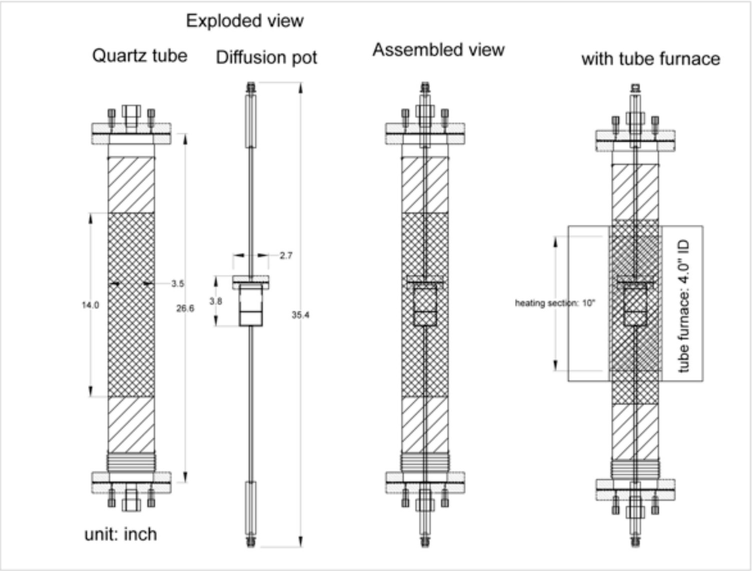
- The experimental apparatus is inside Contamination Area (CA) for tritium
  - Tube furnace in Ventilated Enclosure (VE)
  - Exhaust clean-up system in Fume Hood

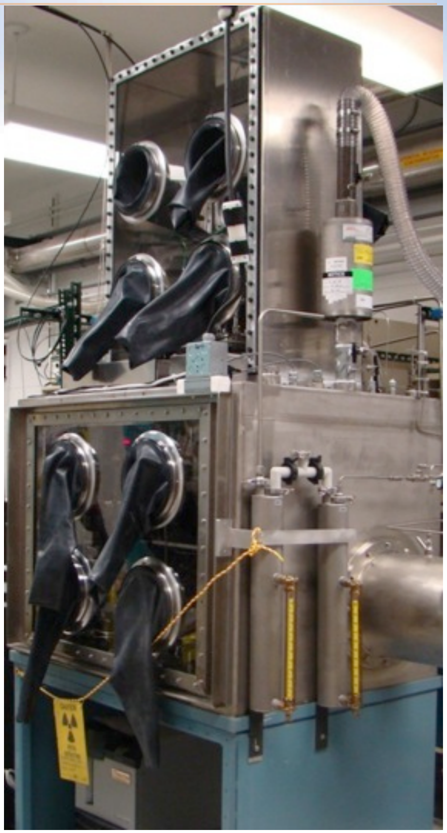




Tritium Gas Absorption Permeation experiment



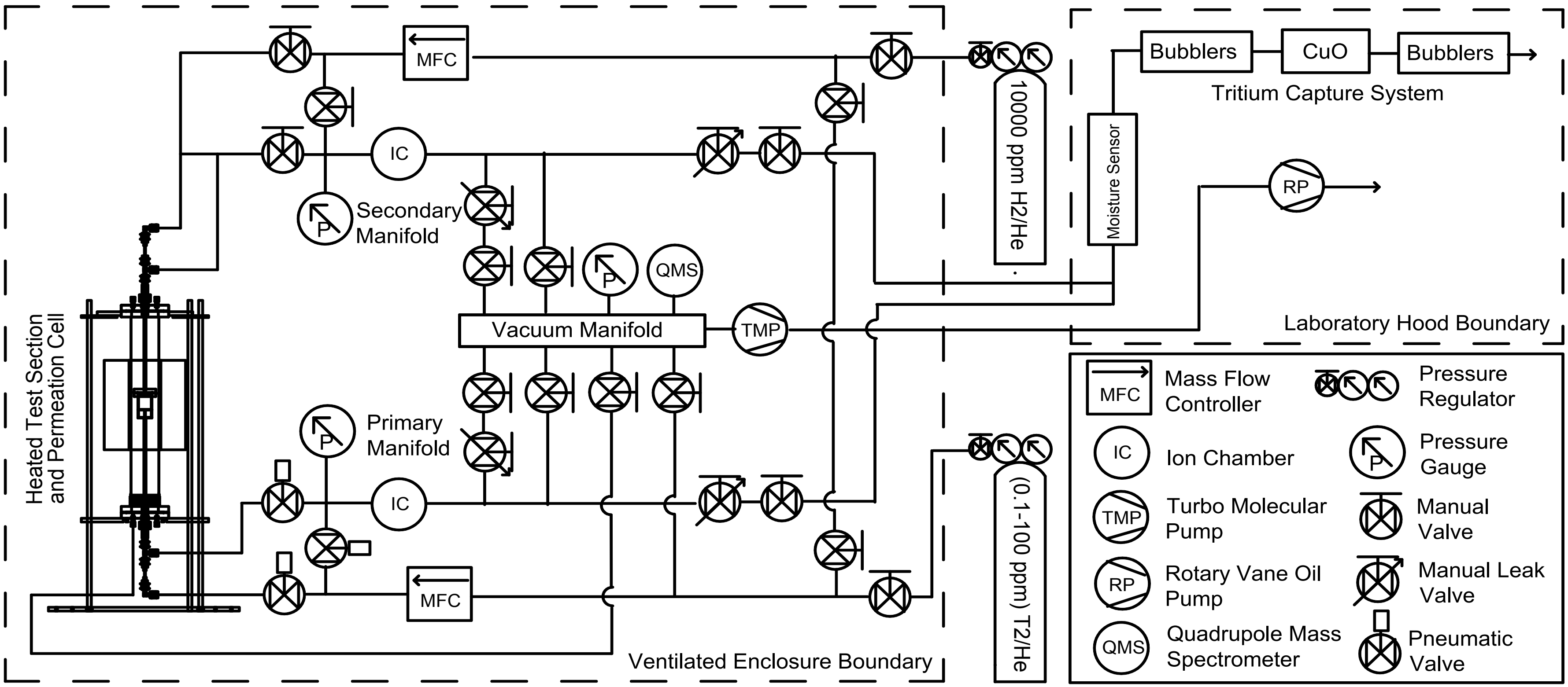




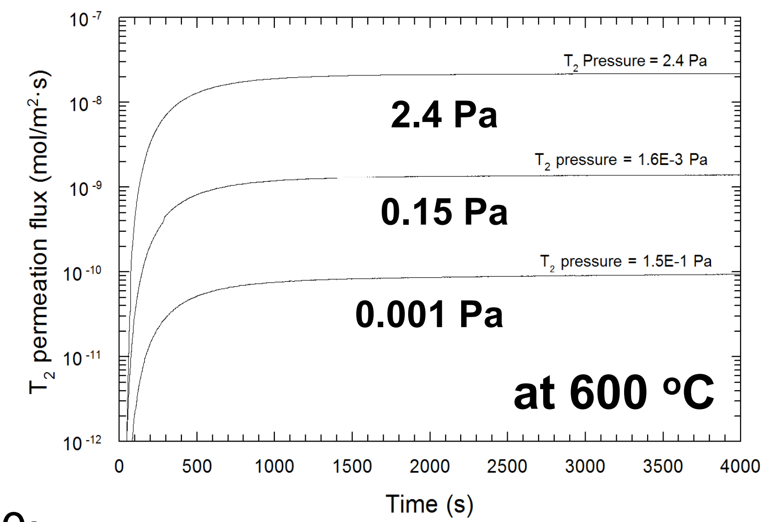
Unique capabilities

- Designed to measure transport properties (e.g. diffusivity, solubility, and permeability) of tritium at realistic blanket conditions (e.g. low tritium partial pressure < 1000 Pa) for disc geometry sample
- Capable of testing liquid breeder material (e.g. PbLi and FLiBe) and disc shaped metal
- Uniform temperature (+/- 10 C) within the test section utilizing 12" tube furnace

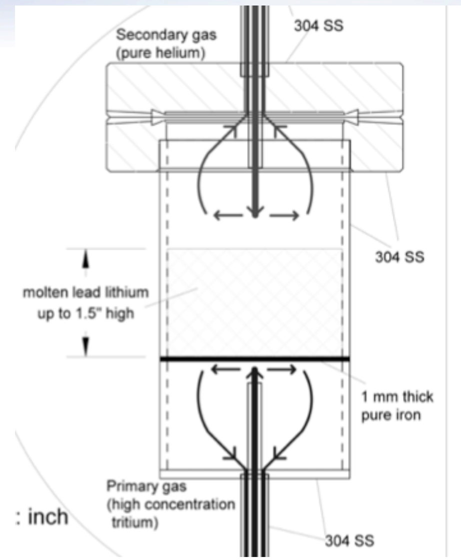
Simplified P&ID of Tritium Gas Absorption Permeation experiment



Experimental procedure



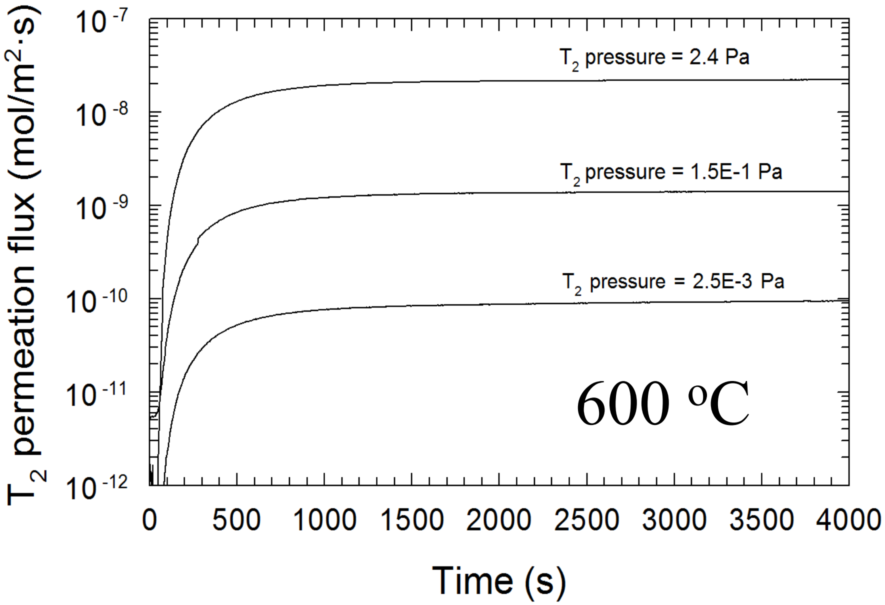
H_2/He

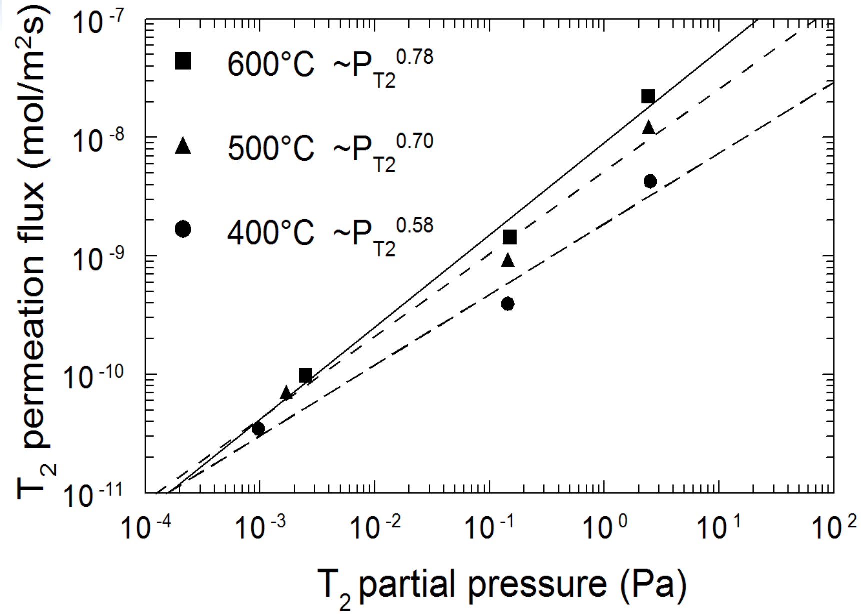


T_2/He

- t < 0:
  - Primary and Secondary was purged with **1 % H_2/He 200 sccm, p_t=10^5 Pa**
  - Bake out at 600 C with for 2 hours to remove oxide
  - Test section was kept at uniform temperature (+/- 10 C) for 1 hour at t<0.
  - Traps in the α-Fe were saturated by hydrogen.
- At t=0,
  - Tritium (0.001, 0.15, 2.4 Pa **T_2/He**) were introduced in the primary.
- t >0 :
  - Fast breakthrough time was obtained (within a minutes) and tritium equilibrates within 30 minutes

Tritium permeation through (1mm) α-Fe

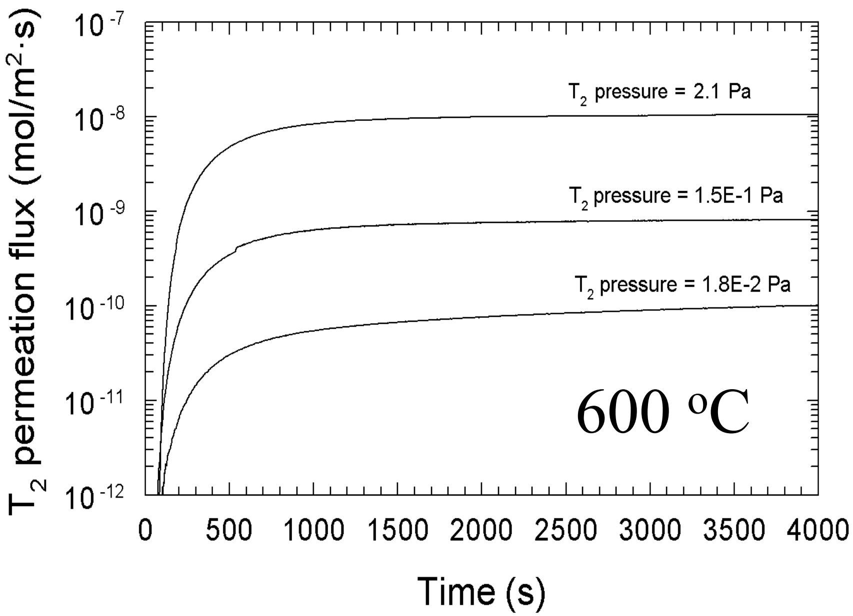


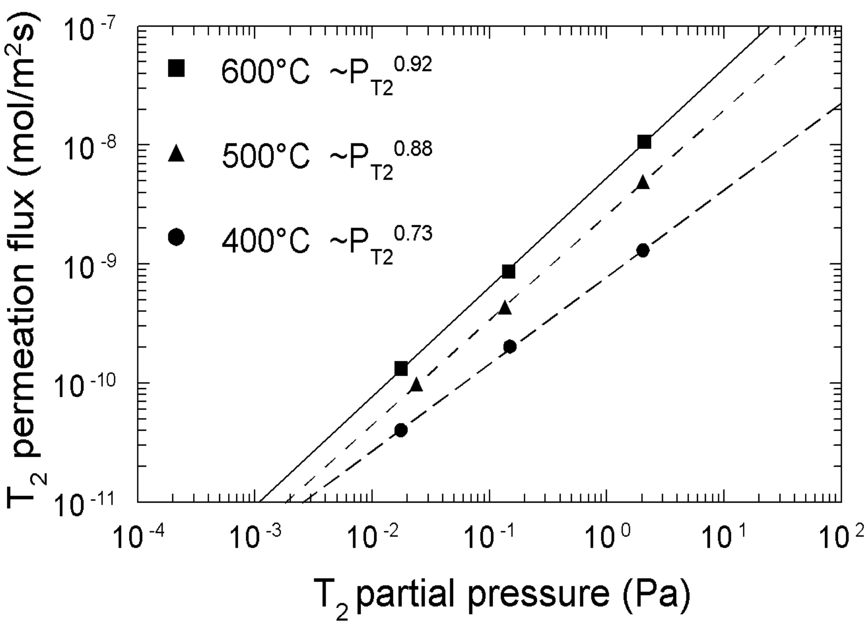


- Tritium partial pressure dependence were $P_{T2}^{0.58} \sim P_{T2}^{0.78}$
- Tritium behavior is in the transition range ($P^{0.5} < P^{x} < P^{1}$) from diffusion limited to surface limited.

- Issues:
  - H_2 and HT concentration in primary are unknown.
  - Should be HT in the secondary

Tritium permeation through (1 mm) α-Fe + (6mm) LLE



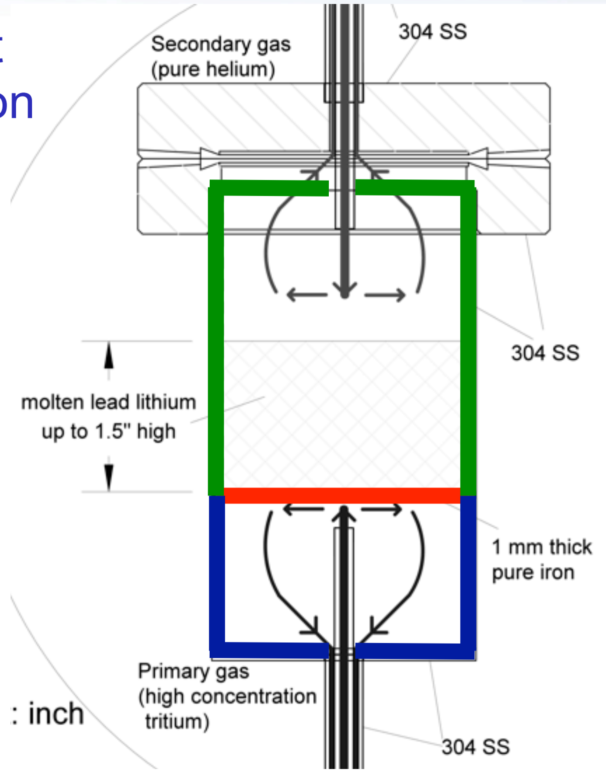


- Tritium partial pressure dependence were $P_{T2}^{0.73} \sim P_{T2}^{0.92}$
- Tritium behavior is in the transition range ($P^{0.5} < P^{x} < P^{1}$) from diffusion limited to surface limited.
- Straight line ($R^2 \sim 1$) fit at all three case

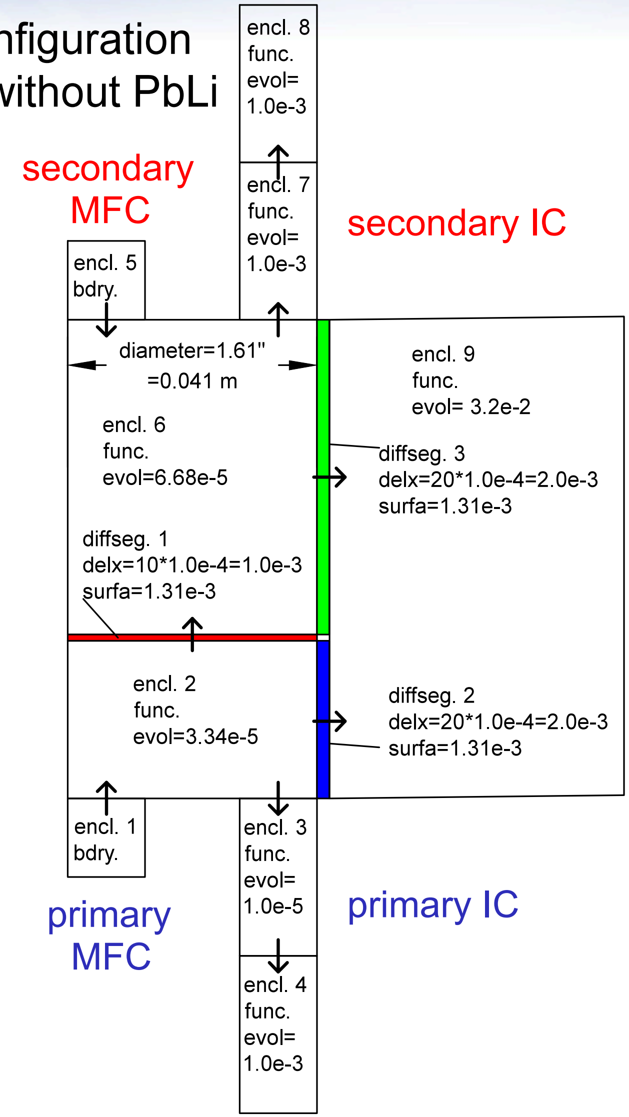
- Issues:
  - Primary tritium partial pressure (especially at lowest case) was higher than that of α-Fe test, making it difficult to compare those two results

TMAP schematics

Experiment configuration



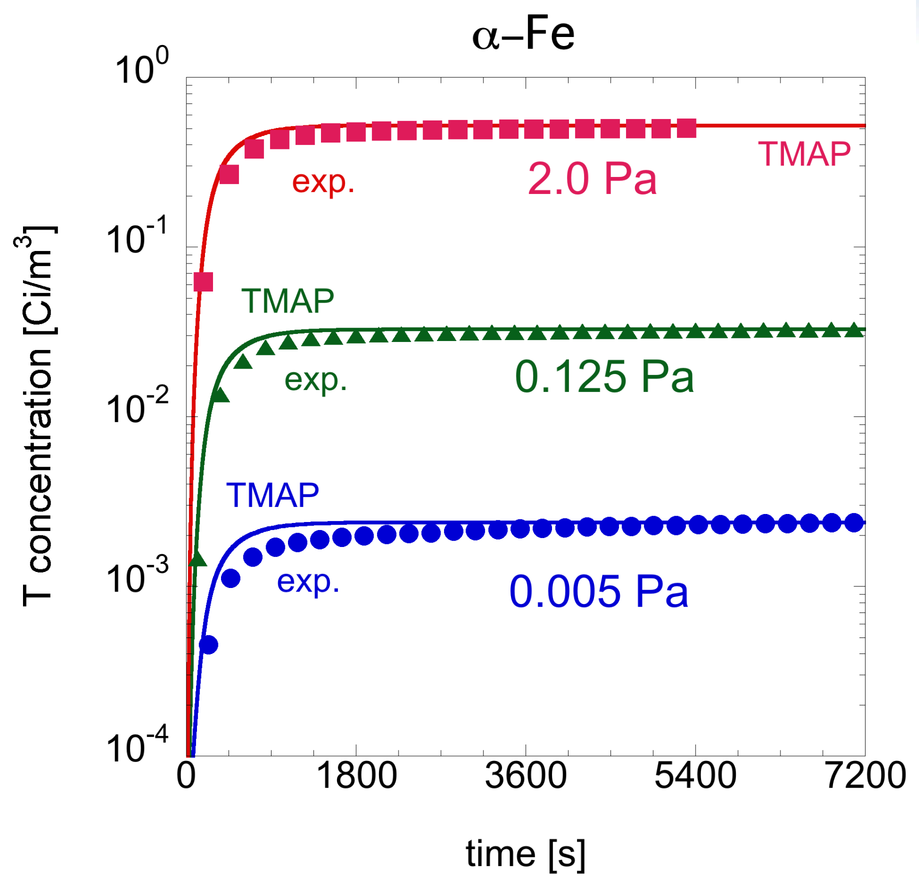
TMAP configuration (1D) for without PbLi



- TMAP
  - 1D geometry
  - 3 enclosure species (H_2, T_2, He)
  - 2 diffusion species (H, T)
  - 3 segments
  - 9 enclosures

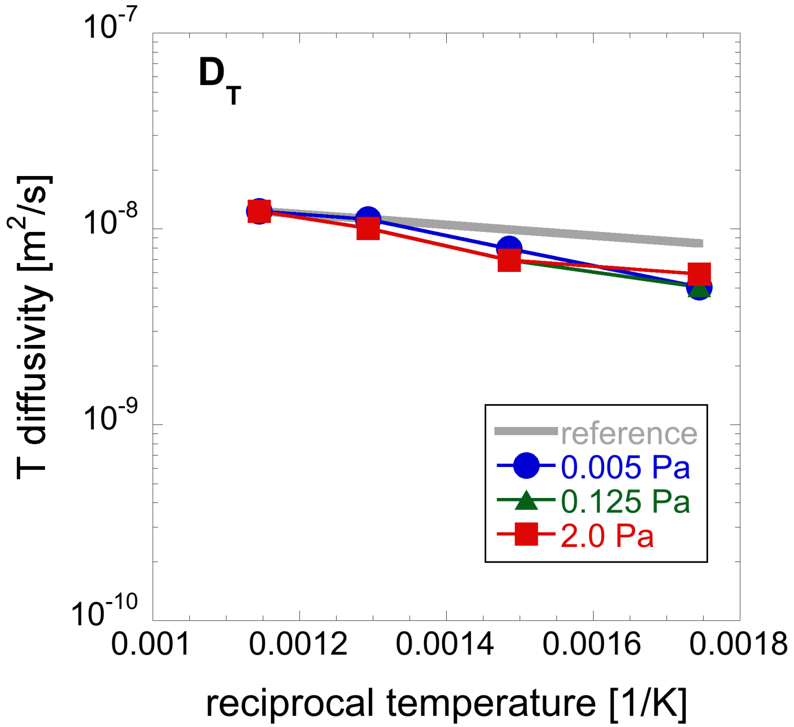
TMAP modeling results (Preliminary analysis)

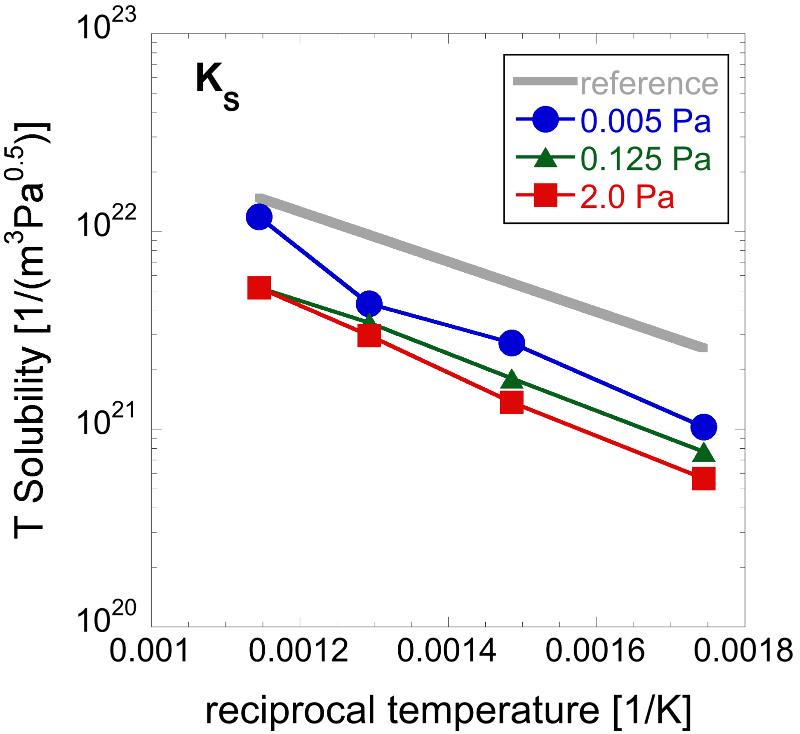
Tritium permeation through (1 mm) α-Fe



- TMAP can reproduce the experimental results well with two fitting parameters

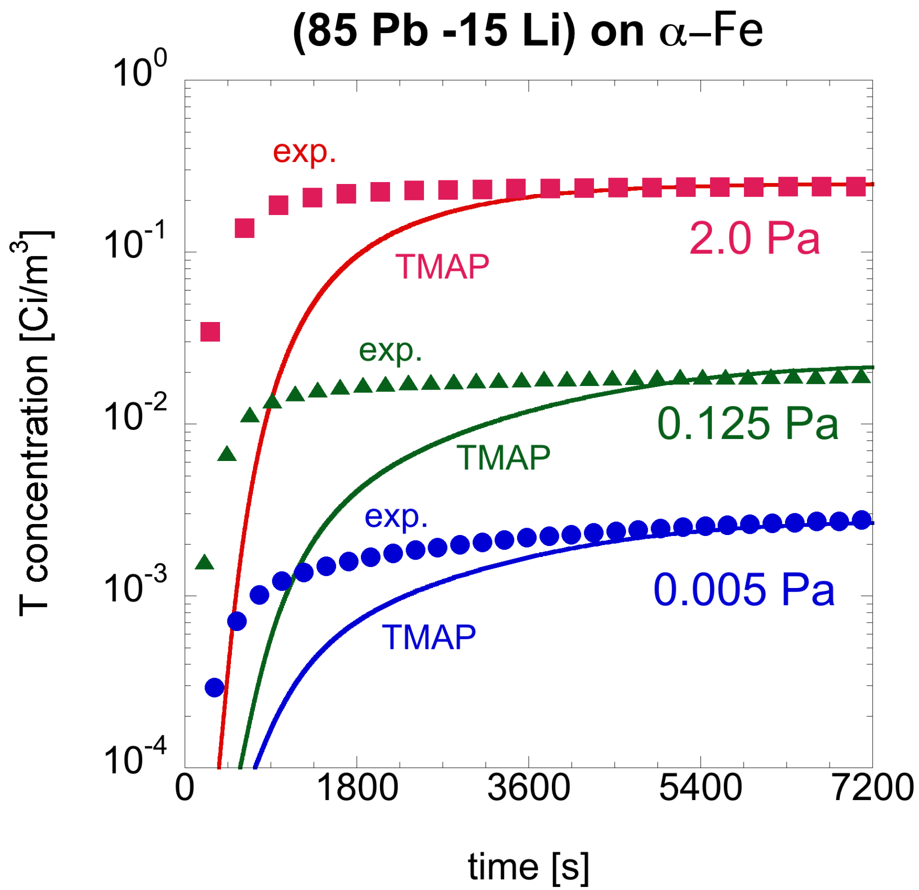
Tritium permeation through (1 mm) α-Fe





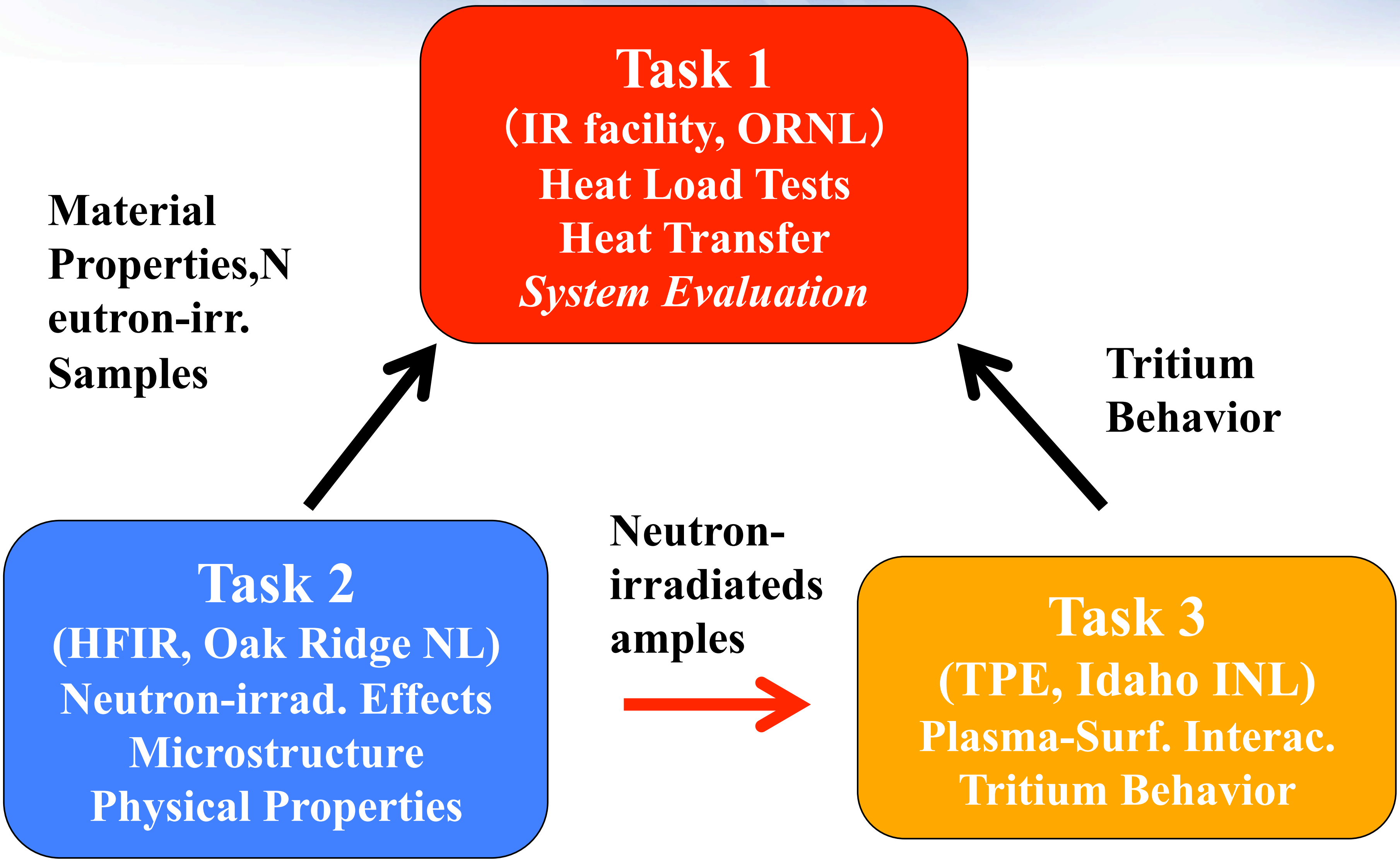
- Tritium diffusivity in α-Fe:
  - Similar to the extrapolation from literature H diffusivity x sqrt(3)
- Tritium solubility in α-Fe:
  - 30-70 % lower than literature data
  - Shows T partial pressure dependence

Tritium permeation through (1 mm) α-Fe + (6 mm) LLE



- Tritium diffusivity in LLE:
  - A factor of 2-3 higher value were needed to fit exp. data
- Tritium solubility in LLE:
  - Similar to literature data

PHENIX project



Alternative facilities with similar capabilities are also acceptable.

Primary facilities (US)

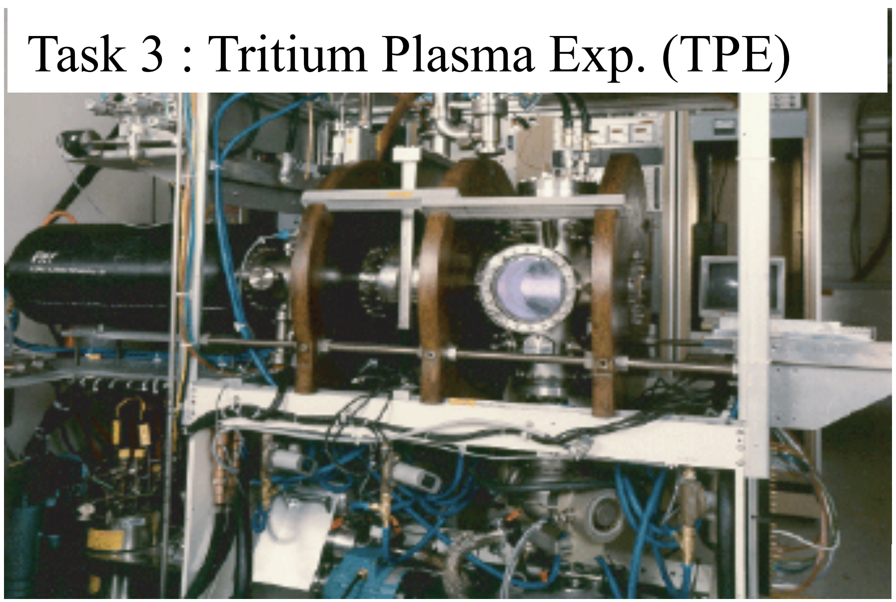
Idaho National Laboratory

Task 1 : IR facility

He loop in GIT is under consideration

Task 2 : HFIR

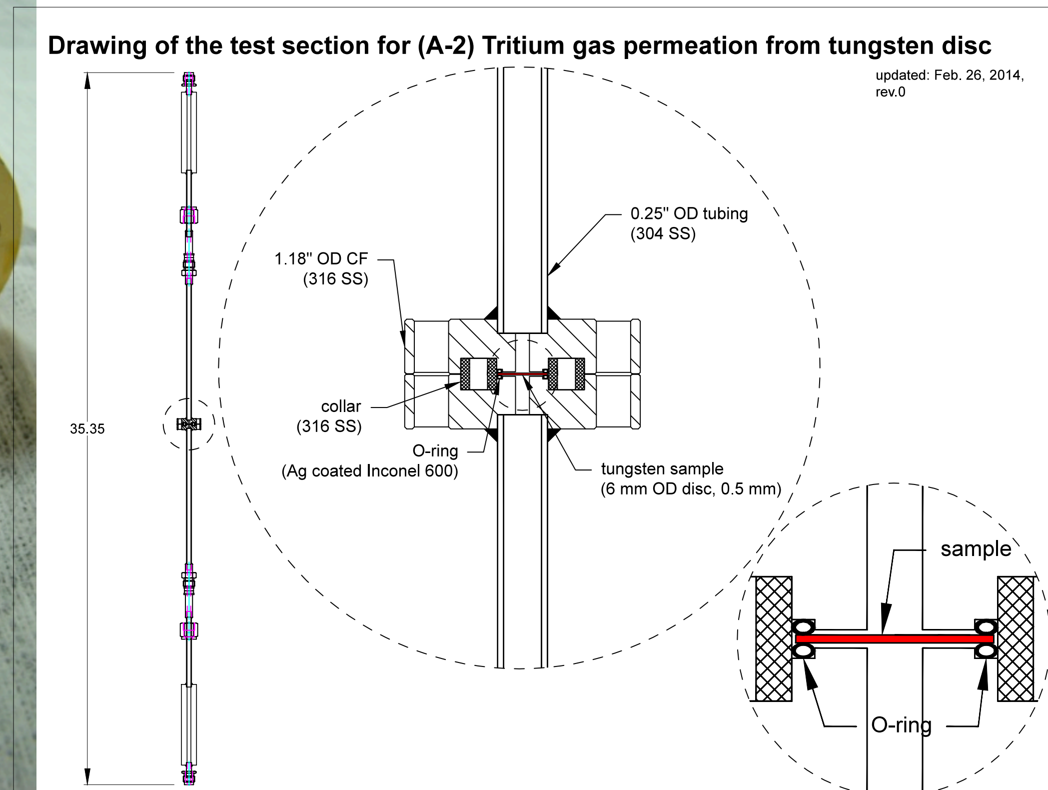
Task 3 : Tritium Plasma Exp. (TPE)



Research at ORNL and INL

Test section for PHENIX 6mm W permeation

- **6 mm OD (non irradiated) tungsten disc**



- Initial test showed anomalous (x10^3 than expected) permeation rate
- Further modification and research is required to feasibility of testing small 6 mm OD tungsten

Summary

- INL started the low partial pressure tritium permeation to obtain tritium permeation rate at realistic fusion and fission reactor conditions.

- We are having some challenges…..
- 1st generation permeation cell: Tritium Heat eXchanger (THX)
  - Tubular sample heated up with induction heater
  - Temperature gradient along test section, measured by 2D IR camera
  - Experimental issues:
    - Tritium depletion along along test section
    - Lack of actual partial pressure of HT, T_2
- 2nd generation permeation cell: Tritium Gas Absorption Permeation (TGAP)
  - Disc sample heated up with tube furance
  - Uniform temperature, measured by 4 thermocouples
  - Experimental issues:
    - Lack of actual partial pressure of HT, T_2
    - Large permeation through O-ring for small 6 mm W sample