Idaho National Engineering and Environmental Laboratory

Update on IFE Safety Work for ARIES

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ARIES e-meeting
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Several safety issues for IFE designs are being studied

- *Target fabrication safety and reliability issues*
- *Risk assessment accident-initiating events*
- *Coolant hazards (Sn, Pb, Sn-25Li)*
  - *Chemical reactivity*
  - *Chemical toxicity*
  - *Radiological hazards*
- *Aerosol considerations for chamber clearing*

Manufacturing industry input for IFE target fabrication

- *INEEL and GA personnel visited Micron Technology (Boise, ID) on July 18 to gather information about manufacturing processes for precision, high quality, large scale production.*
- *Highlights of the Micron facility:*
  - *produces on the order of 400,000 chips/day*
  - *clean room facilities are large and expensive (i.e., \$3k/foot^2).*
  - *1.5 mile tour to visit the manufacturing stations*
- *Micron staff members were enthused about potential collaboration(s) to support IFE target manufacture.*

Industry input on manufacturing quality assurance

- Quality Assurance data about the Micron facilities:
  - an initial production run may have 50% defects, while a mature run has less than 10% defects.
  - batches from an initial production run are tested up to 130 hrs while mature runs are tested up to 10 hrs.
  - an estimated four to five “end user product” returns per million units distributed.
  - facility support services are tightly controlled to maintain manufacturing quality.
  - electrostatic suppression and discharge are very important for maintaining high-quality production.

Accident initiating events are being compiled for IFE designs

- *Current initiator work is focused on the SOMBRERO design.*
  - *SOMBRERO is representative of dry wall, laser driver IFE design concepts*
- *A master logic diagram (MLD) for SOMBRERO has been drafted and is under review. The MLD is a plant-level fault tree of potential hazardous releases.*
- *An MLD for the HYLIFE II plant design has been initiated and will be completed later this year.*
  - *HYLIFE II is representative of liquid wall, ion beam driver IFE design concepts*

Coolant hazards: chemical reactivity

- *Queries of the HSC chemistry database program show:*
  - *molten Pb, Sn, and Sn-25Li exothermically react with air and potentially result in limited aerosol generation;*
  - *liquid Sn exothermically forms SnO_2 in abundant air or SnO in limited air;*
  - *at low temperatures (150 to 550°C), liquid Pb in air exothermically forms gaseous Pb_2O_3. Above 550°C, the gas dissociates into PbO gas and PbO_2. The PbO_2 will potentially form aerosol;*
- *Li and Sn individually react in air to form chemically toxic species, thus the same behavior is anticipated for Sn-25Li in air.*

Coolant hazards: chemical reactivity (cont)

- *Li dehydrates concrete: reaction rates are low in the 200°C range and increase in the 400°C range.*
- *In the 400 °C range, other liquid metals will also dehydrate concrete. Thus safety design provisions are required.*
- *Li reacts in air to form Li_2O and generate 3-10$\%_{wt}$ respir-able aerosol. LiOH aerosol is also formed if water vapor is present in the air (HEDL TME 80-79; HEDL TME 85-25)*
- *Molten Pb-Li and Sn-Li will react with water to release hydrogen gas (M. H. Anderson, 14th TOFE).*

Coolant hazards: chemical toxicity

- *Li, Pb, Sn, and Sn-25Li have un-irradiated chemical safety concerns.*
- *DOE has established Temporary Emergency Exposure Levels (TEELs) for aerosol inhalation of chemical substances by the general public.*
- *The DOE-Idaho Operations Office recommends TEEL-2 as a prudent 1-hour maximum exposure level for public safety.*
- *DOE-HQ has not yet released guidance on exposure levels for chemical releases in energy research.*

TEELs for candidate IFE coolants

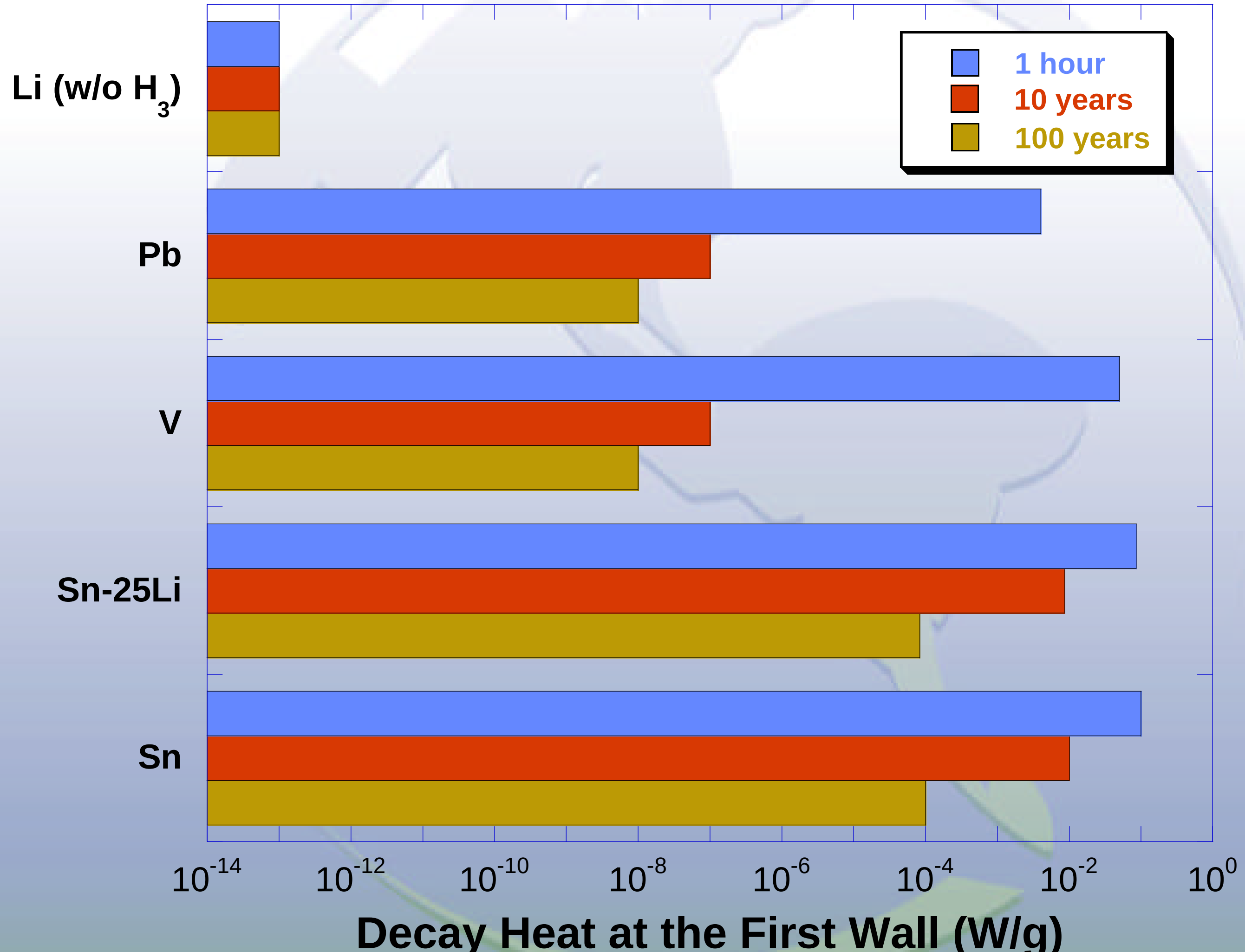
Material	TEEL-0 (mg/m^3)	TEEL-1 (mg/m^3)	TEEL-2 (mg/m^3)	TEEL-3 (mg/m^3)
Tin (Sn)	2	6	10	100
Tin oxide (SnO)	2	6	10	100
Lithium (Li)	10	30	50	500
Lithium oxide (Li_2O)	--	--	AIHA cites 1 mg/m^3 for workers = TEEL-2	--
Lithium hydroxide (LiOH)	0.05	0.15	1	100
Lead (Pb)	0.05	0.15	0.25	100
Lead oxides (PbO and PbO_2)	0.05	0.05	0.05	100
TEEL Level Health Effects	no health effects	mild, transient effects	serious, transient effects	life can be threatened past 1 hour exposure

note: TEELs are from report WSMS-SAE-00-0266, revision 17m, January 2001. See also WSRC-TR-98-00080, "Methodology for Deriving TEELs," April 1998.

Coolant hazards: radiological concerns

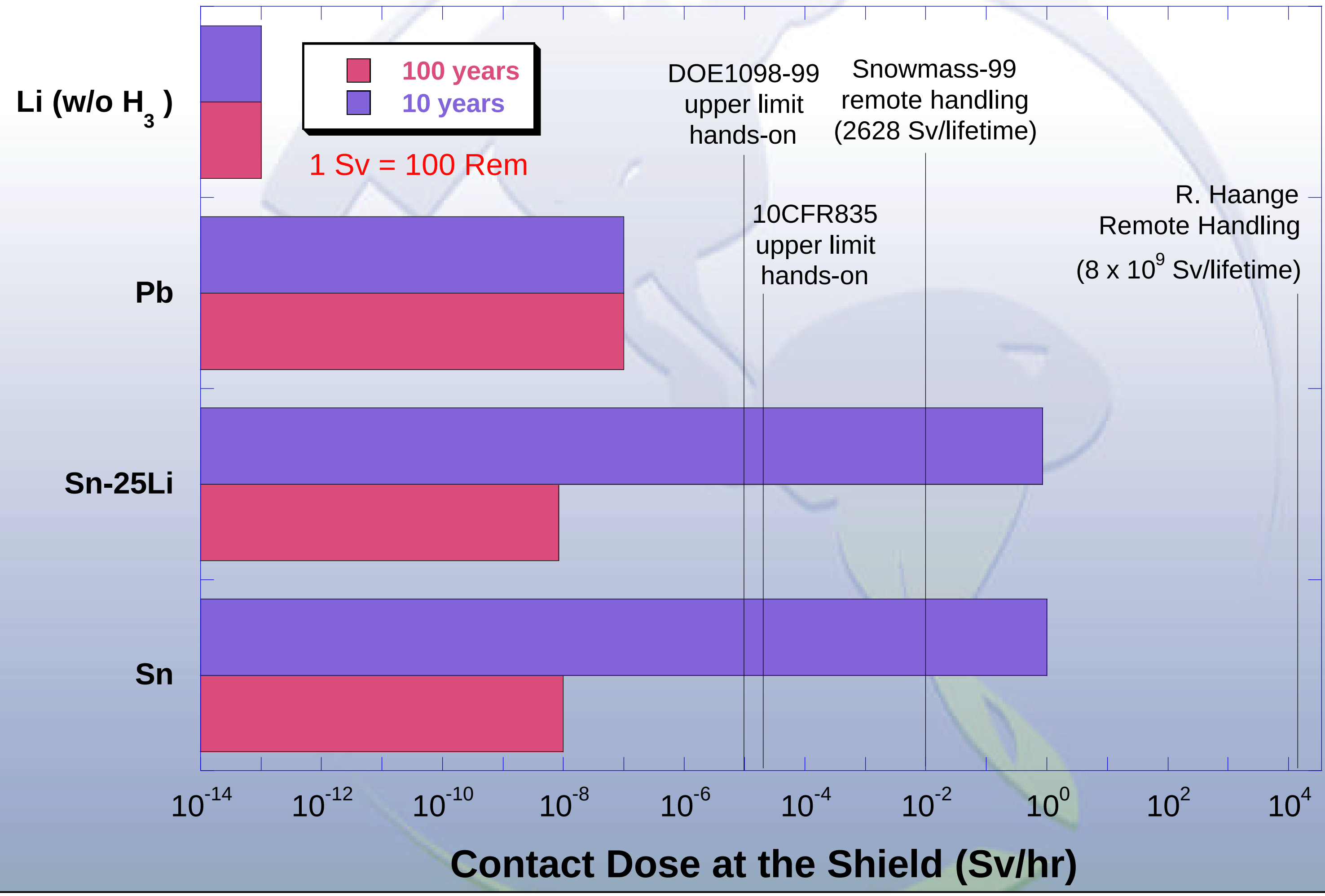
- *A radiological-based analysis of the coolants focused on five factors:*
  - *<u>Decay heat generation</u>: influences accident response*
  - *<u>Contact dose (gamma)</u>: influences worker safety and maintenance*
  - *<u>Vapor pressure</u>: volatility under air in steam ingress condition*
  - *<u>Radiotoxicity</u>: identifies the isotopes whose activity levels produce radiation concerns*
  - *<u>Class C waste</u>: identifies materials that can meet the low level waste criteria*

Decay heat comparison



From: C.B.A. Forty et. al., Handbook of Fusion Activation Data, Part 1, AEA FUS 180, May 1992 and Part 2, AEA FUS 232, May 1993, AEA Technology Fusion, Culham Laboratory, Abingdon, Oxon.

Contact dose (gamma) comparison



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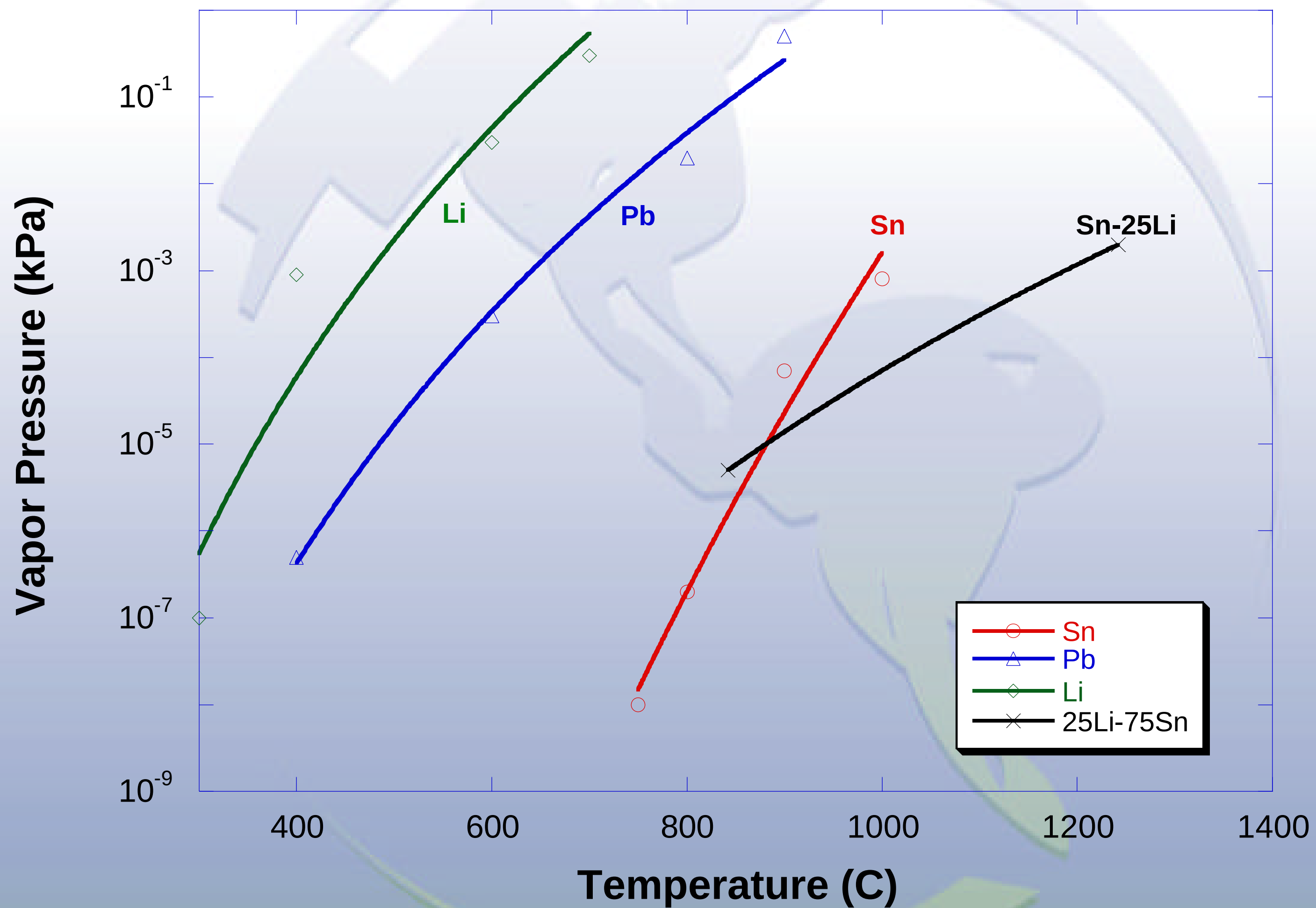
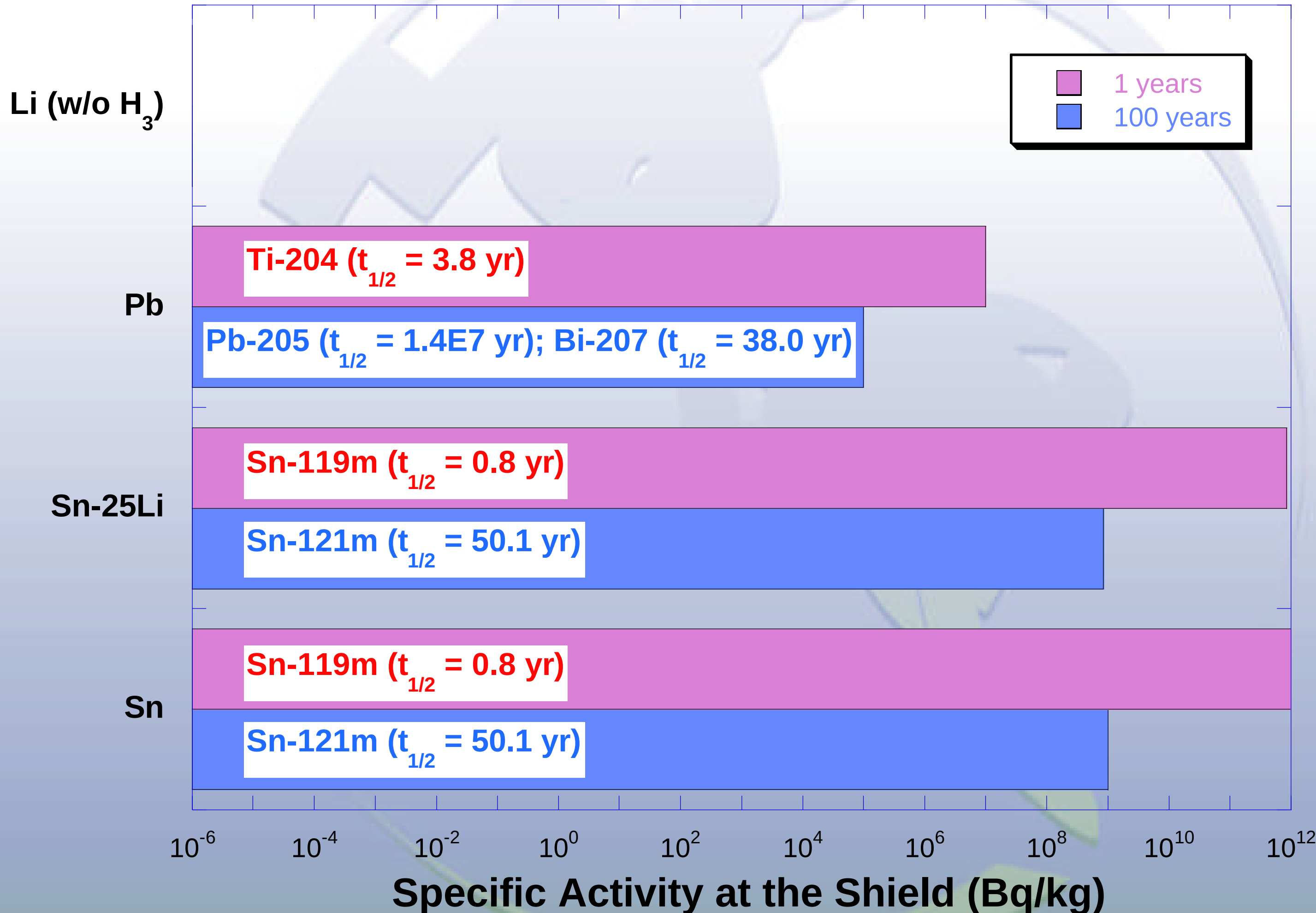
Vapor pressure comparison



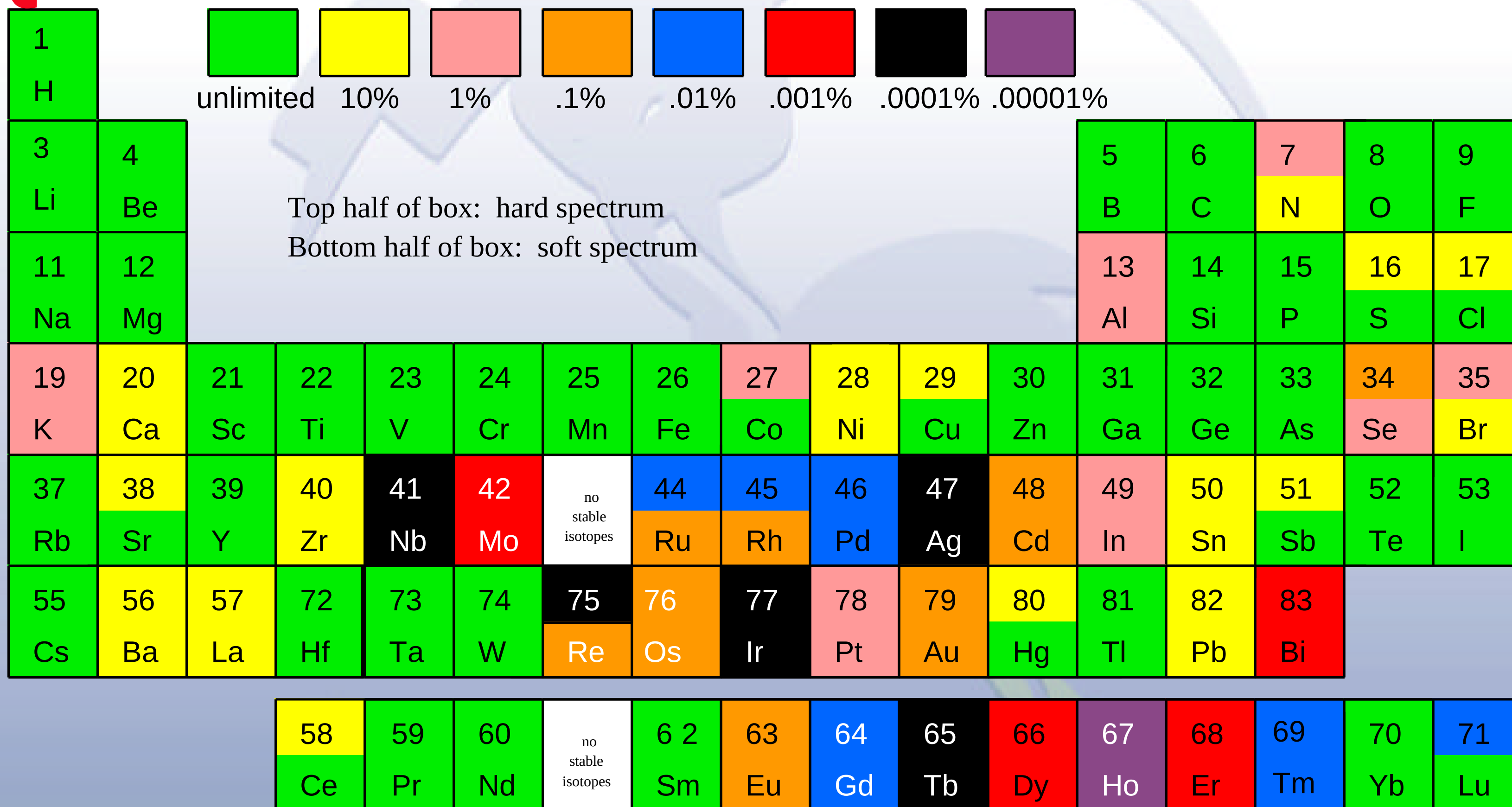
From: The Characterization of High-Temperature Vapors, edited by J.L. Margrave, John Wiley & Sons, Inc. 1967. Sn-25Li data from R.A. Anderl et al., “Vaporization Properties of Sn-25at%Li Alloy,” Proceedings of the 10th International Conference on Fusion Reactor Materials, October 14-19, 2001, Baden-Baden, Germany.

Radiotoxicity of Liquid Metals



From: C.B.A. Forty et. al., Handbook of Fusion Activation Data, Part 1, AEA FUS 180, May 1992 and Part 2, AEA FUS 232, May 1993, AEA Technology Fusion, Culham Laboratory, Abingdon, Oxon.

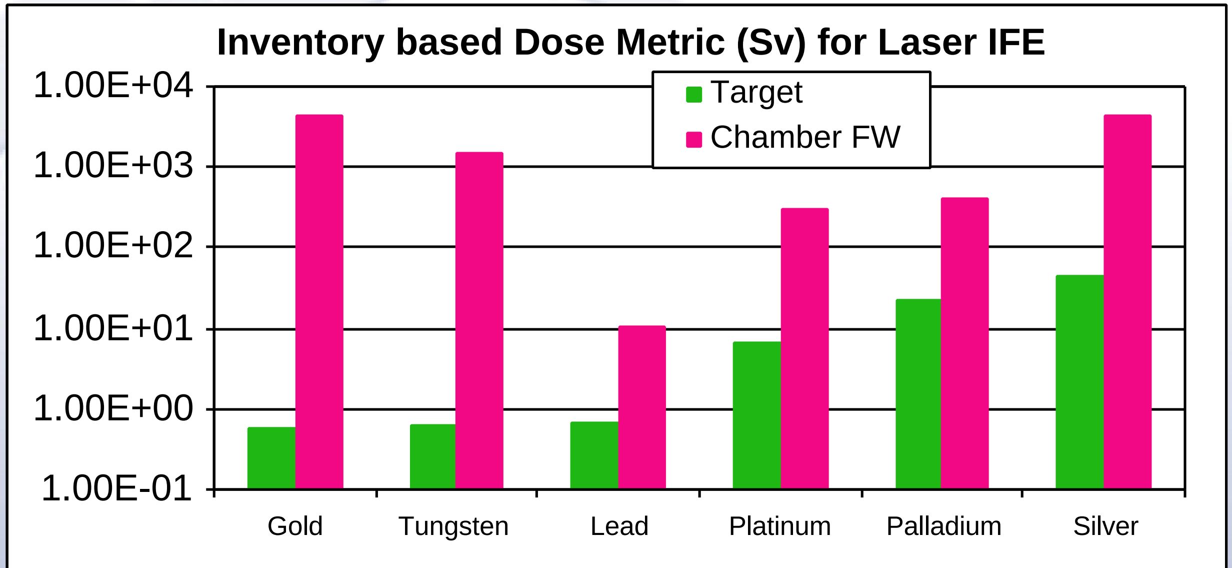
Limits on Elements for Class C Waste Qualification

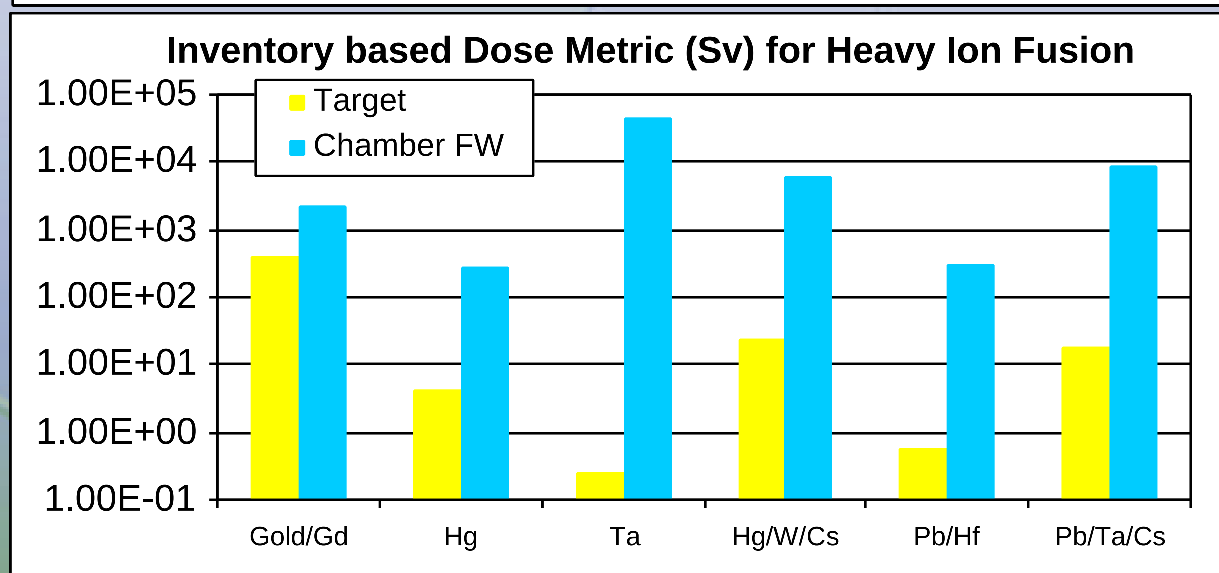


From: S.J. Piet, et al., "Initial Integration of Accident Safety, Waste Management, Recycling, Effluent, and Maintenance Considerations for Low-Activation Materials", **Fusion Technology**, Vol. 19, Jan. 1991, pp. 146-161. Assumes 5 MW/m^2 for 4 years; and E. T. Cheng, "Concentration Limits of Natural Elements in Low Activation Materials", **presented at ICFRM-8, Sendai, Japan,October 1997**

Inventory-based radiotoxicity

Metric(Sv) =
S [Inventory (Ci)* Radiotoxicity (Sv/Ci)]





Aerosol considerations for chamber clearing

- *Issues of aerosol generation and transport*
  - *Aerosol conservation model*
  - *Representative nucleation and growth rates*
  - *Particle transport*
  - *Particle deposition*
- *Future work*

Aerosol conservation model

- *Evolution of the aerosol size distribution is governed by the aerosol General Dynamic Equation (GDE):*

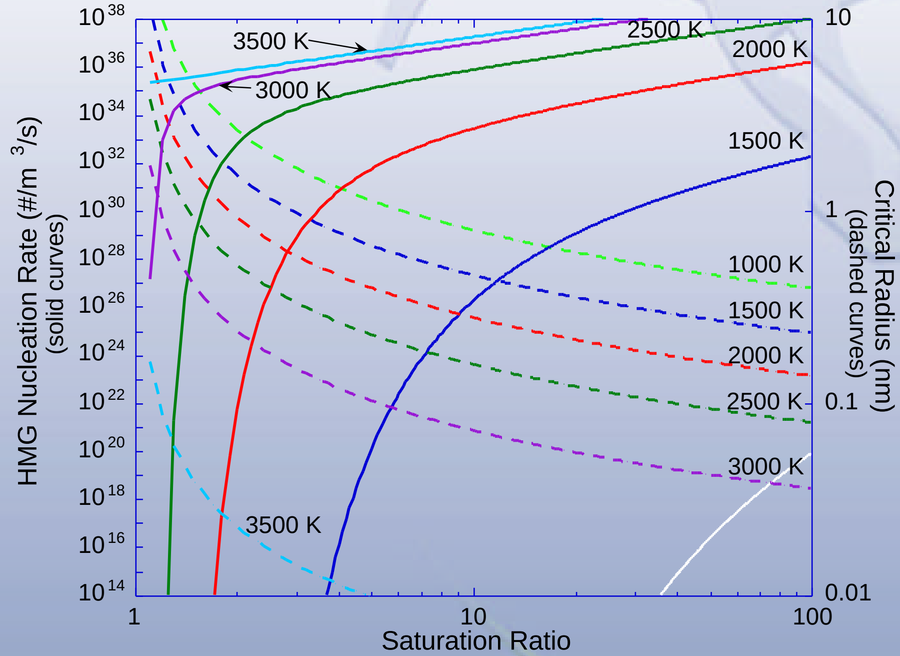
$$\underbrace{\frac{\partial n}{\partial t} + \nabla\cdot(n\vec{n}) - \nabla\cdot(D\nabla n) + \nabla\cdot\vec{c}n}_{\textbf{Convective Diffusion and Transport}} = \underbrace{\left[\frac{\partial n}{\partial t}\right]_{growth,\ \mathbf{homo}} + \left[\frac{\partial n}{\partial t}\right]_{growth,\ \mathbf{hetro}} + \left[\frac{\partial n}{\partial t}\right]_{\mathbf{coag}}}_{\textbf{Particle Growth and Coagulation}}$$

- *This equation demonstrates aerosol particle conservation, where n is the number of particles per unit particle volume per unit gas volume.*

Homogeneous nucleation rate of Pb:

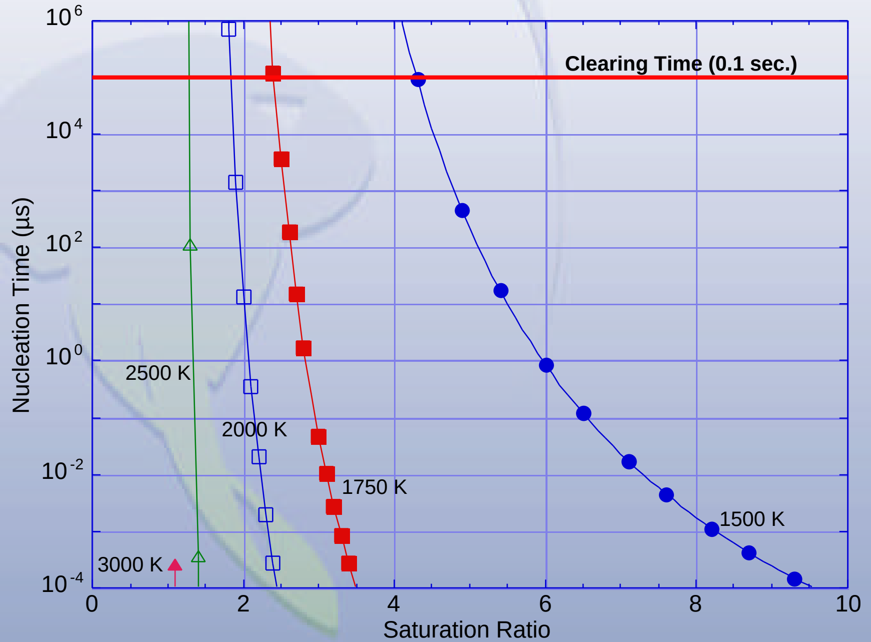
Nucleation rate and critical radius of Pb at various saturation temperatures

(these saturation ratios are comparable to those achievable in cloud chambers)



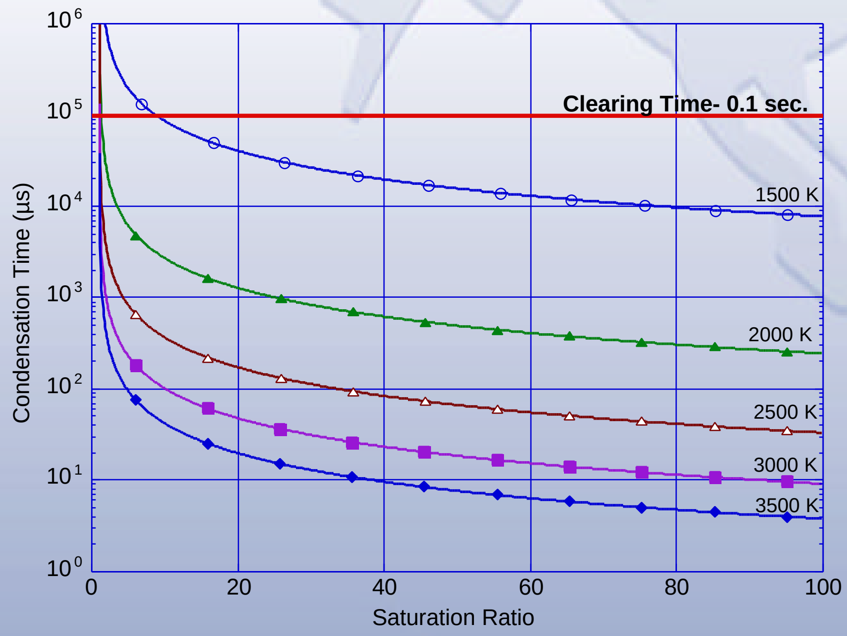
Time required to form 10^{15} Pb particles/m^3

(where coagulation becomes increasingly important)

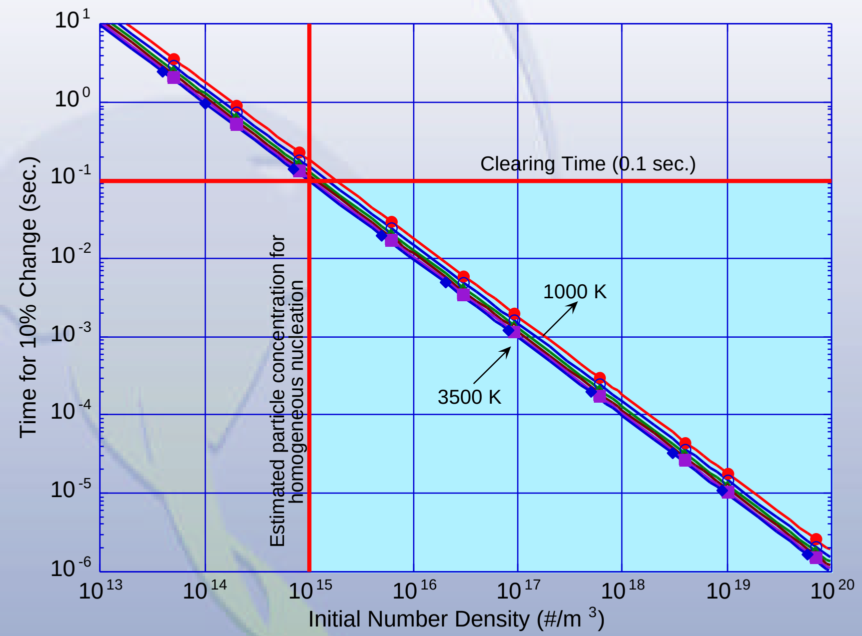


Heterogeneous growth and coagulation rate of Pb:

Time needed for particles in saturated vapor to increase volume by 10%



Time required for 1 μm dust particles to change total number by 10%

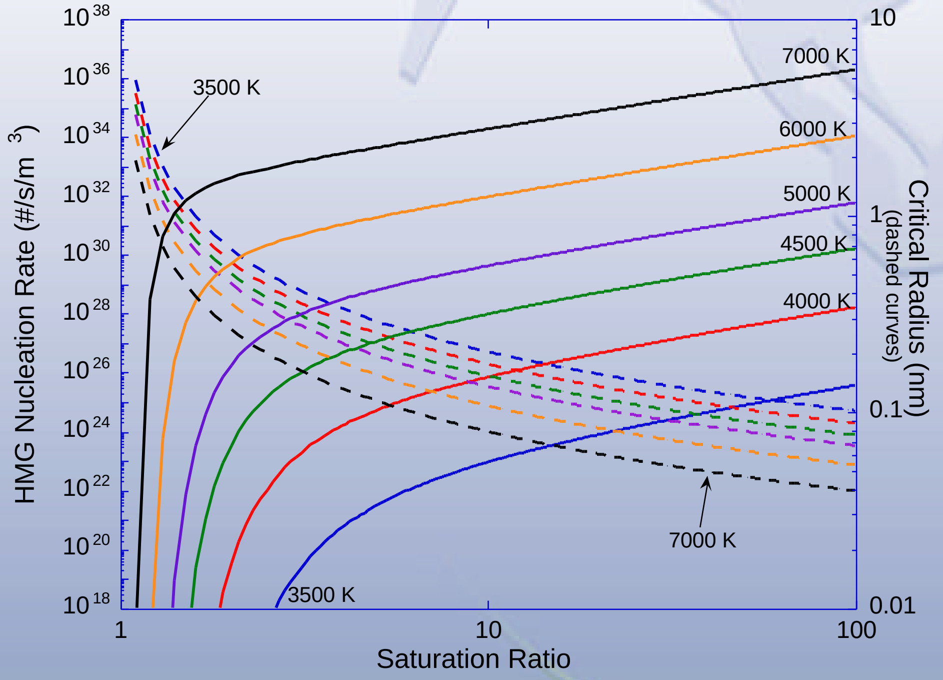


- *Dust particle concentrations generated from homogeneous nucleation are sufficiently large so that particle growth and coagulation occur faster than chamber clearing times*

Homogeneous nucleation rate of W:

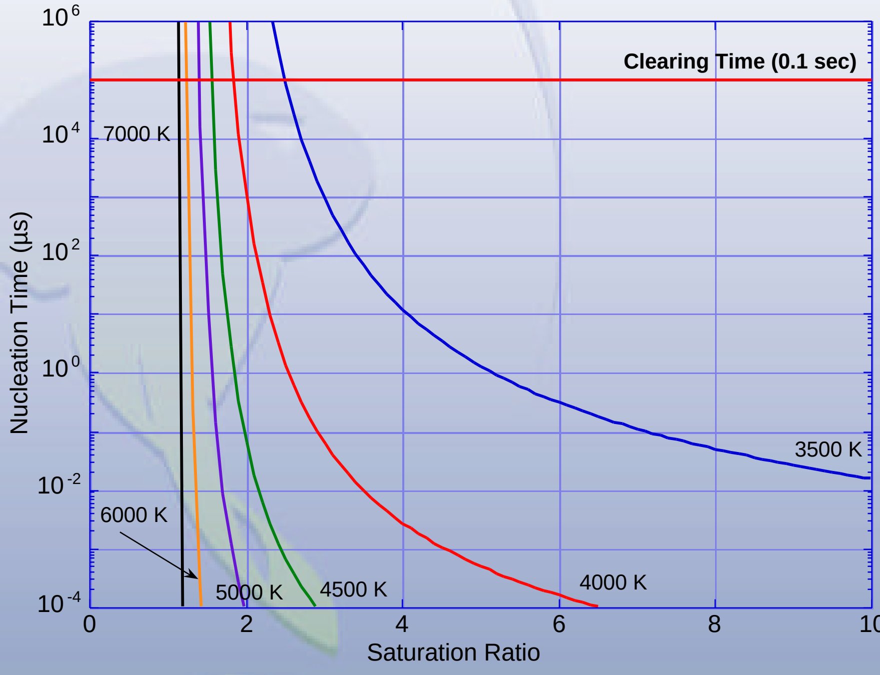
Nucleation rate and critical radius of W at various saturation temperatures

(these saturation ratios are comparable to those achievable in cloud chambers)



Time required to form 10^{15} W particles/m^3

(where coagulation becomes increasingly important)



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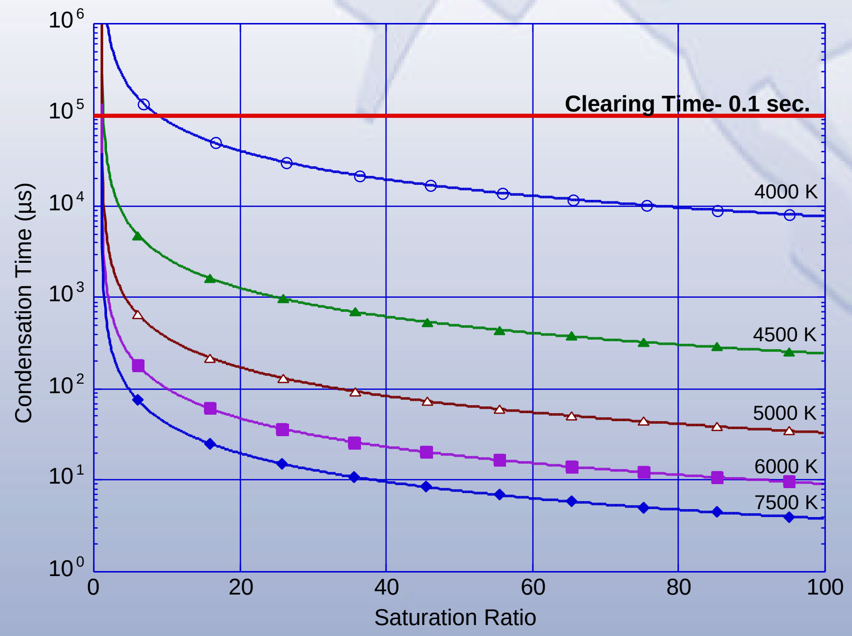

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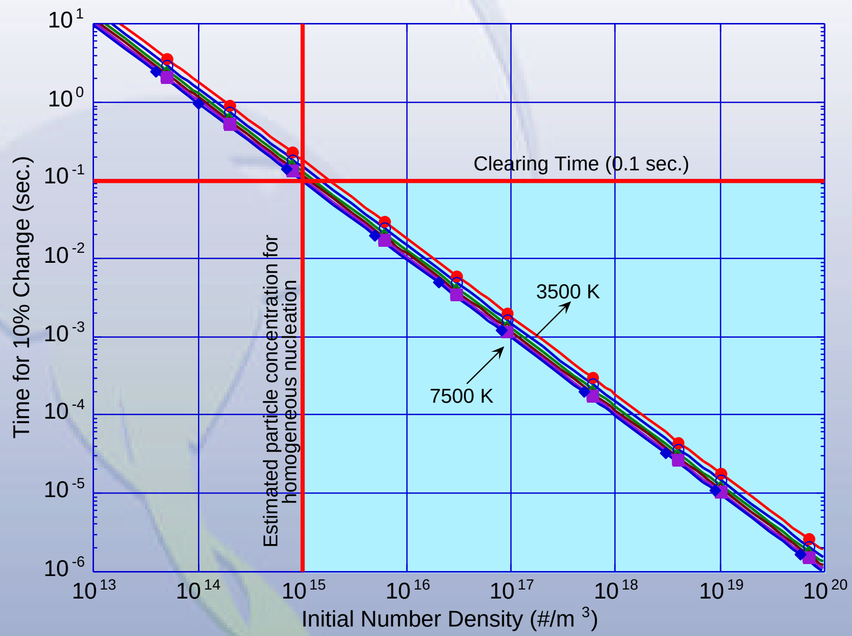

- *Dust particle concentrations generated from homogeneous nucleation are sufficiently large so that particle growth and coagulation occur faster than chamber clearing times*

Convective diffusion and transport

$$\partial n / \partial t + \nabla \bullet (n\vec{v}) - \nabla \bullet (D \nabla n) + \nabla \bullet \vec{c} n$$

- *The diffusive transport time constant is* $t_{diff} = \frac{L^2}{D}$
- *for a characteristic gradient length L = 1 cm and D ~ 10^{-5} m^2/s, t_{diff} = 10 s. This value decreases when particle slip is considered.*
- *Migration velocities for gravitational settling, electrostatic mobility, and thermophoretic forces yield time constants $t_{migration}$ ~ L/C_i ~ 1 - 10 s.*
- *These mechanisms are of less importance for inter-shot aerosol transport than for long-term transport associated with accident analysis*

Particle deposition

$$\vec{J}\Big|_{wall} = -D\nabla n + \left(\vec{c}_{migration} + \vec{c}_{inertial} + \vec{c}_{turbulent}\right)n$$

- *Deposition via diffusive and/or migratory transport of particles are secondary effects for inter-shot aerosol transport*
- *inertial deposition and turbulent deposition are important for inter-shot aerosol transport because they are responsible for placing particles at undesired locations, such as on final optics or in ducts.*

Future work for aerosol formation

- *Aerosol model requires local state properties (T,P) for determining nucleation and growth rates. Flow field is also needed for particle convection and deposition*
- *Solve within Hydrodynamic Chamber Model*
- *Modify existing INEEL fluids/aerosol model to simulate a dry-wall IFE chamber for the purpose of scoping studies*
- *Experimental benchmarking*