

Idaho National Engineering and Environmental Laboratory

IFE Dry Wall Safety and Environmental Issues

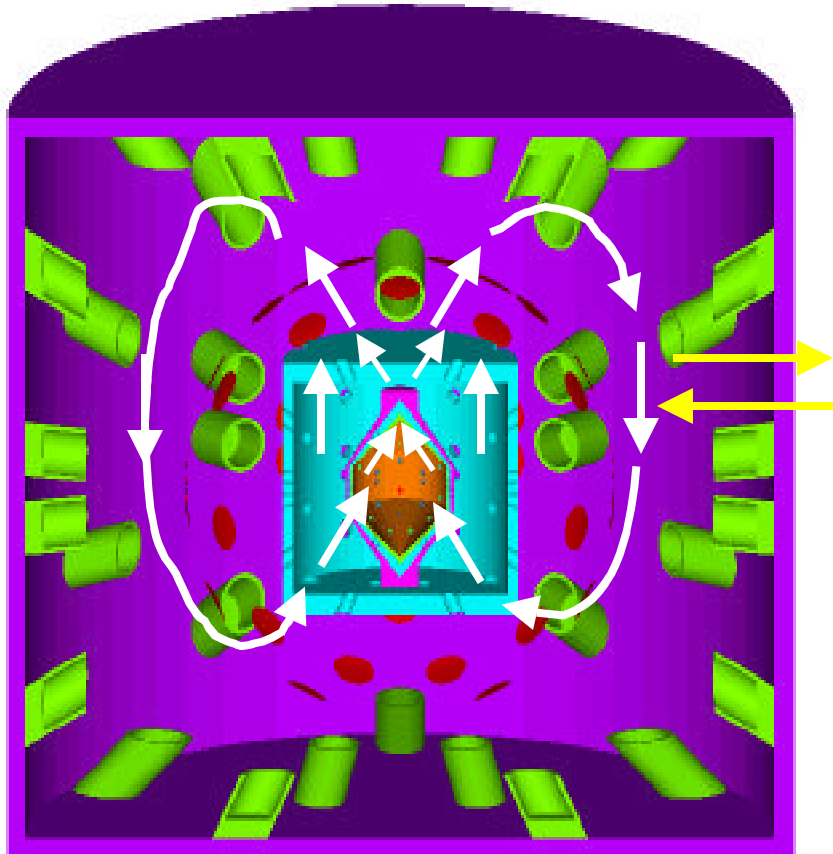
**Dave Petti
Fusion Safety Program
May 31, 2001**



OUTLINE

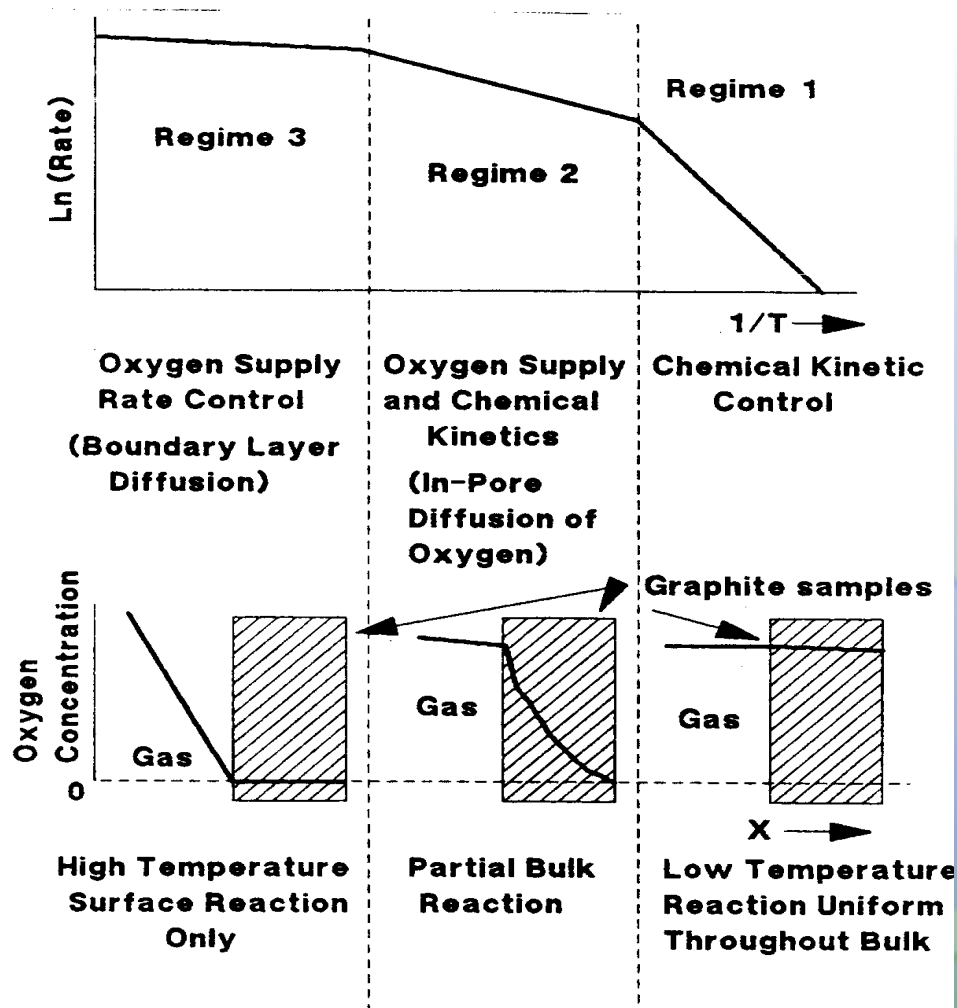
- **Carbon blanket response to loss of vacuum/air ingress**
- **Co-deposition**
- **Radiological Confinement**
- **Chamber Gas Contamination and Activation Issues**
- **Other materials**
 - **W**
 - **Mo**
- **Waste considerations (Volume vs. Hazard)**

Important phenomena in loss of vacuum/air ingress with loss of heat sink



- Air enters vacuum chamber through break (~ 3 hrs to reach 1 atm)
- With only one boundary to breach, the accident begins
- Blanket starts to cool down
- Graphite oxidation begins to produce CO/CO₂. Blanket heats up
- Vessel breaths (based on Japanese LOVA experiments) --> natural convection flow pattern is established --> CO/CO₂ flows out and more air flows in

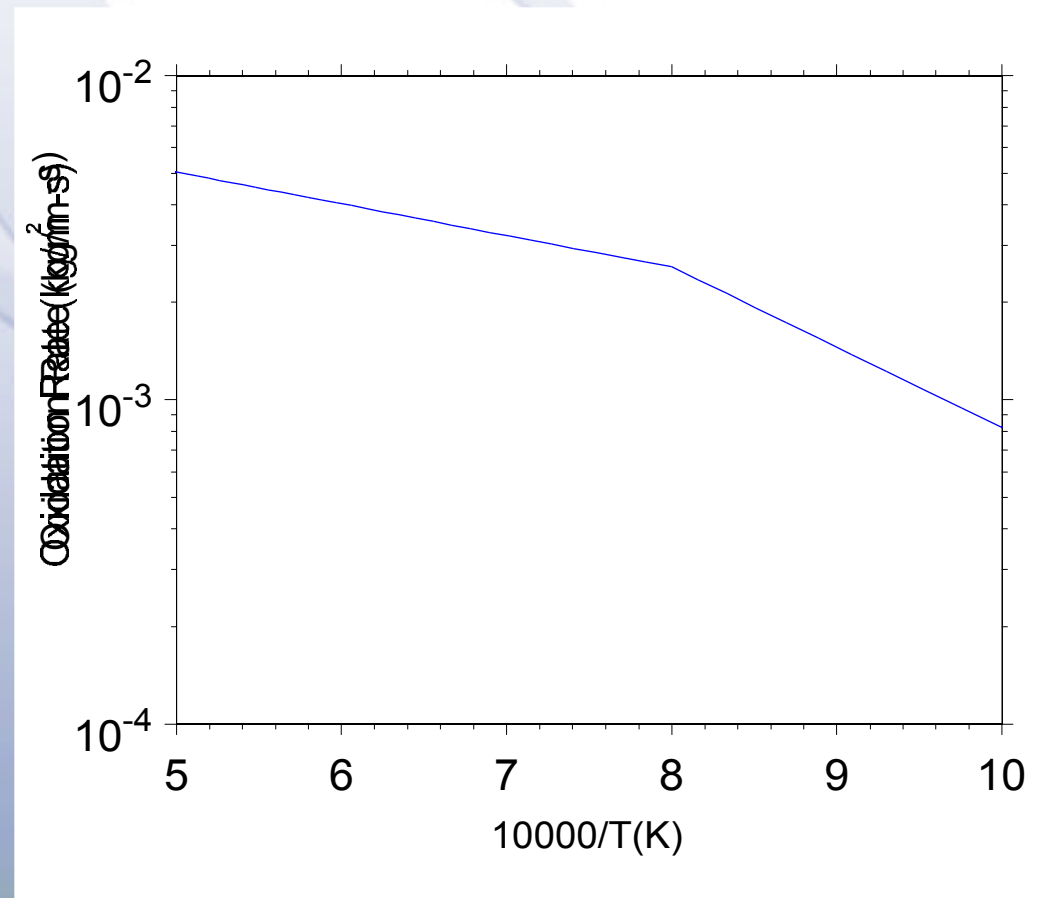
Graphite Oxidation Kinetics



- Experiments at INEEL in 1990
 - Poco graphite
 - bulk Union Carbide graphite
 - C-C composite
- Tests conducted between 800 and 1600°C
- 15 L/min air flow (very low flow)
- Most likely in Regime 2 based on data

Oxidation data used in calculation

- For $T < 1000^{\circ}\text{C}$
 - $R_{\text{OX}} = 0.248 \cdot \text{EXP}(-5710/T) \cdot (\text{PO}_2/0.181\text{E}5)$ [kg/m²-s]
- For $1000 < T < 1800^{\circ}\text{C}$
 - $R_{\text{OX}} = 1.57\text{E}-2 \cdot \text{EXP}(-2260/T) \cdot (\text{PO}_2/0.181\text{E}5)$ [kg/m²-s]
- Flow velocity was 3.5 - 6 m/s. This resulted in a laminar boundary layer. Increasing flow by a factor of 5 resulted in increase in reaction rate by 40%
- Oxidation scales linearly with partial pressure of oxygen in system
- Reaction rates for all 3 types of graphites are quite similar in this temperature range



Codes used and cases examined

MELCOR

- Fully integrated system response tool
- Hydrodynamics of building/vessel
- Conduction, convection and radiation modes of heat transfer for structures
- Oxidation at the surface
- Partial pressure of O₂ influence on reaction rate

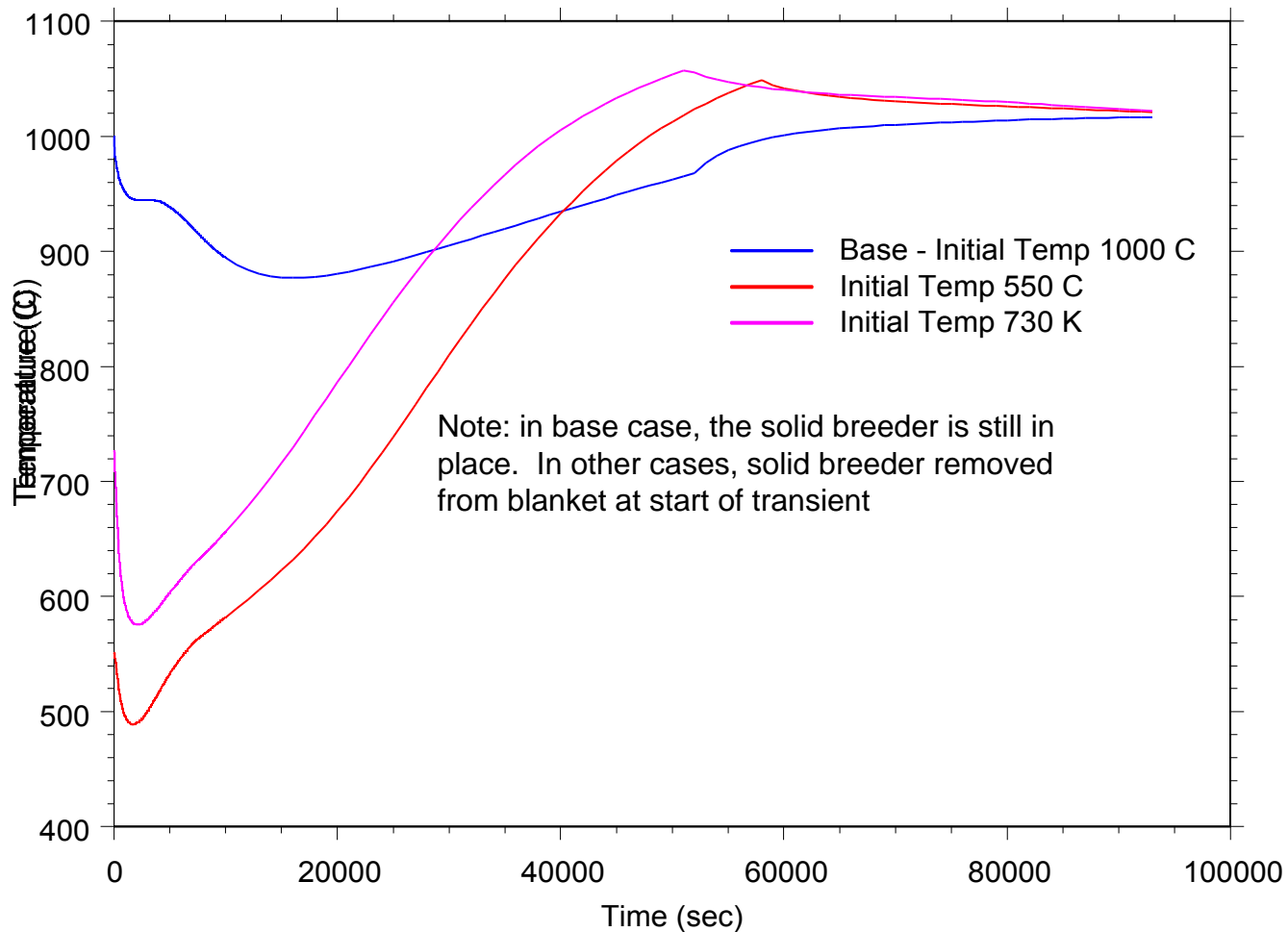
CHEMCON

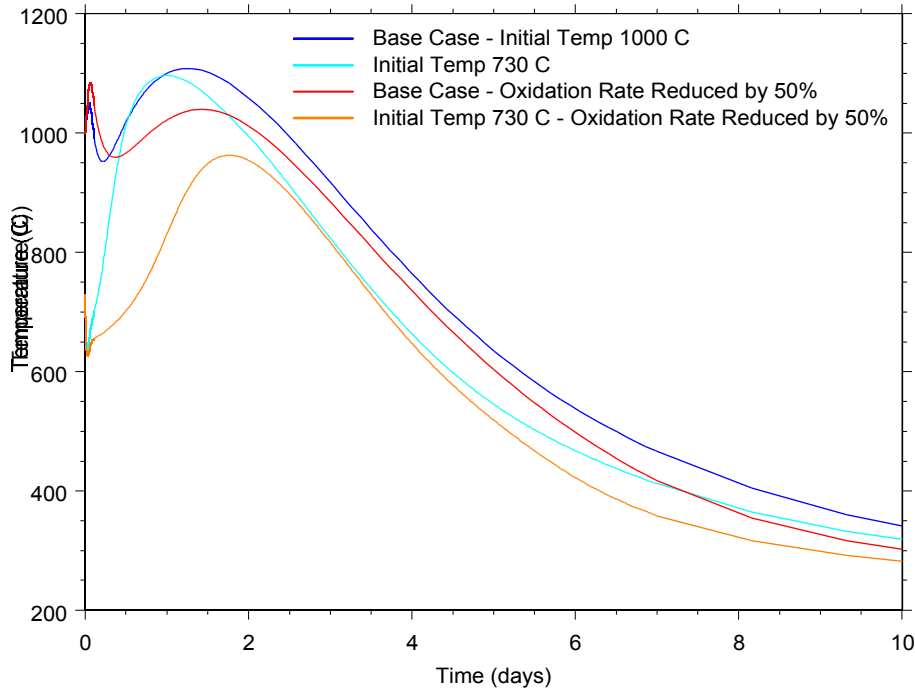
- Same as above but no hydrodynamics

- Failure of one window out of 60 (~ 1 m²)
- Base case performed by LLNL with MELCOR and CHEMICON
- Sensitivity studies with newer version of MELCOR
 - Effect of initial temperature of blanket (cooldown effect) (INEEL)
 - Effect of reaction rate (2 x reduction) (INEEL)
 - Effect of putting non-oxidizing material on back of blanket

Summary of cases: effect of initial temperature of blanket following cooldown

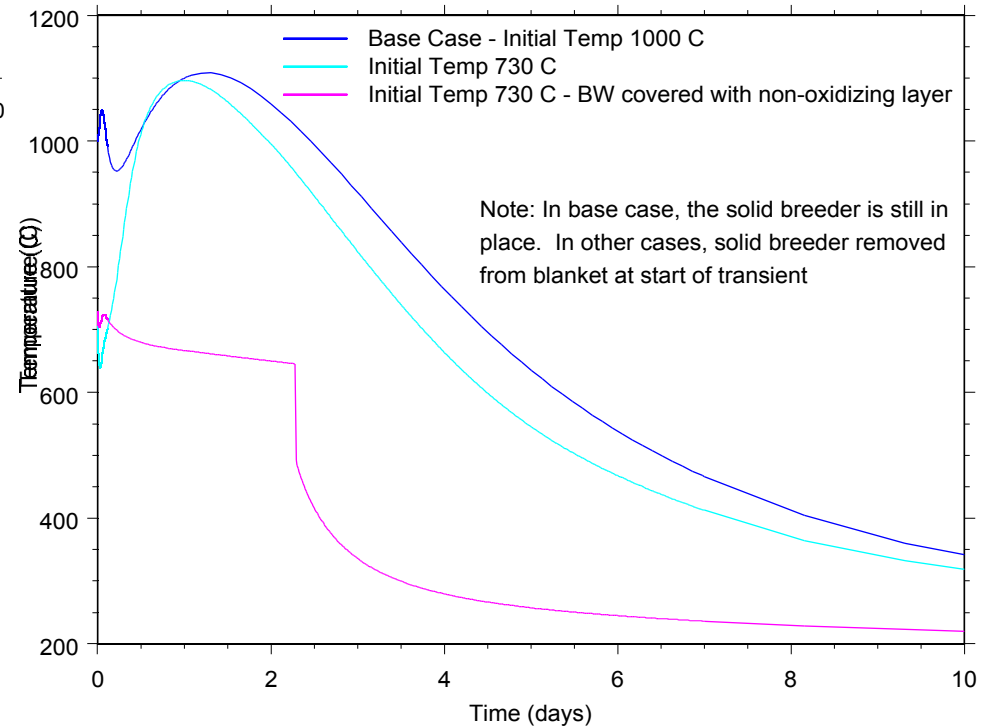
Blanket heat up still occurs





Putting non-oxidizing material on back of blanket will mitigate the overall course of the accident

Cutting the reaction rate in half drops the peak temperature between 75 and 150°C at lower rates.



Co-deposition in IFE systems

(based on concensus at recent ARIES tritium town meeting)

- **Formation of C-T films in cooler regions of the system (vacuum ducts, penetrations etc)**
- **Carbon erosion/ablation from FW is a source of C in the plasma**
- **Plastic coating of the target is a source of C in the plasma**
- **Large inventories can build up very quickly (in excess of 1 kg tritium)**
- **No effective removal method yet identified except heating in air which can cause collateral damage to the graphitic walls**

Radiological Confinement

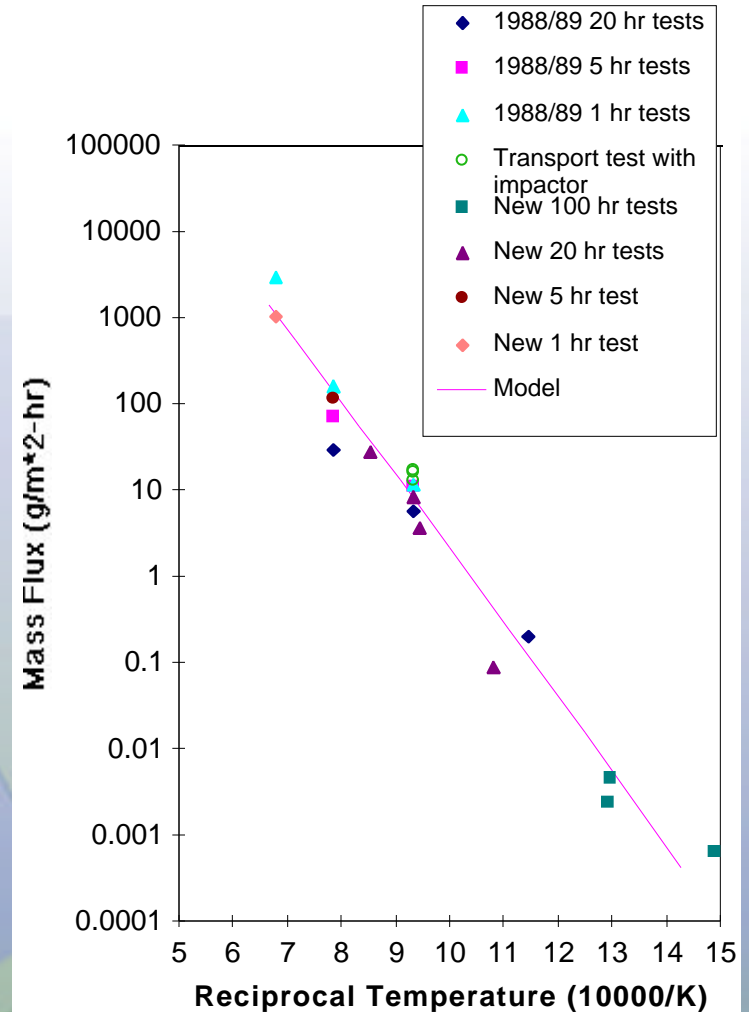
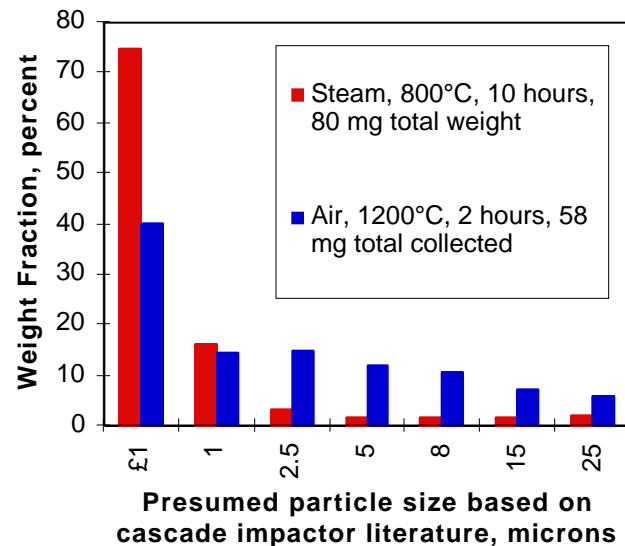
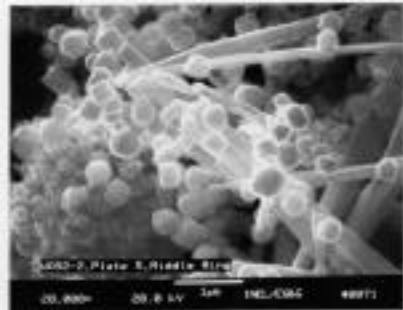
- **Confinement buildings have been used in previous IFE studies as a strong barrier**
- **There are concerns with this approach related to testing of the boundary for the appropriate leak rate**
- **The large size of the building (900,000 m³) could make testing even a moderate leak-rate building a costly operational burden. This building is 15 times the size of a PWR containment!**
- **Use of the building to get the needed confinement goes against conventional safety wisdom of confining the hazard as close to its source as possible**

Radiological Contamination

- **Tritium contamination up the beam lines in an IFE power plant is expected**
 - **Can the beam lines be enclosed?**
- **The contamination “boundary” could be quite large and impede worker activities at the facility**
- **The activated gases in the chamber will produce condensable fission products (Cs from Xe and I from Kr) that will plateout on cooler surfaces and cause fixed contamination.**
 - **How will maintenance of the vacuum pumps and other in-vessel systems be performed?**

W alloy safety concerns

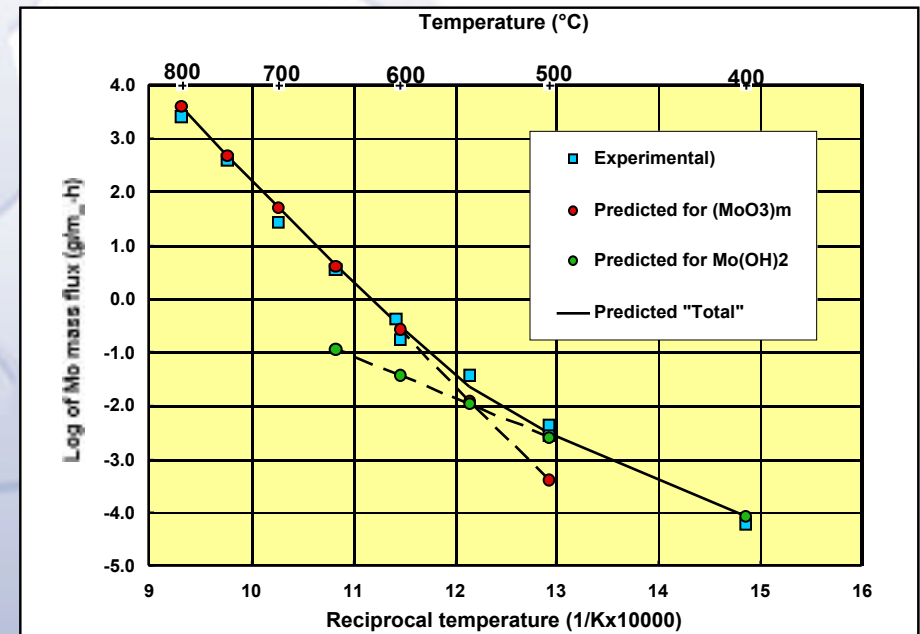
- Volatilization in steam leads to $WO_3 \cdot H_2O$ which is quite volatile
- Significant mobilization is observed as fine particulate
- High decay heat and high activation (can be managed)



Mo alloy safety and environmental concerns

- Volatilization of Mo in air produces volatile MoO_3
- MoO_3 melts at 800°C
- Irradiation of Mo produces Tc^{99} , which is a long-lived radionuclide that results in the production of long-lived waste

Mobilization and Modeling Results



TZM samples after exposure


700°C/2 hrs/0.5 l/min air 800°C/1 hrs/1 l/min air



Deposition profile along tube in 700°C test

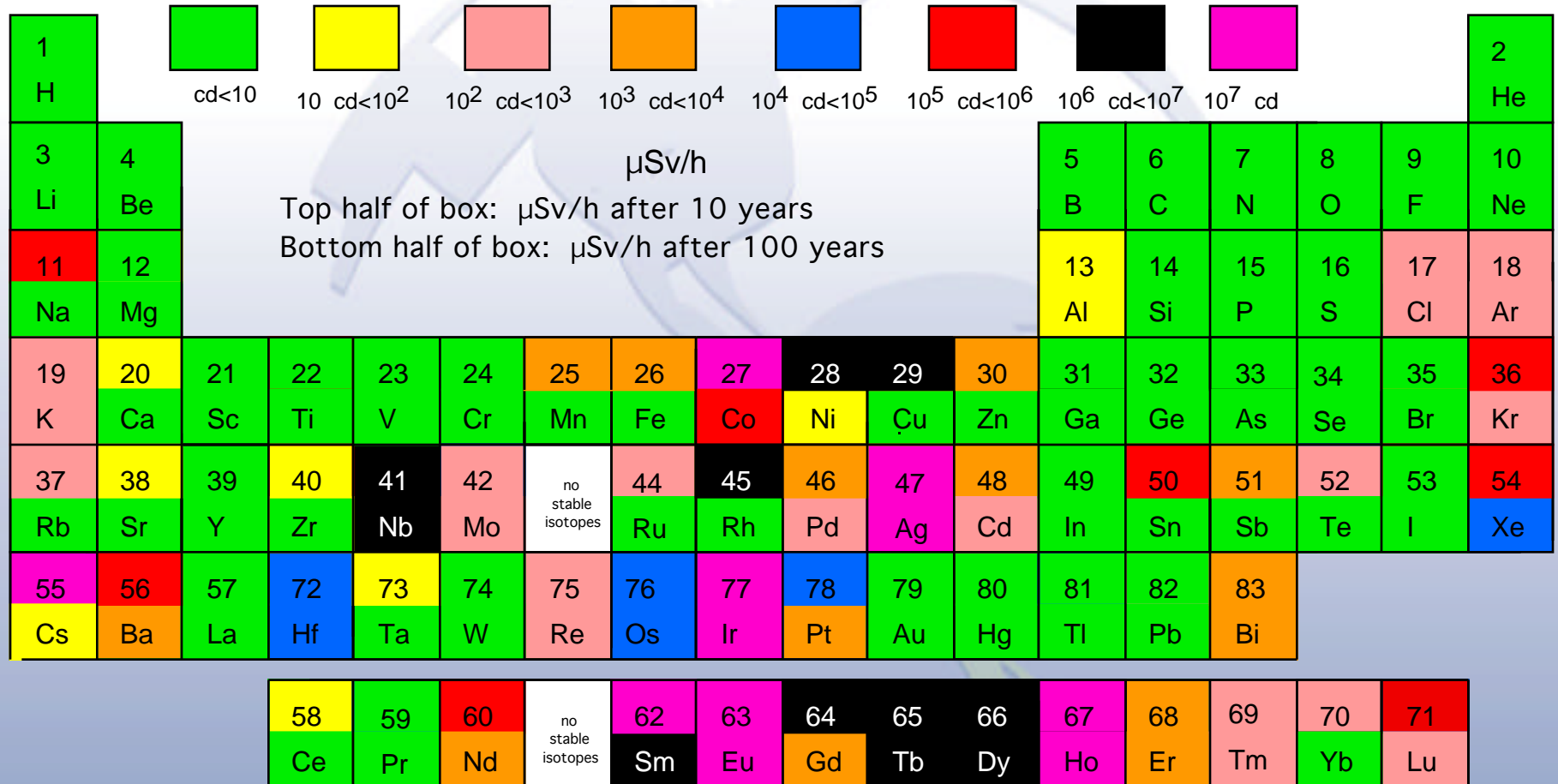


Limits on Elements for Class C Waste Qualification

| | | | | | | | | | | | | | | | | |
|----------|--|---|----------|----------|--------------------|--------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 1 H |  | | | | | | | | | | | | | | | |
| 3 Li | 4 Be | Top half of box: hard spectrum Bottom half of box: soft spectrum | | | | | | | | | | 5 B | 6 C | 7 N | 8 O | 9 F |
| 11 Na | 12 Mg | | | | | | | | | | | 13 Al | 14 Si | 15 P | 16 S | 17 Cl |
| 19 K | 20 Ca | 21 Sc | 22 Ti | 23 V | 24 Cr | 25 Mn | 26 Fe | 27 Co | 28 Ni | 29 Cu | 30 Zn | 31 Ga | 32 Ge | 33 As | 34 Se | 35 Br |
| 37 Rb | 38 Sr | 39 Y | 40 Zr | 41 Nb | 42 Mo | no stable isotopes | 44 Ru | 45 Rh | 46 Pd | 47 Ag | 48 Cd | 49 In | 50 Sn | 51 Sb | 52 Te | 53 I |
| 55 Cs | 56 Ba | 57 La | 72 Hf | 73 Ta | 74 W | 75 Re | 76 Os | 77 Ir | 78 Pt | 79 Au | 80 Hg | 81 Tl | 82 Pb | 83 Bi | | |
| | | 58 Ce | 59 Pr | 60 Nd | no stable isotopes | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu | |

From: Piet, et al., "Initial Integration of Accident Safety, Waste Management, Recycling, Effluent, and Maintenance Considerations for Low-Activation Materials", **Fusion Technology**, Vol. 19, Jan. 1991, pp. 146-161. Assumes 5 MW/m² for 4 years; and E. T. Cheng, "Concentration Limits of Natural Elements in Low Activation Materials", **presented at ICFRM-8, Sendai, Japan, October 1997**

Contact Dose at Shield After 10 and 100 Years



Based on C. B. A. Forty, et al., Handbook of Fusion Activation Data; Part 1. Elements Hydrogen to Zirconium, AEA FUS 180, May, 1992. Assumes 4.15 MW/m² for 25 years

Summary/Recommendations

- **In this continuing chamber design work, it is important to integrate current safety requirements, state of the art safety tools, and the most recent safety-relevant data in the design/material selection process**
- **Given the larger inventory of tritium in the system than estimated in the design study 10 years ago, better confinement is needed in dry wall systems to reduce probability of air ingress**
 - **Beam tubes should be considered. Shutters might also help. These would help the design implement double confinement**

Summary/Recommendations

- **Contamination control in the 900,000 m³ building is a serious safety concern both in terms of tritium and activation products of the gas in the chamber**
 - **Beam tubes could help deal with contamination and Xe activation, and mitigate concerns about dust/debris**
 - **Also beamtubes could reduce concerns during personnel maintenance in the target bay**
- **Can the blanket be redesigned to reduce the inlet temperature to 400°C, which might also reduce the consequences of air ingress?**
- **Other materials under consideration have safety and environmental issues. These can be addressed by safety and design engineers working together**