Magnetic Intervention Dump Concepts

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Recap on Magnetic Intervention from Last Couple of Meetings

- **Magnetic intervention to steer ions away from the chamber to reduce threat (ion implantation + energy deposition) on chamber first wall and provide for longer dry wall chamber armor lifetime**

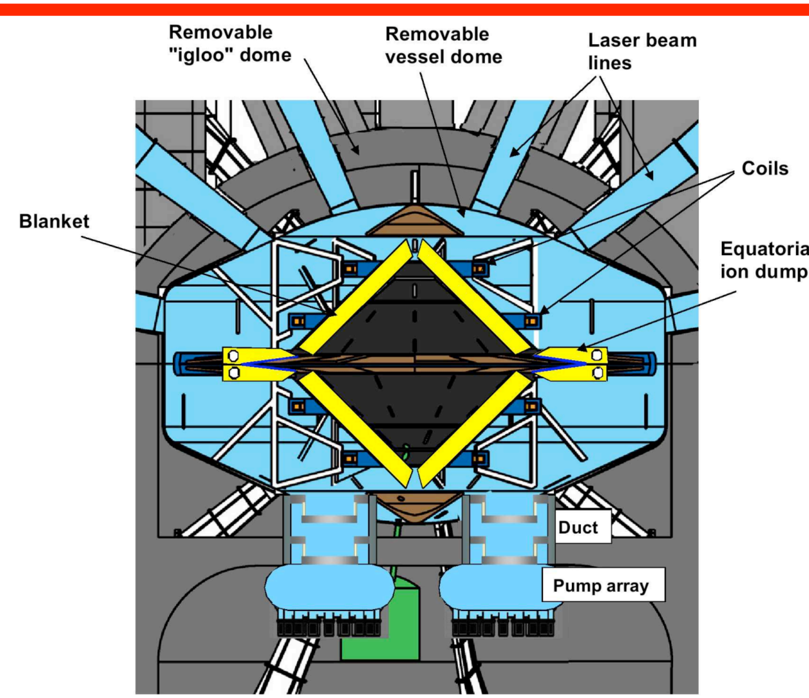
- **Ions guided to separate ion dumps away from chamber**

- **Intriguing possibility of even using liquid walls provided geometry allows for it without unacceptable contamination of main chamber**

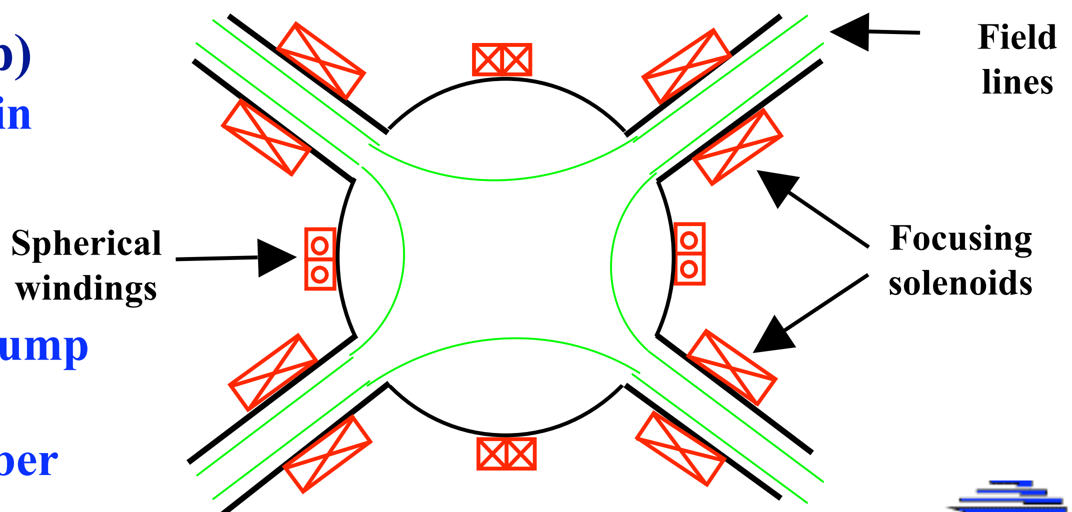
- **Two arrangements recently considered:**
  - **Conventional symmetric cusp arrangement with poles and an equatorial ring**
  - **Octagonal arrangement (octacusp)**

2 Magnetic Intervention Concepts Considered Recently

- **Conventional symmetric cusp arrangement with poles and an equatorial ring, and a duck bill ion dump configuration**
  - **Extremely challenging (if at all feasible) to accommodate huge ion energy fluxes at poles**
  - **Also very difficult to accommodate footprint and peaking factor of ion fluxes at equatorial ring with dry-armored duck bill ion dumps**



- **Octagonal arrangement (octacusp)**
  - **Ion fluxes require fluid protection in dump region (e.g. Pb mist)**
  - **Gravity works against an upper liquid wall dump concept**
  - **Challenging to design liquid wall dump region to accommodate ion fluxes without contaminating main chamber**



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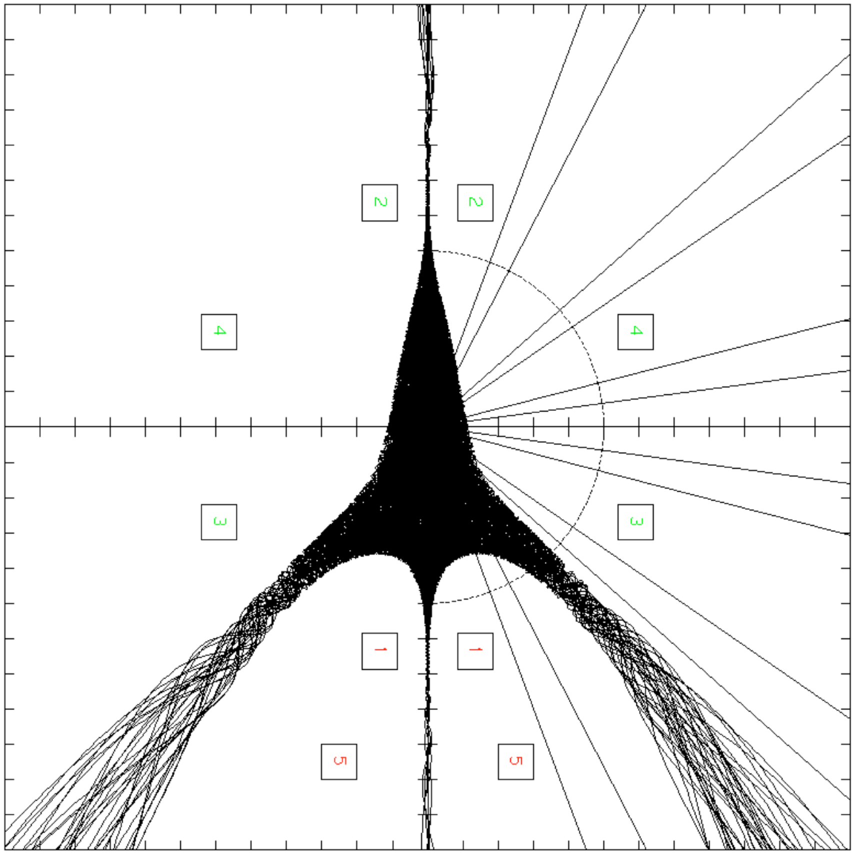
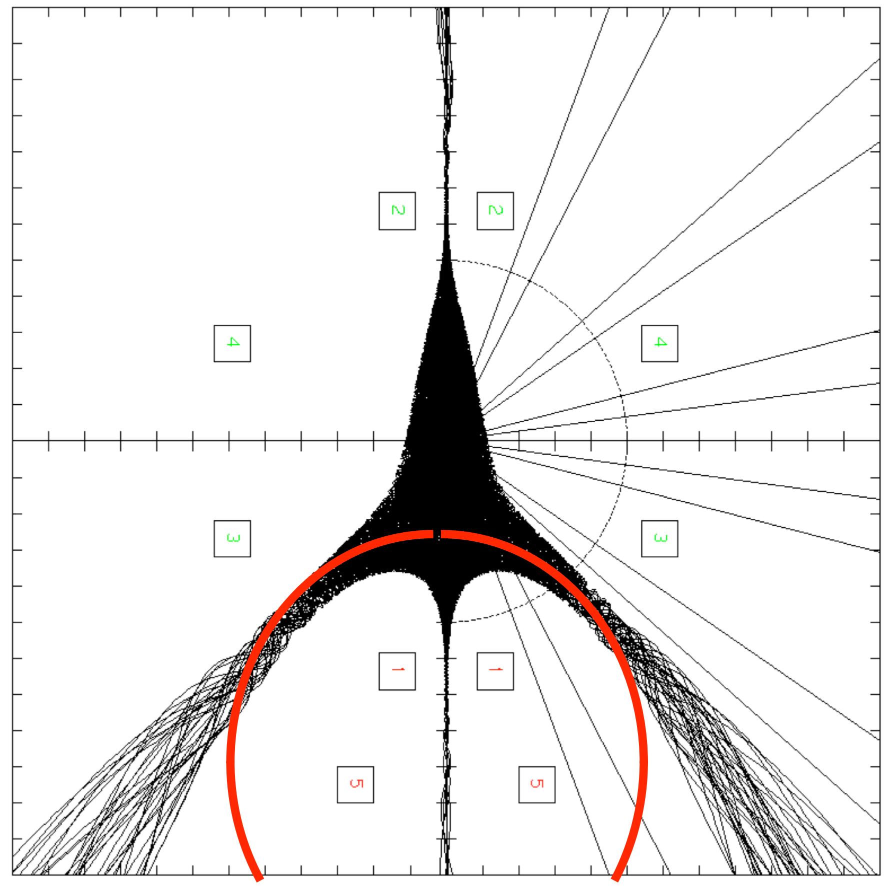
New Inverted Martini Glass Cusp Concept
(From B. Robson)



- 97% of ion energy though annular dump port
- Gravity works for us in designing a liquid Pb dump at bottom

Better to Use Inverted Burgundy Glass Concept (if possible) to Prevent Direct Line-of-Sight Contamination of Main Chamber



Possibility of Using a Liquid Dump Concept without Contaminating main Chamber

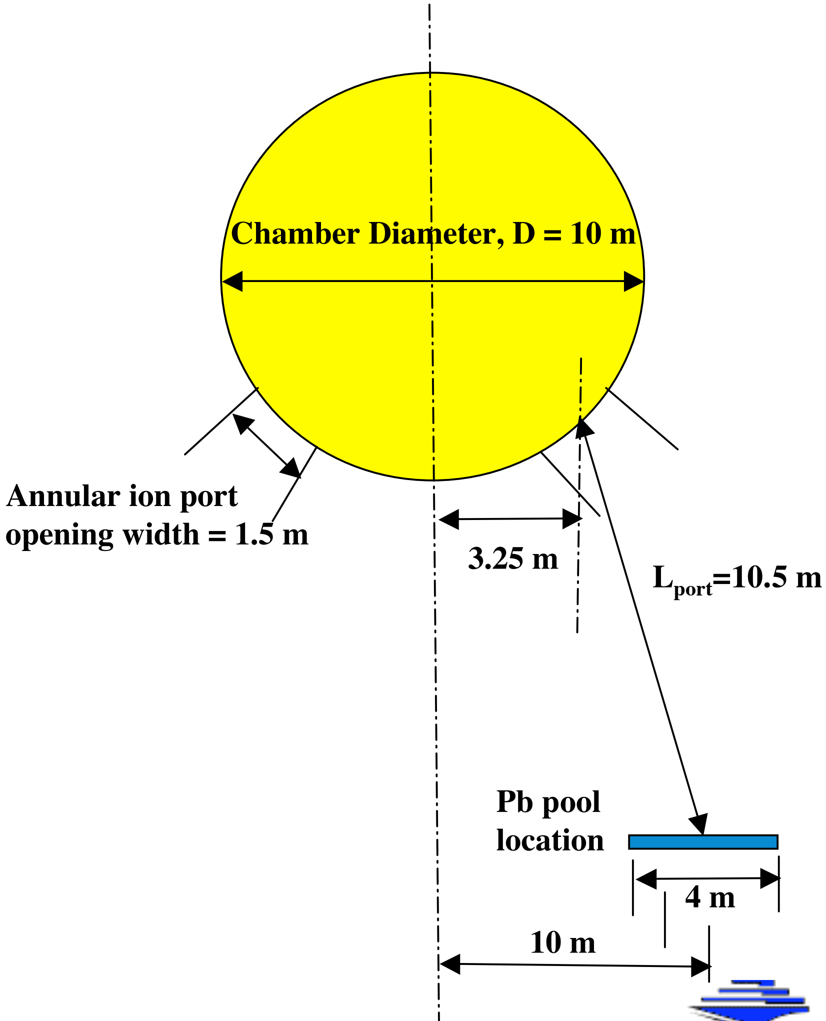
- **Initial liquid dump concept based on separation of function**
  - Recycled liquid Pb to accommodate ion energy and particle deposition, including diverted "bleeding" flow for clean-up
  - Separate coolant for power removal (e.g. Pb-17Li)

- **Different liquid Pb configurations considered**
  - All assume Pb pool at bottom and low-temperature condensation trap (< main chamber wall temperature)
  - "Waterfall" concept
  - Mist concept
  - Liquid film concept (presented here as example)

- **Analysis in very early stage**
  - Need to analyze all concepts to get a better understanding and to help in deciding direction of effort
  - Need also right analysis tools

Assumptions for Calculating Temporal and Spatial Power Deposition in Liquid Pb Pool

- **Chamber diameter, D = 10 m**
- **Annular Pb ion dump pool, 4 m wide and 10 m in average radius from center line**
  - Pb dump pool area = 250 m^2
- **Time of flight of ions based on:**
  - Number of transits, n_{trans} = 6
  - Opening for annular cusp port as a fraction of chamber wall area = 0.0975
    - 0.0975 of ion energy based on direct flight to liquid Pb dump pool
    - 0.9025/6 assumed lost after each of the 6 assumed transits with time of flight based on (i_{trans} x D + L_{port})
  - To be verified by more detailed calculations (D. Rose)



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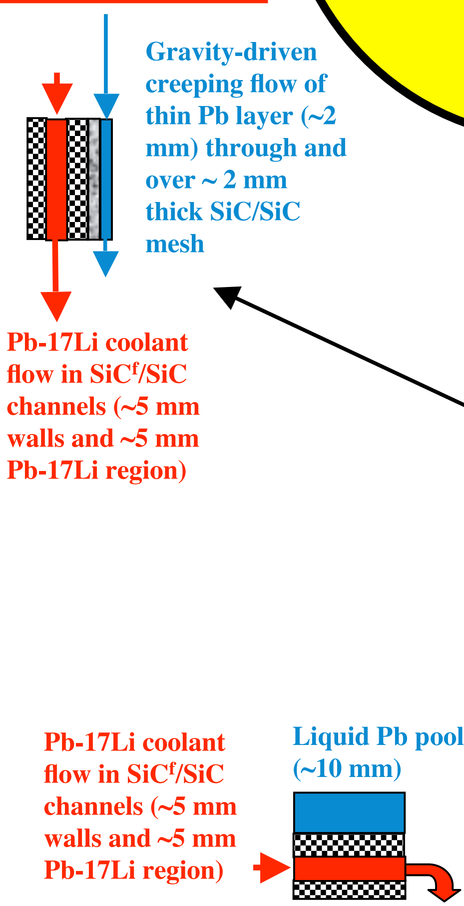
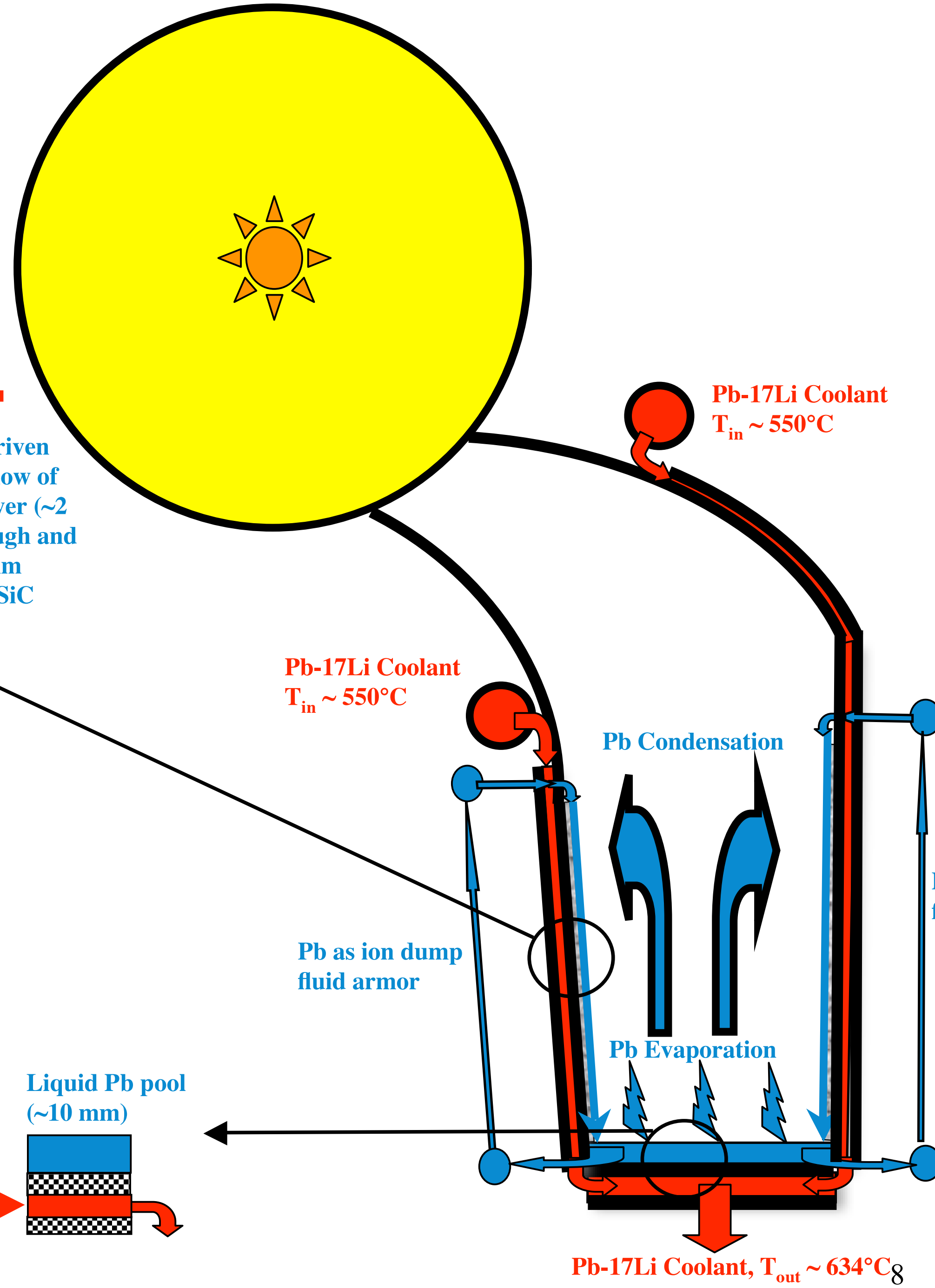
Example Liquid Pb Pool Dump Concept with Gravity-Driven Creeping Flow through/over SiC/SiC Mesh

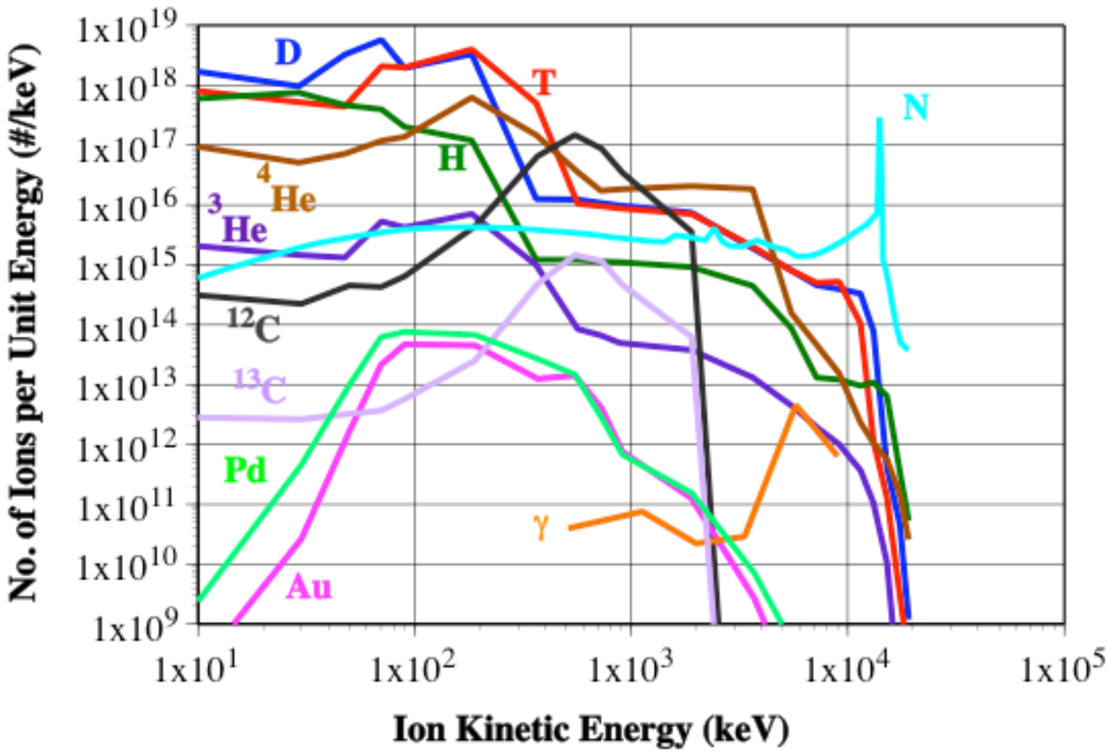




Ion Spectra from 367 MJ Target

		Total (MJ)
X-rays		4.937 (1.34%)
Gammas		0.01680 (0.0046%)
Neutrons		274.3 (74.72%)
Protons	1.763	
Deuterons	21.724	
Tritons	26.50	
3He	0.0777	
4He	30.28	
12C	6.880	
13C	0.08367	
Pd	0.1844	
Au	0.3607	
Pt	< 0.000001	
Total Ions		87.85 (23.93%)
Total out		367.1 MJ
Residual thermal energy		(0.03494)
Laser Energy Absorbed		(2.426)
Nuclear Energy Produced		364.7 MJ

From John Perkins' Data on HAPL 350 MJ-Class Baseline Target Design, 10/10/05



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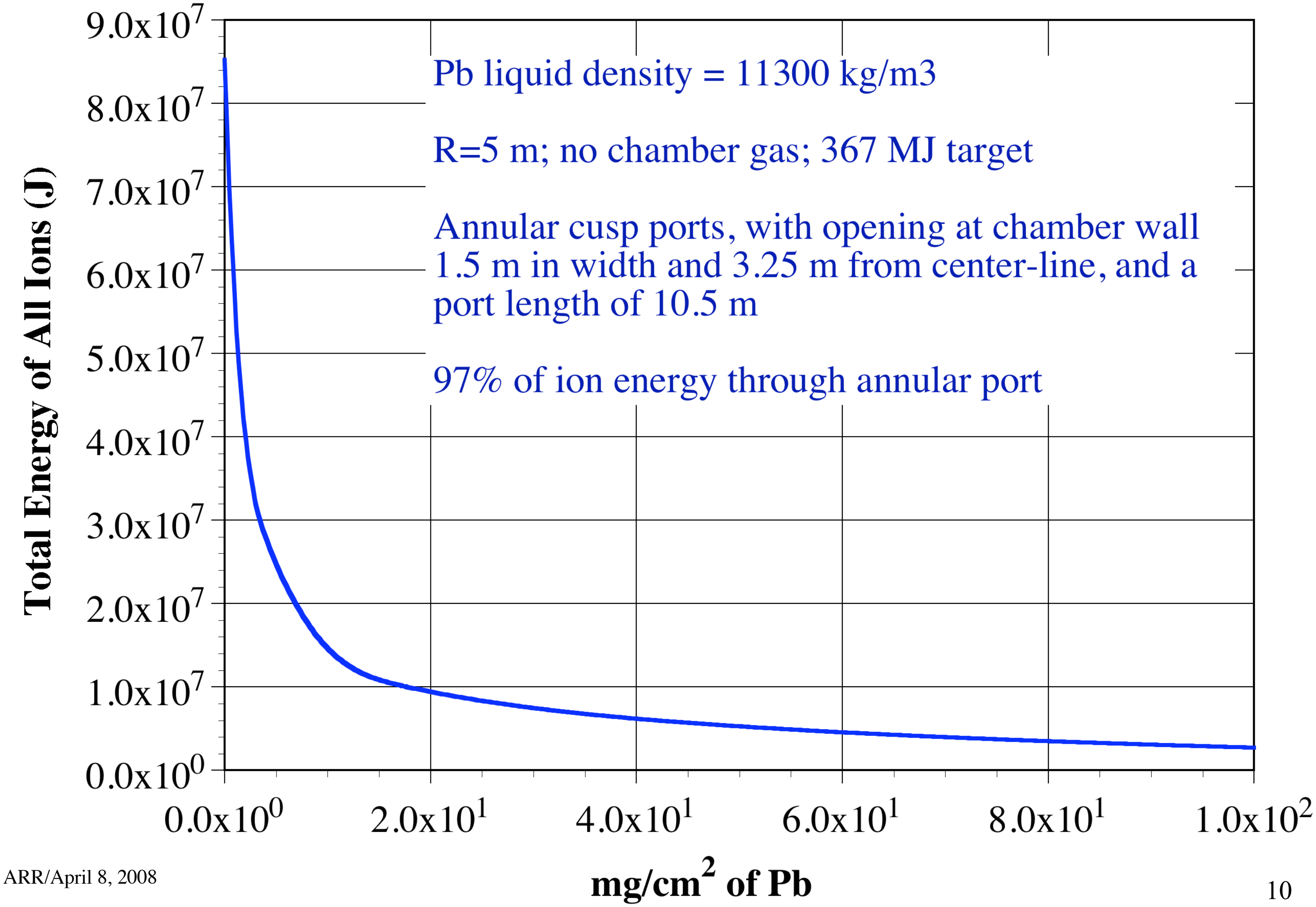
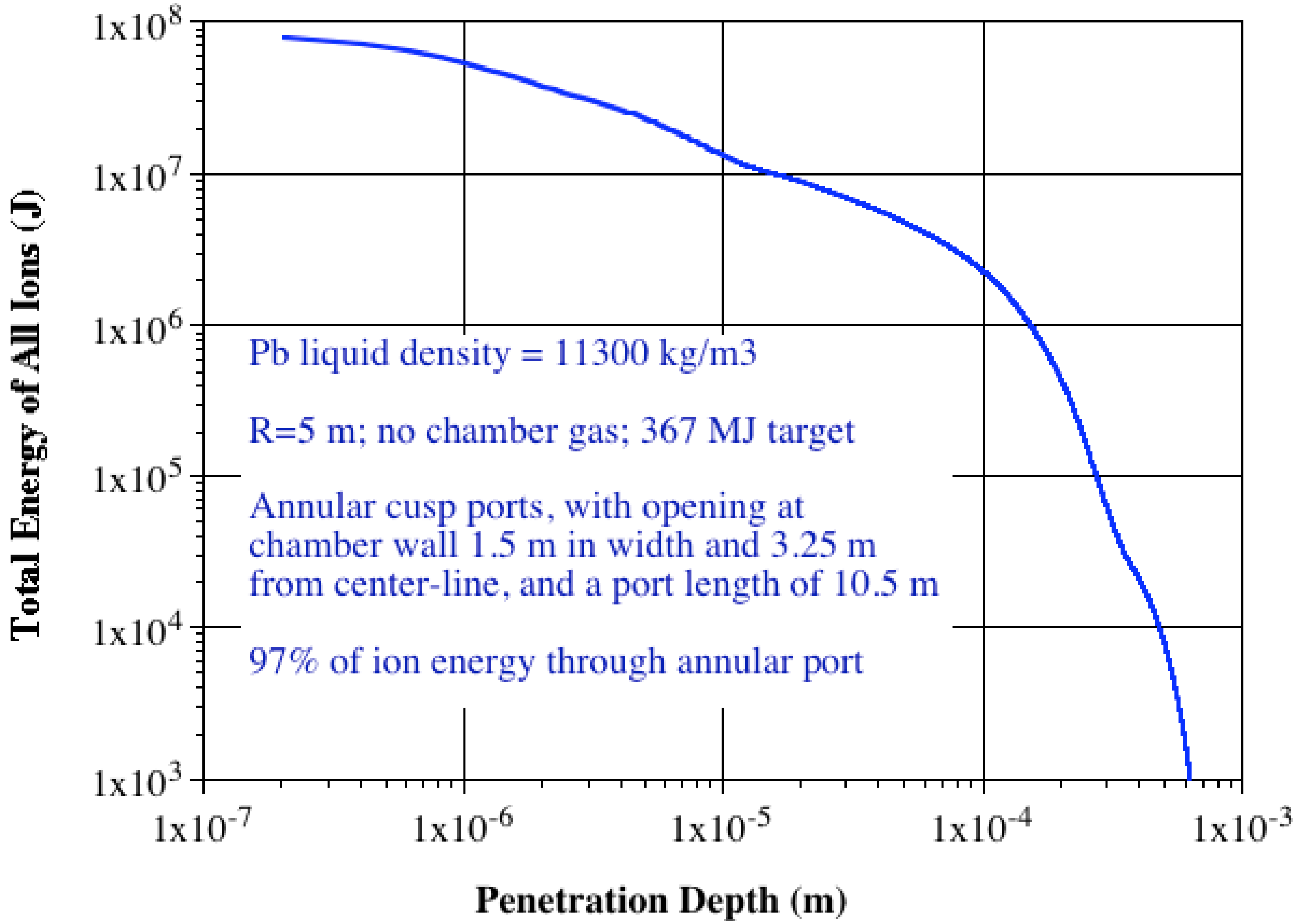
Attenuation of Ion Spectra By Pb

- **350 MJ target (total ion energy = 87.8 MJ)**



Energy of Ions as a Function of Penetration Depth



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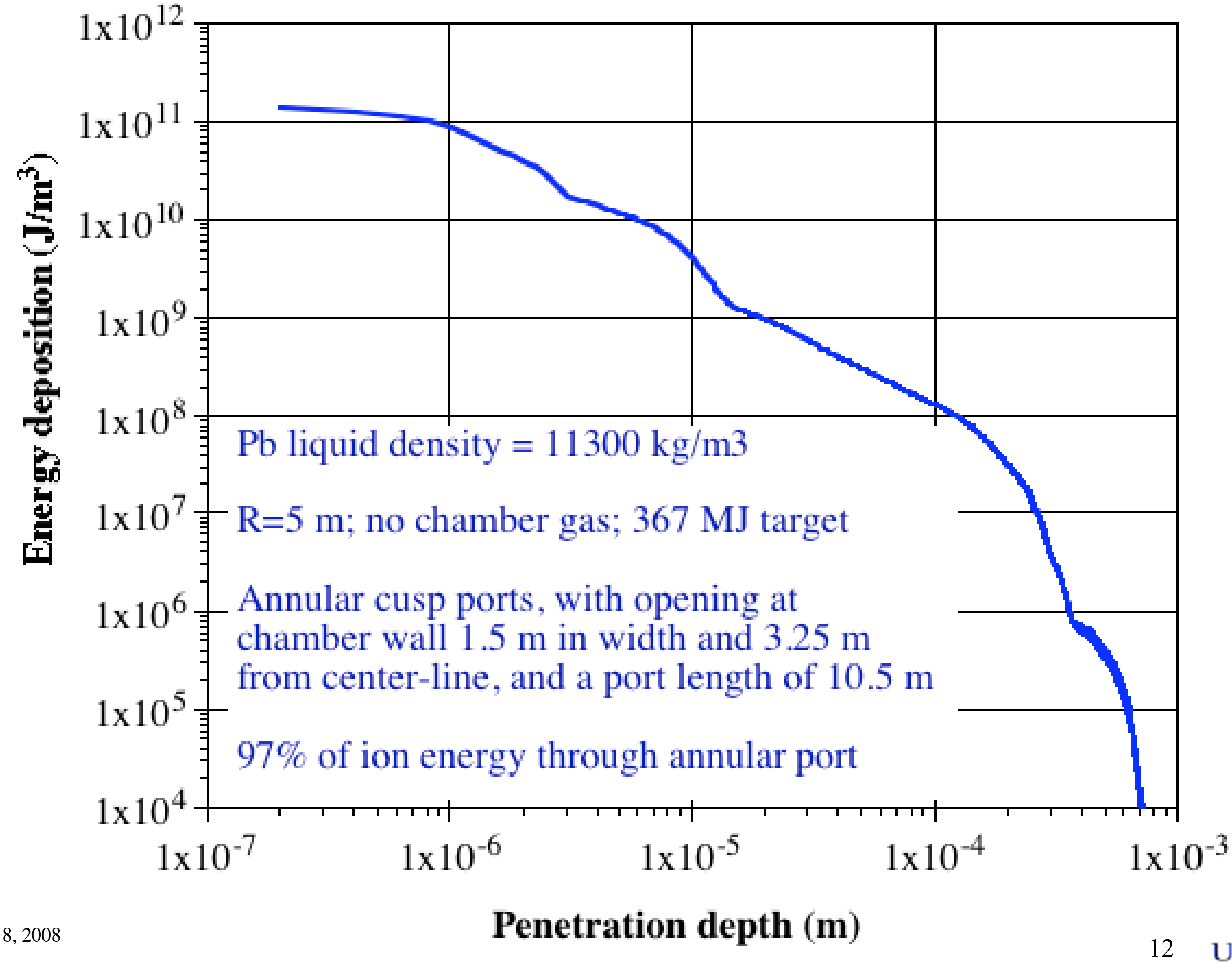
Spatial Ion Energy Deposition in Liquid Pb Ion Dump



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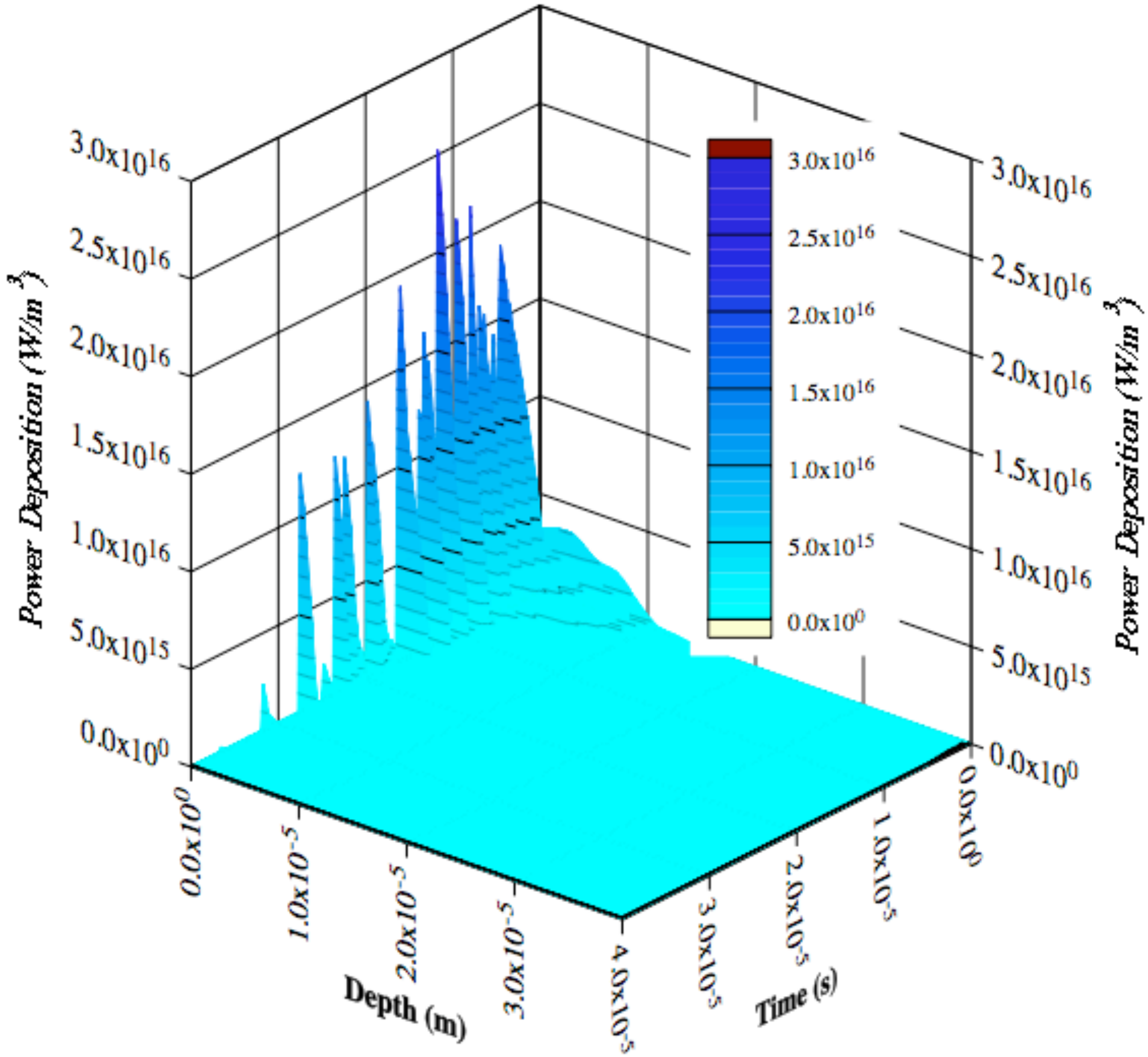
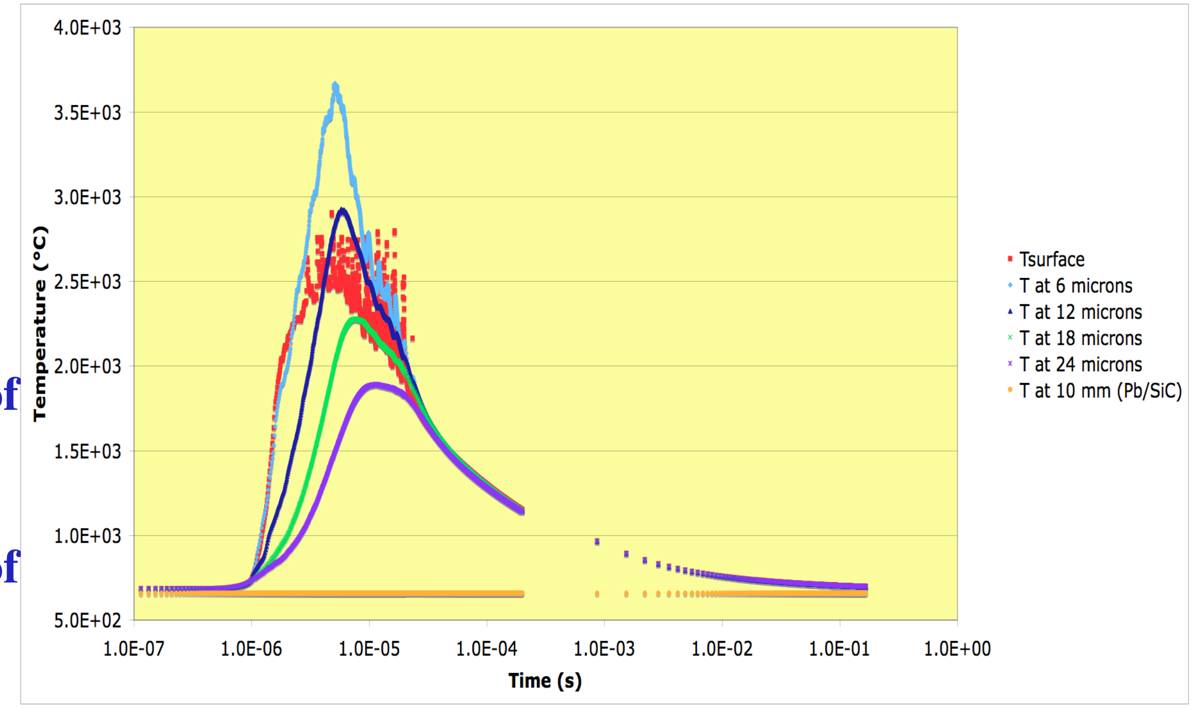
Temporal and Spatial Power Deposition in Liquid Pb Pool

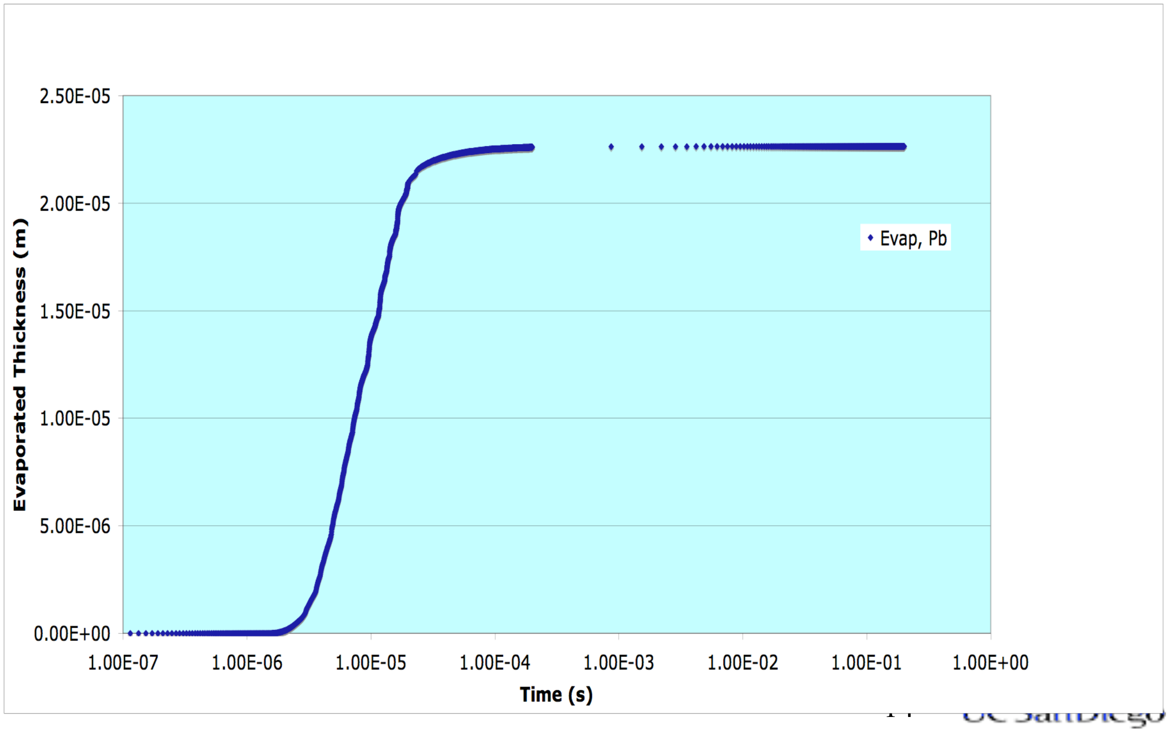
- **R = 5 m; no chamber gas; 367 MJ target**
- **Annular cusp ports, with opening at chamber wall 1.5 m in width and 3.25 m from centerline, and a port length of 10.5 m**
- **97% of ion energy through annular port**
- **Pb liquid density = 11300 kg/m^3**



Temperature and Evaporation History for Liquid Pb Pool without Vapor Shielding

- **Avg Pb-17Li coolant T at back of Pb pool ~ 625 °C**
- **Pb pool surface T at beginning of cycle = 690 °C**
- **Total ion energy in annular dump = 85.2 MJ**
- **From analysis:**
  -Total evaporation energy = 55.2 MJ
  -Energy to liquid Pb pool ~ 30 MJ
- **Large amount of evaporated Pb (~23 μm) would provide vapor shielding (see next slide)**





Temperature and Evaporation History for Liquid Pb Pool WITH Vapor Shielding

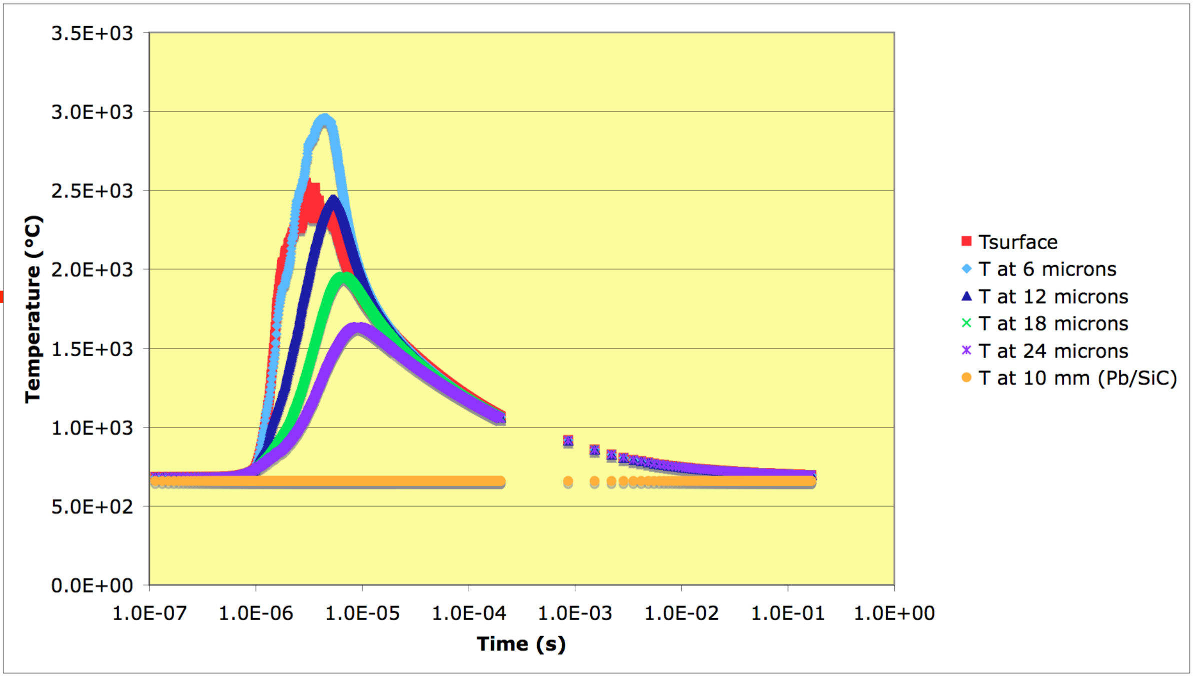
- **Avg Pb-17Li coolant T at back of Pb pool ~ 625 °C**

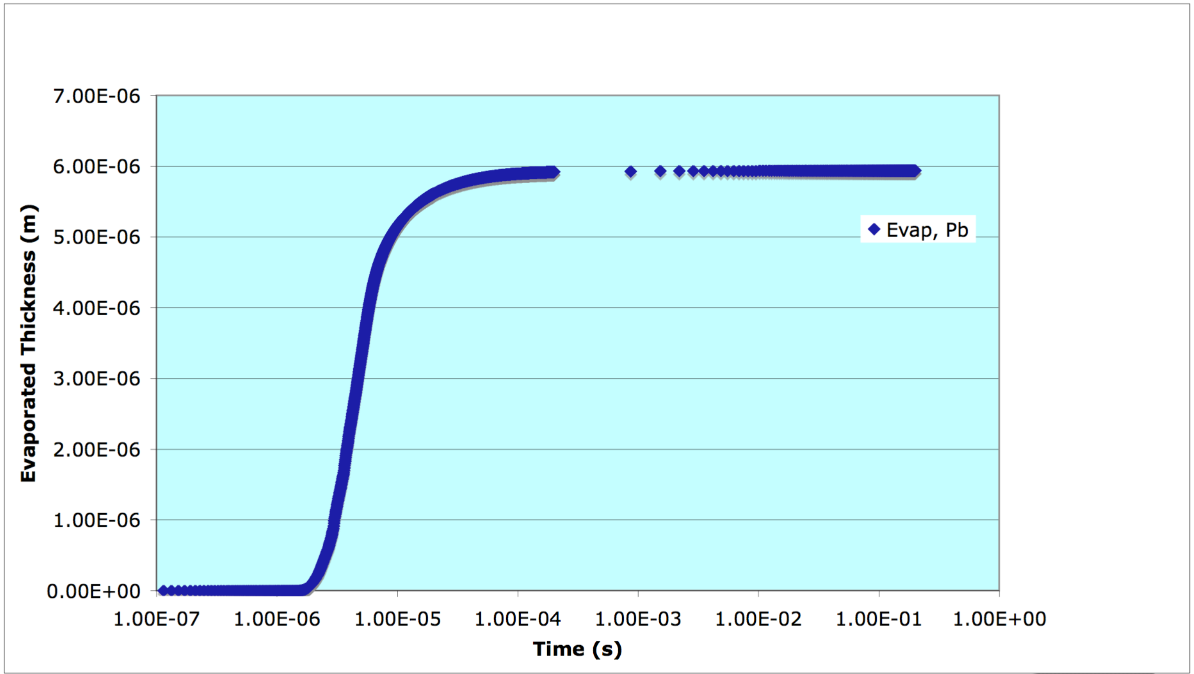
- **Total ion energy in annular dump = 85.2 MJ**

- **From analysis:**
  -Total evaporation energy = 14.5 MJ
  -Assume energy to liquid Pb pool still ~ 30 MJ (probably much lower)
  -Then vapor shield energy > ~ 41 MJ

- **Smaller amount of evaporated Pb (~6 µm) with vapor shielding**

- **Pb temperature below surface (~12 microns) > surface temp. and > BP (1749°C at SP) indicating possibility of much higher mass loss and vapor shielding and lower energy deposition in Pb dump (need correct analysis tool)**





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Quasi Steady-State Temperature of Pb in Bottom Pool and in Thin Layer Along Port Walls

PORT REGION WITH Pb FILM

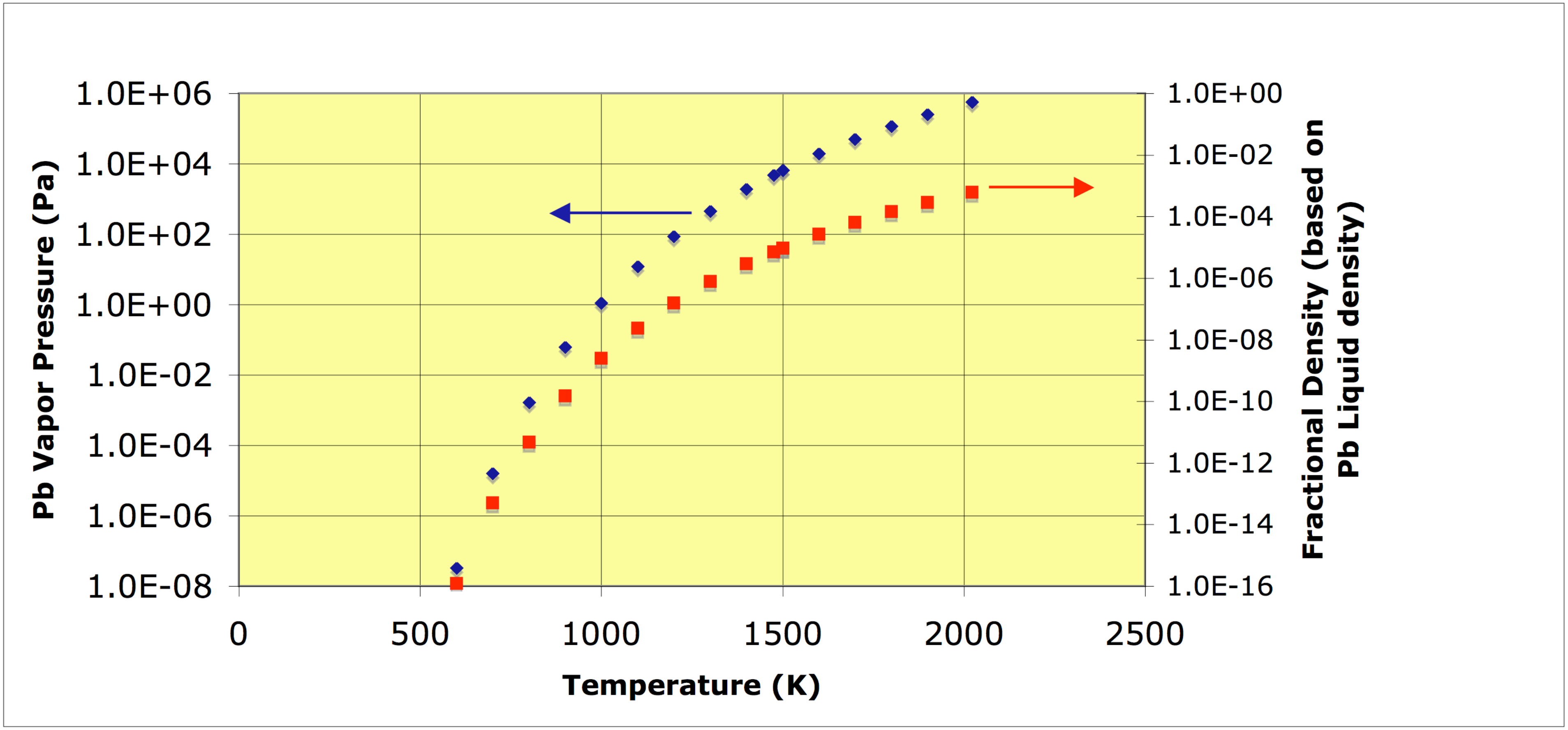
- Rep rate = 5
- Energy flux on condensing surface in port = 70 MJ
- Condensing surface area = 1319 m^2
- Avg. eff. q'' = 0.21 MW/m^2
- ΔT through 2 mm Pb (k = 15 W/m-K) = 35°C
- ΔT through 5 mm SiC/SiC structure + 2 mm mesh (k = 15 W/m-K) = 124°C
- Inlet Pb-17Li temperature ~ 550°C
- Pb-17Li temperature at exit of Pb film ~ 619°C
- Max/Avg/Min Pb surface temperature in port = 812/777/743°C

BOTTOM REGION WITH Pb POOL

- Rep rate = 5
- Energy flux to Pb in bottom pool = 15 MJ (<30 MJ, rough estimate here)
- Pb pool surface area = 250 m^2
- Avg. eff. q'' = 0.6 MW/m^2
- ΔT through 1 cm Pb (k = 15 W/m-K) = 199°C
- ΔT through 5 mm SiC_f/SiC structure (k = 15 W/m-K) =100°C
- Pb-17Li temperature at entry to Pb pool ~ 619°C
- Exit Pb-17Li temperature ~ 634°C
- Max/Avg/Min Pb surface temperature in pool = 969/962/954°C

Pb Vapor Pressure as a Function of Temperature

- **Liquid Pb density = 11,300 kg/m^3**



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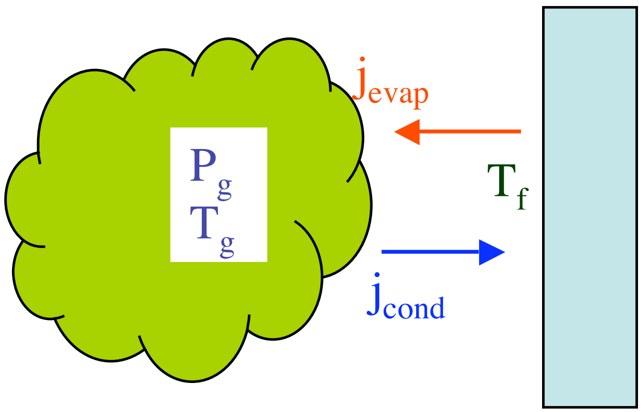
Film Condensation in Ion Dump Port



$$j_{net} = \left(\frac{M}{R2\pi}\right)^{0.5}\left[\Gamma\sigma_c\frac{P_g}{T_g^{0.5}} - \sigma_e\frac{P_f}{T_f^{0.5}}\right]$$

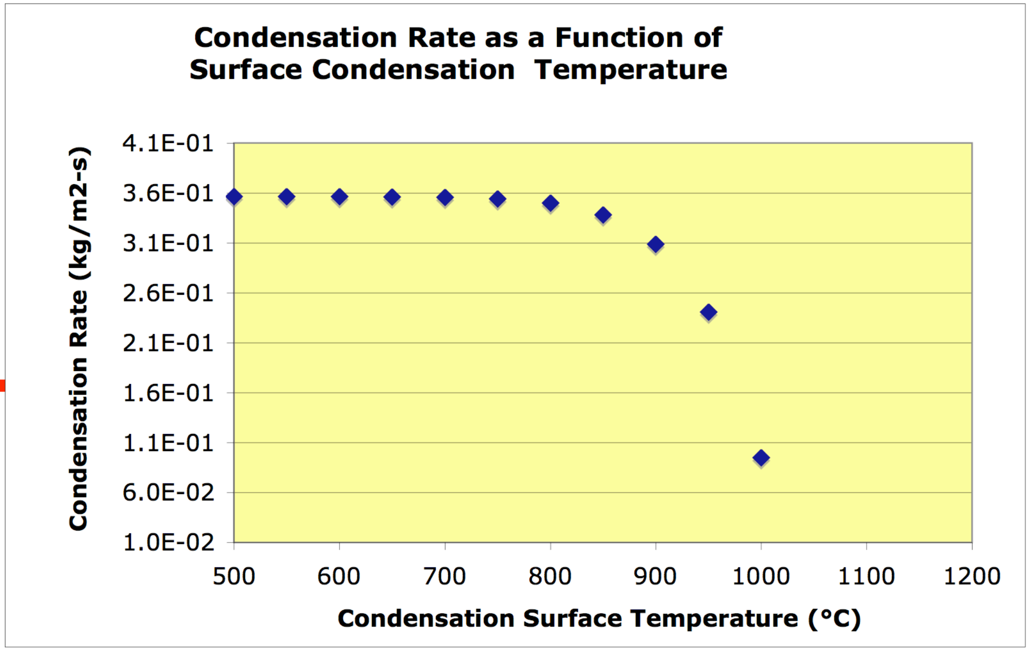
j_{net} = net condensation flux (kg/m^2-s)
M = molecular weight (kg/kmol)
R = Universal gas constant (J/kml-K)
Γ = correction factor for vapor velocity towards film
σ_c, σ_e = condensation and evaporation coefficients
P_g, T_g = vapor pressure (Pa) and temperature (K)
P_f, T_f = saturation pressure (Pa) and temperature (K) of film

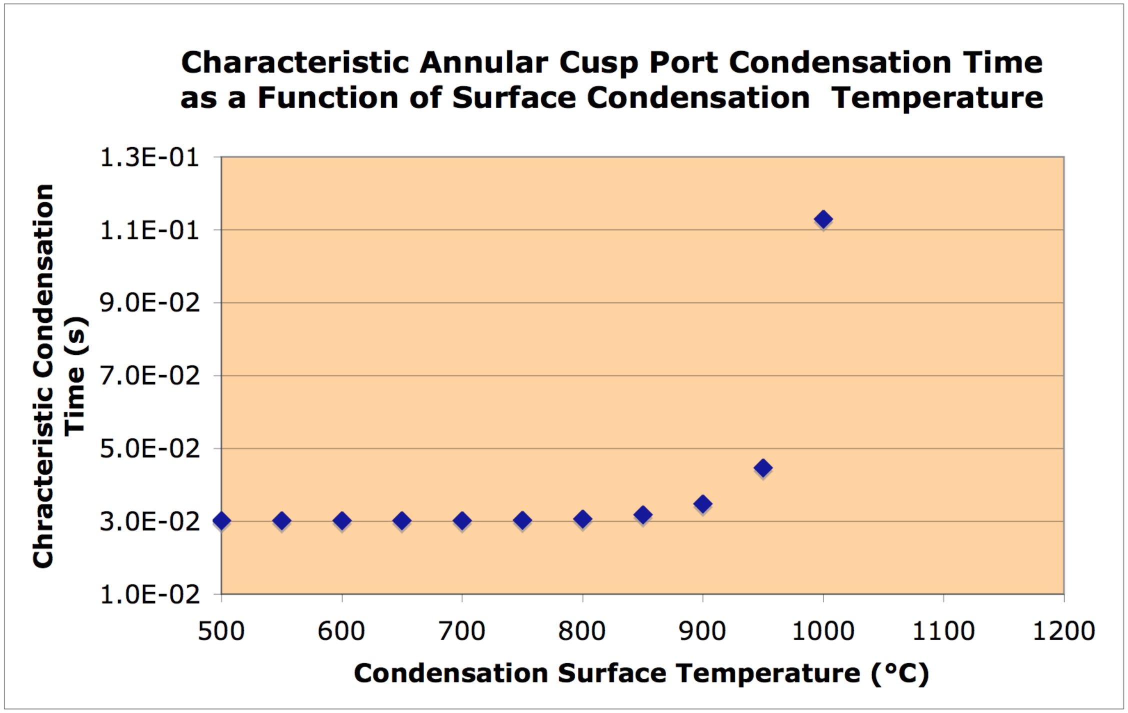
Example Scoping Calculations for Annular Dump Port

- Liquid Pb as film material
- Surface Condensation Area = 1319 m^2
- Port Volume = 2639 m^3
- σ_c, σ_e = 0.5
- Γ = 1
- Pb evaporated thickness (~10 microns) and vapor temperature (~2500°C) estimated from RACLETTE results
- Characteristic condensation time estimated based on vapor mass in chamber and condensation rate corresponding to assumed conditions

Scoping Analysis of Pb Condensation in Example Annular Port Dump Region

- Characteristic condensation time fast, ~0.03 s, over a large range of condensation surface temperature (time to condense all Pb vapor at given conditions)





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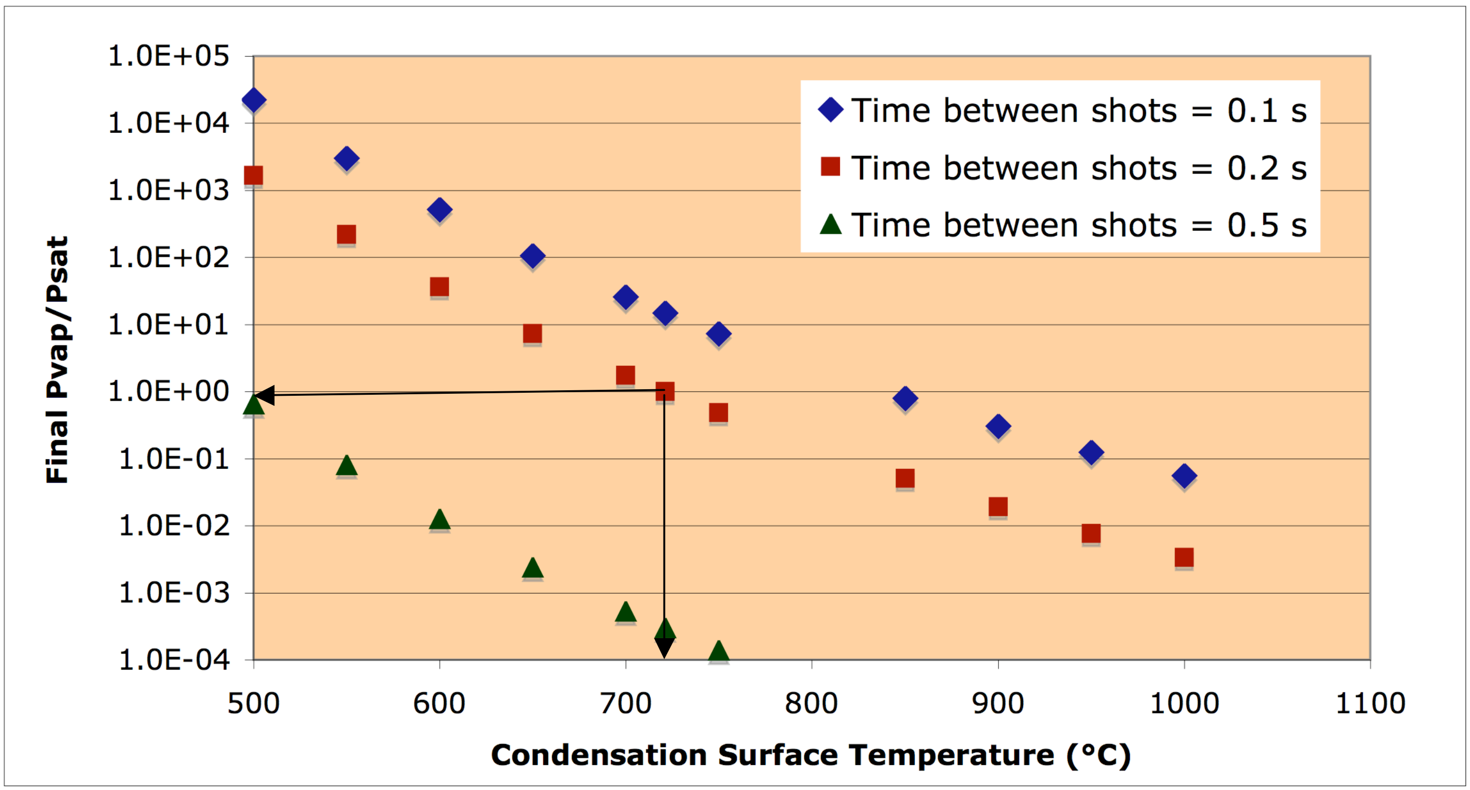
Rough Estimate of Integrated Condensation Assuming Linear Decrease in Vapor Temperature

- **Simple integration of condensation rate as a function of changing conditions assuming linear decrease in vapor temperature (from a maximum temp. of 2500°C to the condensation surface temperature)**
  - **Faster return to vapor pressure for higher higher condensation surface temperature and for longer time between shots (lower rep rate)**
  - **For a rep rate of 5, results indicates return to vapor pressure for a surface temperature of ~720°C (0.96 Pa)**



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Proposed Inverted Burgundy Glass Concept Encouraging but More Analysis Needed to Determine Feasibility and Attractiveness

Questions needed to be addressed include:

- Better characterization of behavior of Pb pool under ion energy deposition
- Ion energy attenuation in Pb vapor and radiation analysis needed to characterize energy deposition on port walls and whether a protective film is needed
- Can the port geometry and coolant hardware be placed so as not to interfere with the laser beams?
- Does the configuration provide enough geometry restriction and condensation trapping to prevent unacceptable main chamber Pb contamination?
- Would a thick liquid wall or a mist configuration provide better protection against contamination of main chamber?
- How to design the dumps to accommodate the polar ion fluxes (~3%)?

MORE WORK NEEDED AND COMMENTS ARE MOST WELCOME