IFE Wetted-Wall Chamber Engineering

"Preliminary Considerations"

Mofreh R Zaghloul

A Rene Raffray

Mark S Tillack

Farrokh Najmabadi

Aries Meeting, UCSD

June 7-8, 2001

Initial Computations

"Primary Evaporation"

The target X-rays reach the liquid film prior to burn products and ionic debris and can cause substantial evaporation. The primary evaporated mass can be used to assess:

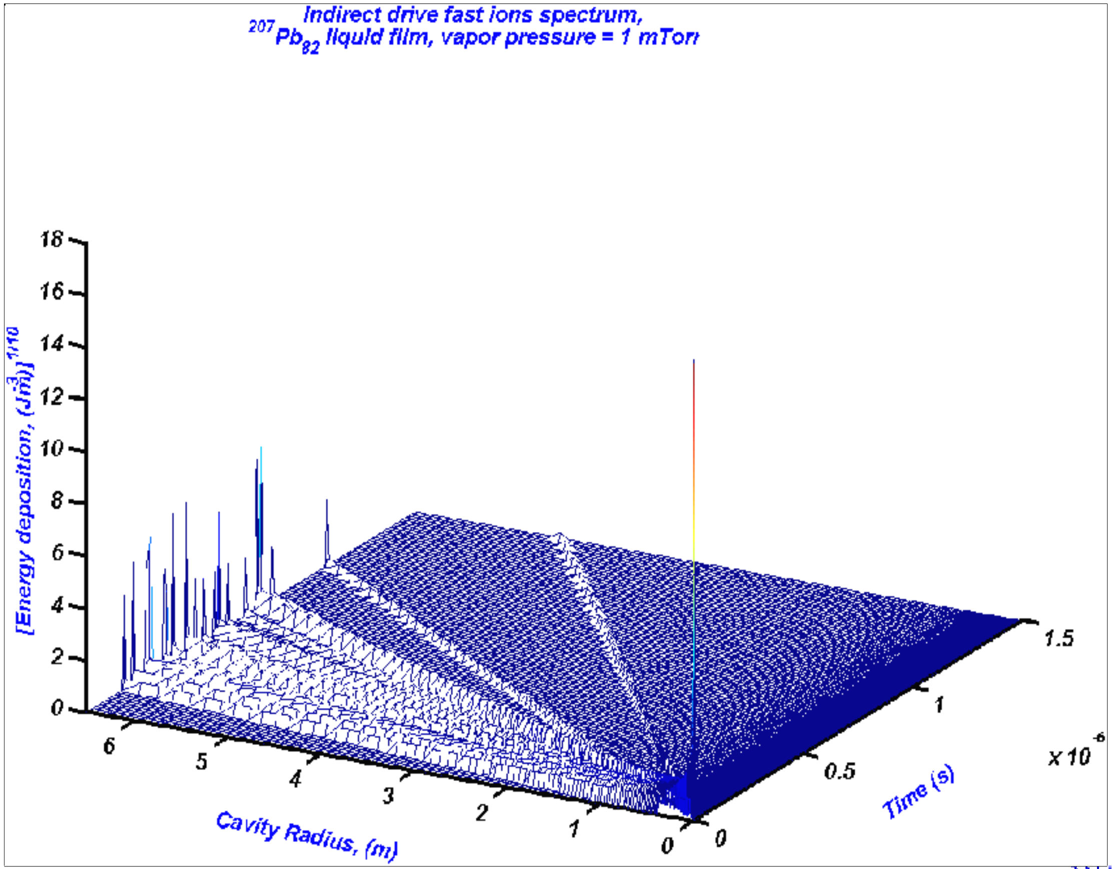
- Material choice ***(Li vs. Pb & No gas vs. Xe filled cavity)***
- Spectral effects ***(Indirect drive vs. Direct drive)***
- After-blast pressure effect
- Minimum mass needed to ensure aerosol existence

Time of Flight to the First Surface

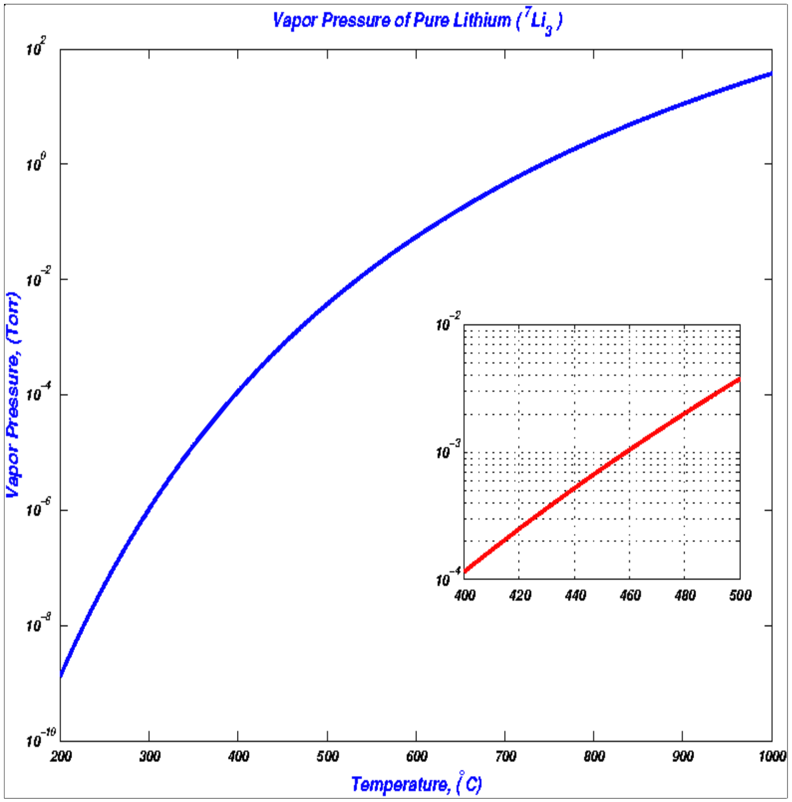
Typical time of flight to wall:

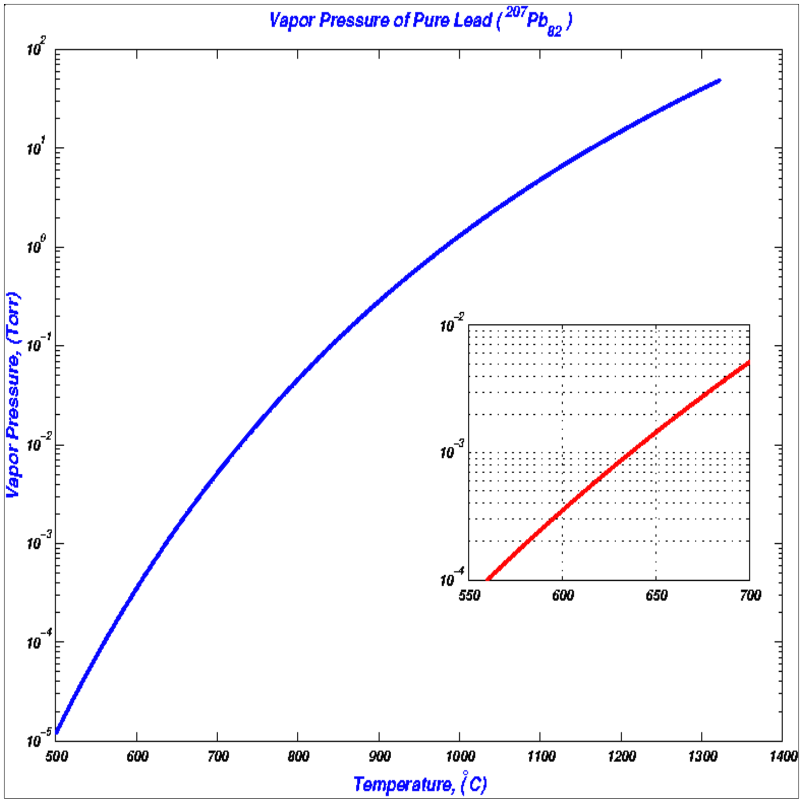
- ❑ X-rays (~22 ns)
- ❑ Fusion neutrons (>120 ns)
- ❑ Burn products (>200 ns)
- ❑ Debris ions (~1-10 μs)

➢ **Interaction of the target X-rays with the first surface (liquid film) can be studied separately**

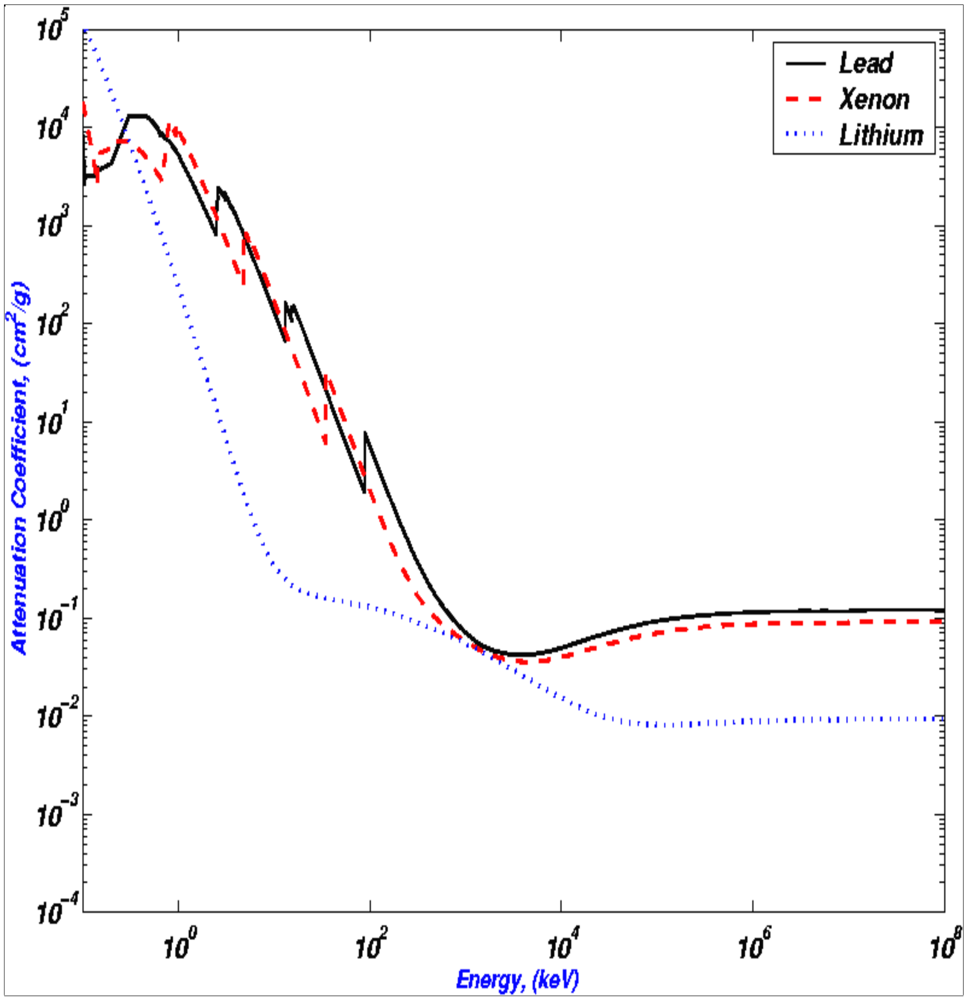


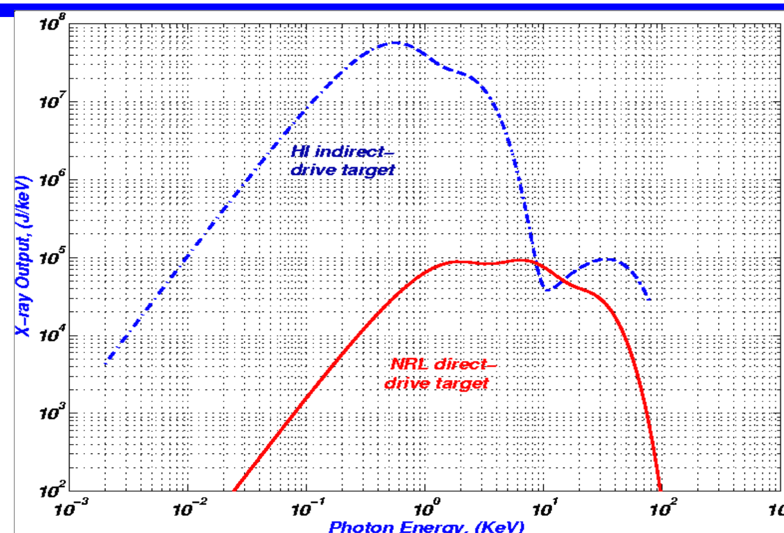
Vapor Pressure

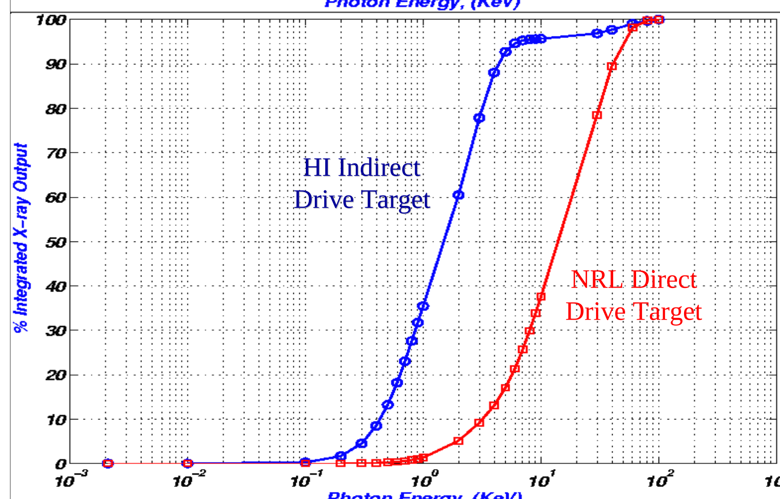




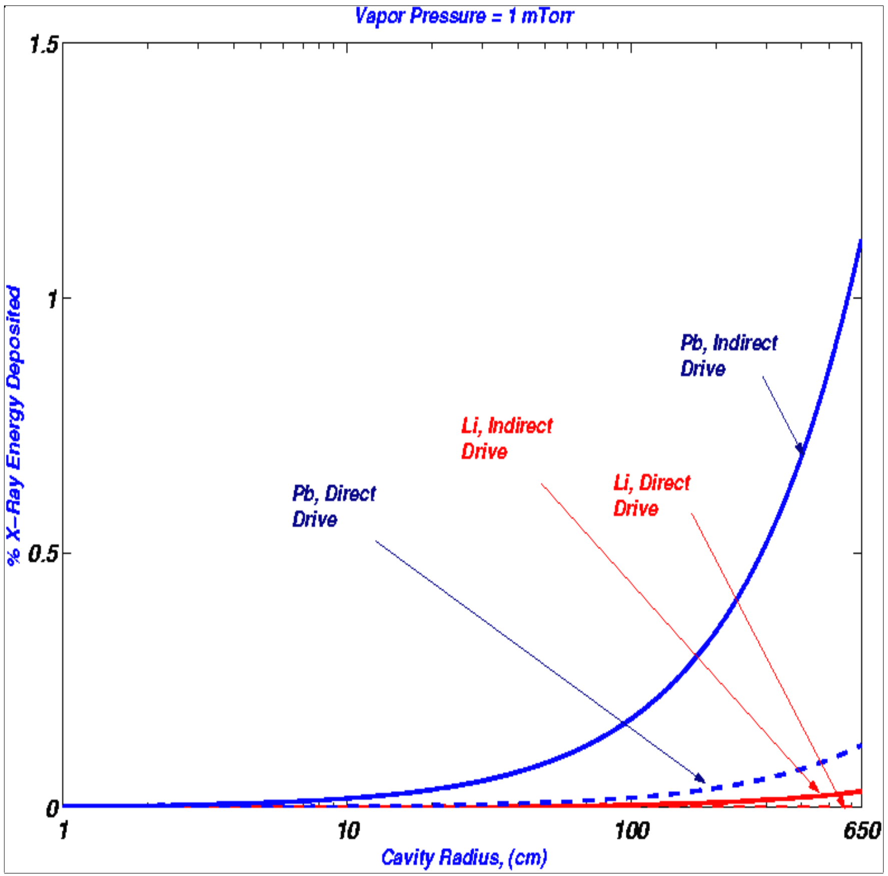
X-rays Spectra and Photon Attenuation Coefficient

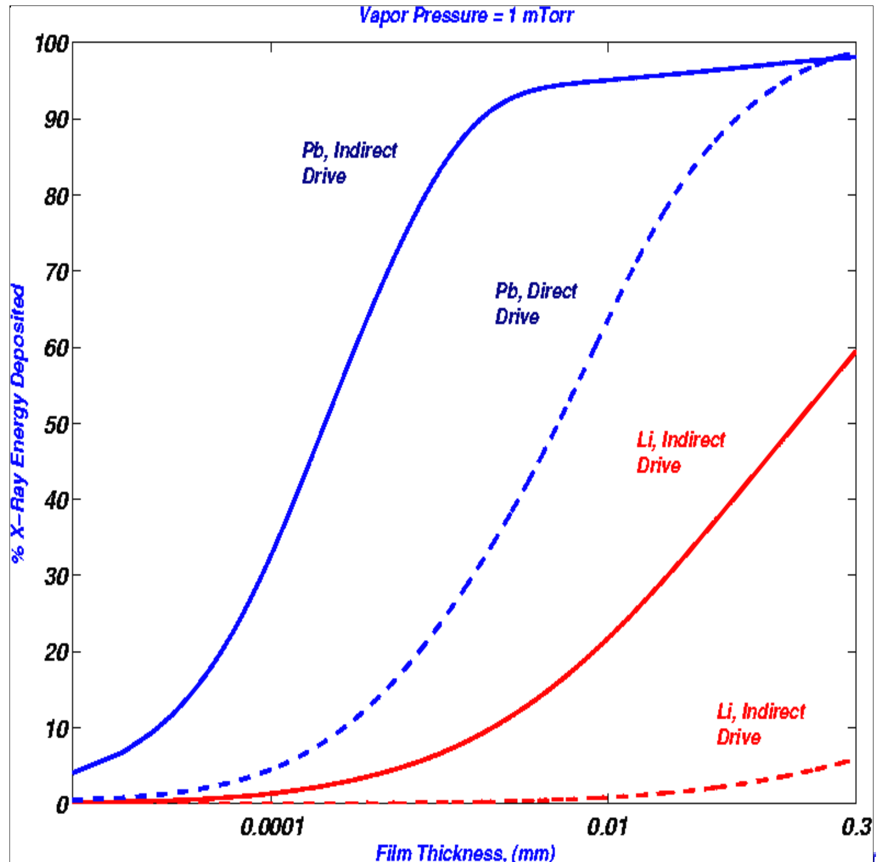




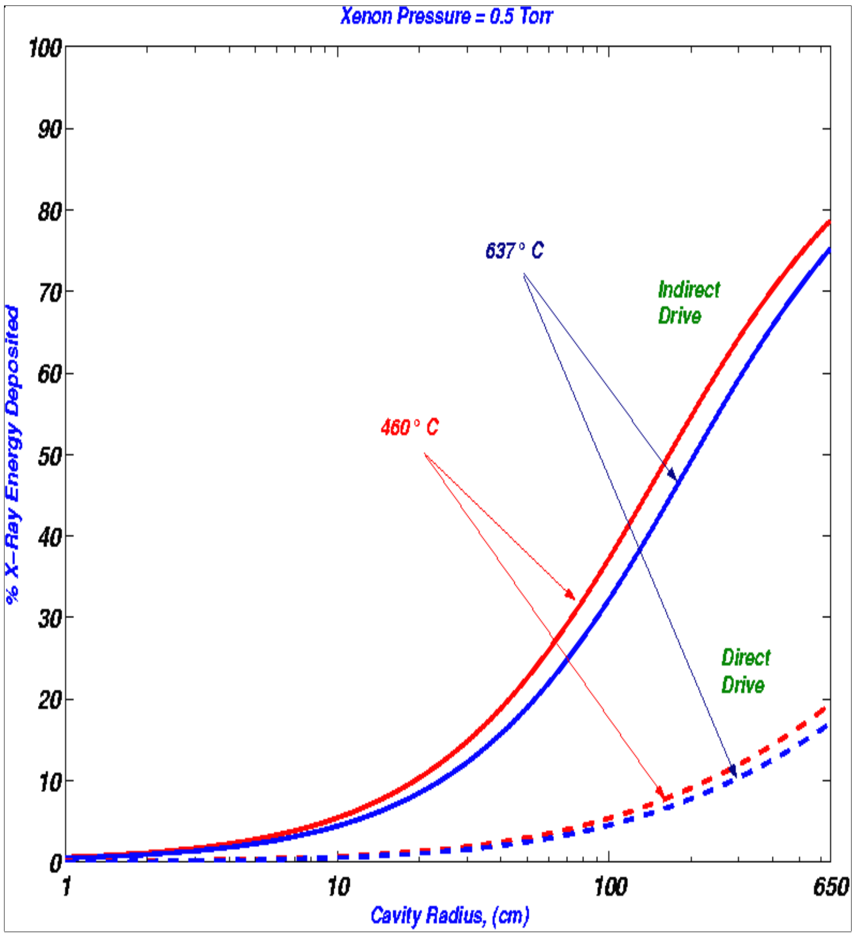


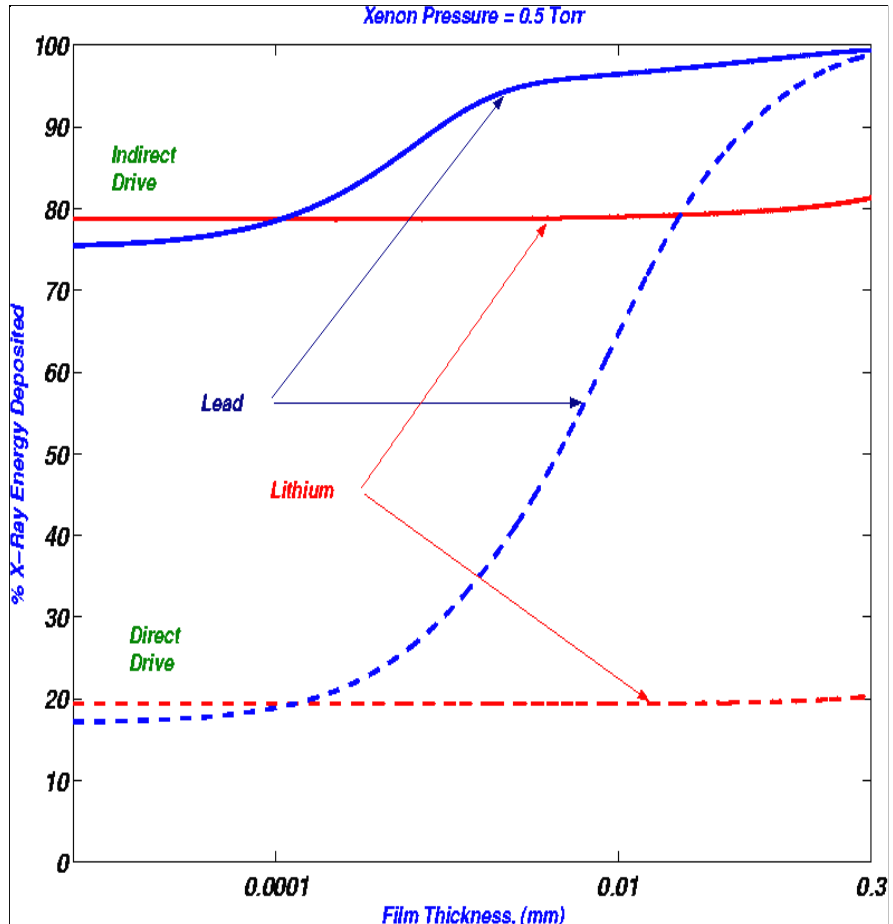
Photon Energy Deposition
No External Gas
P_{cavity} = Vapor Pressure = 1 mTorr





Photon Energy Deposition
Xenon Cavity @ P_{xe} = 0.5 Torr





Film Response
"Phase Transitions"

Alternative Ways of Modeling

Kinetic Model

"Kinetic Theory"

Volumetric Model

"Lumped Heat Capacity Model"

- ***Useful in cases where the volumetric energy deposition is rapid enough that the resulting hydrodynamical motion and thermal diffusion are insignificant***
  - $\tau_{ed} \sim$ ***ns*** $\ll \tau_{td} = L^2/\alpha = \rho\, C_P\, (\Delta x)^2/\kappa \sim$ ***ms***
  - ***Hydrodynamic motion in*** $\tau_{ed} \sim C_s \tau_{ed} \sim$ ***μm*** $\ll$ ***film thickness ~ mm***

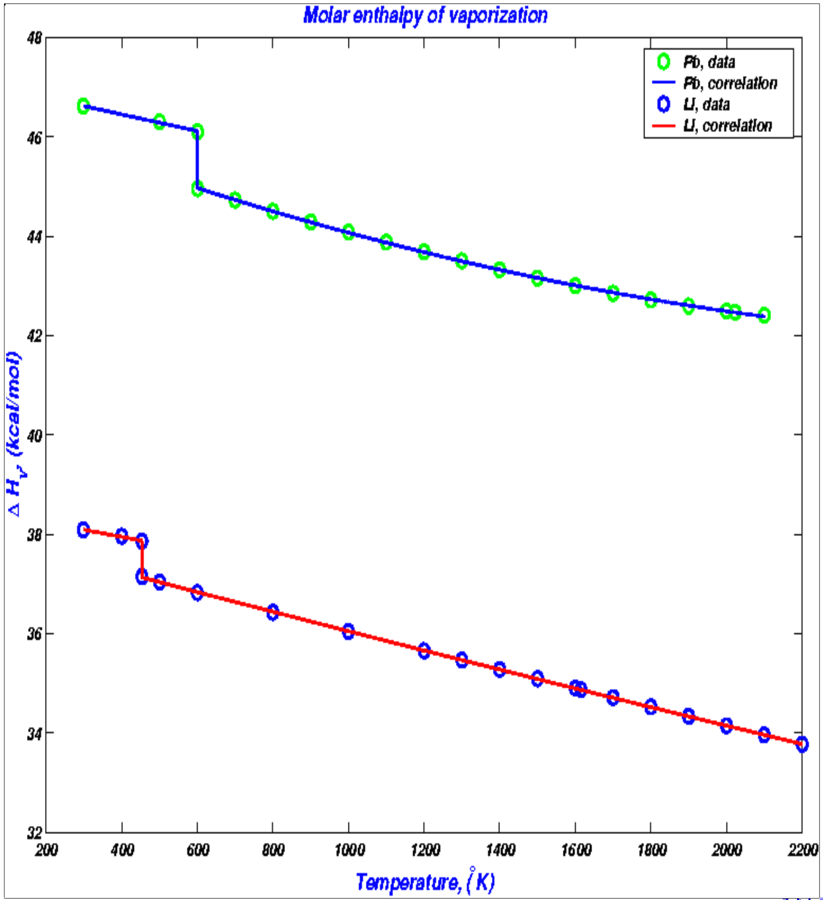
UC San Diego

Temperature Dependence of Heat of Vaporization (Correlating Data)

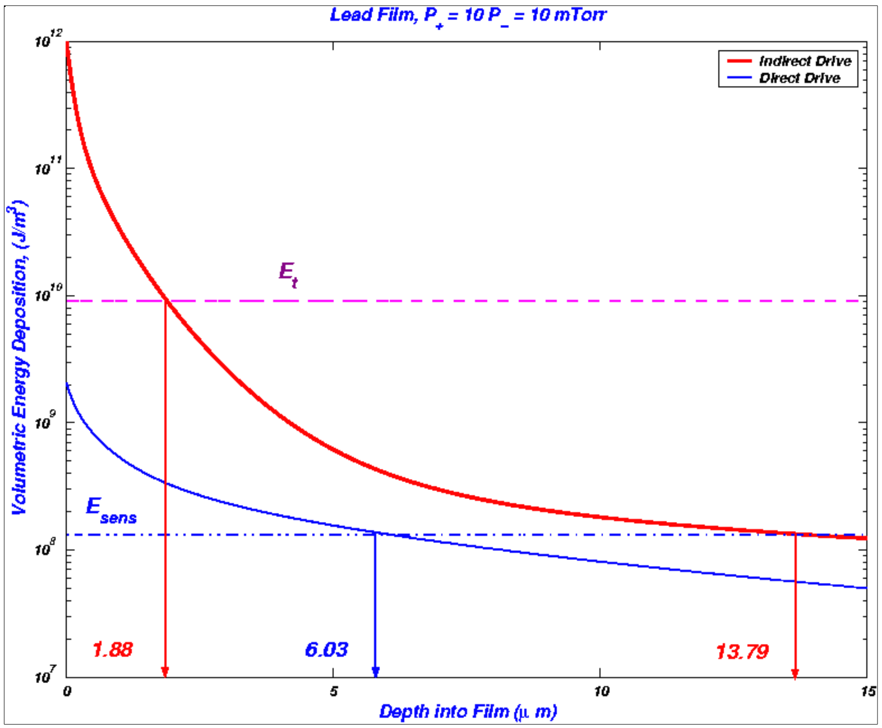
$\Delta H_v = a\,T + b$ for T [T1 T2]

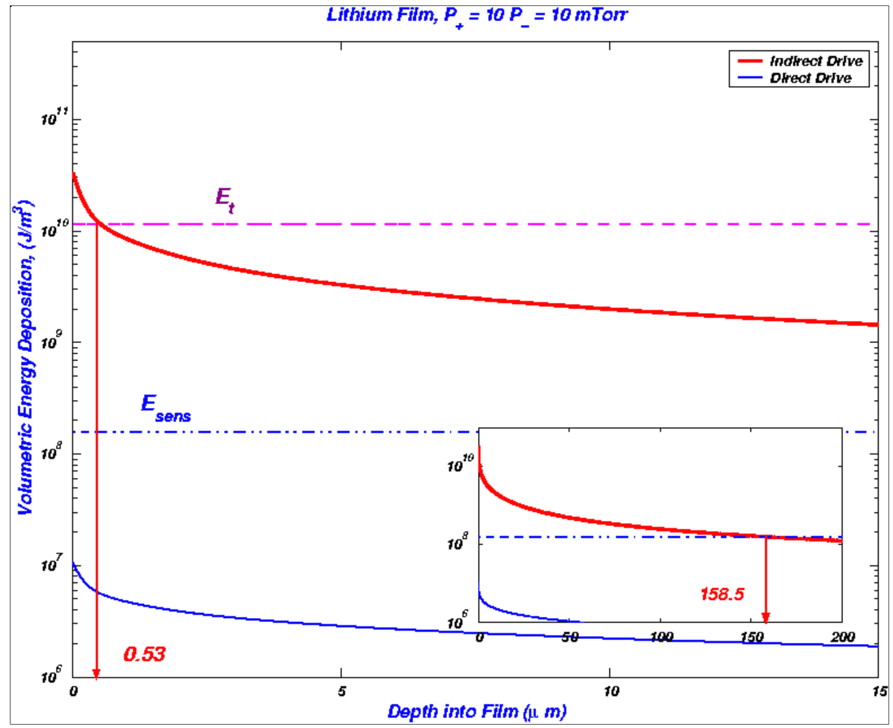
$\Delta H_v = c\,T^2 + d\,T + e$ for T [T3 T4]

Film	Lithium	Lead
a	-1.4191×10^{-3}	-1.6809×10^{-3}
b	3.8518×10^{1}	4.7127×10^{1}
c	4.9837×10^{-8}	4.7697×10^{-7}
d	-2.0508×10^{-3}	-3.0114×10^{-3}
e	3.8052×10^{1}	4.6607×10^{1}
T1 (K)	298.15	298.15
$T2_s$=$T3_l$	453.7	600.6
T4 (K)	2200	2100



Energy Density Profile in Pb & Li Films





E_{sens}: Energy density required for the material to be at the transition temperature

$$E_{sens} = \int_{T_{in}}^{T_{sat}(P)} \rho C_p \, dT$$

E_t: Total evaporation energy

$$E_t = E_{sens} + \rho(T_{sat}) ? \Delta H_v(T_{sat})$$

Effect of after-X-ray-blast pressure on film evaporation

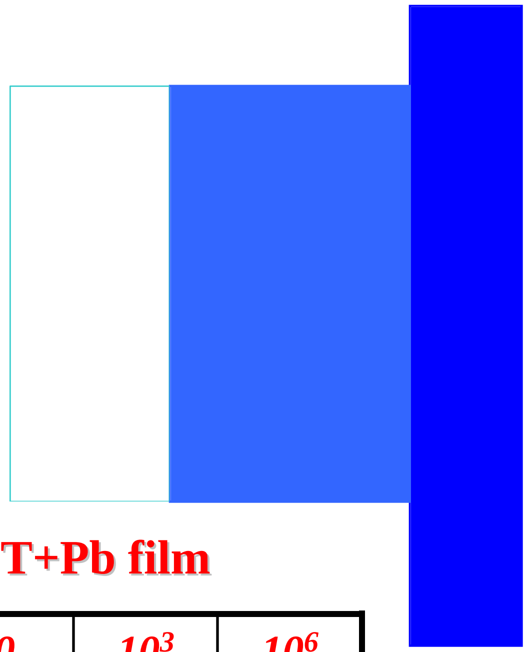
Summary of Results for
Indirect Drive Spectrum and Different Materials

Li vapor @ 1 mT + Li film | **Pb vapor @ 1 mT+ Pb film** | **Xe gas @ 0.5 T+ Pb film**

P_+ / P_-	10	10^3	10^6	10	10^3	10^6	10	10^3	10^6
E_t (GJ/m^3)	11.4	11.7	12.5	9.15	9.15	9.15	9.15	9.14	9.26
E_{sens} (GJ/m^3)	0.16	0.60	1.94	0.13	0.49	1.48	0.42	0.94	2.75
X_{vap} (μm)	0.53	0.50	0.44	1.88	1.88	1.88	1.27	1.27	1.26
X_{bp} (μm)	158.5	40.4	10.4	13.8	5.5	3.7	5.1	3.6	2.3
X_{tot} (μm)	7.41	4.55	2.30	2.85	2.66	2.45	2.03	1.90	1.65
m_{vap} (kg)	0.144	0.136	0.117	10.1	9.8	8.9	6.7	6.4	5.1
m_{tot}(kg)	2.0	1.2	0.6	15.3	13.9	11.6	10.7	9.5	6.8

Minimum Mass Needed for Aerosol Existence

Assuming all of the ionic energy and thermal radiation energy in the cavity will be deposited later in the two phase region, shall aerosol exist due to X-ray ablation?



Pb vapor @ 1 mT+Pb film

P_+ / P_-	10	10^3	10^6
X_{bp} (μm)	13.8	5.5	3.7
X_{tot} (μm)	2.85	2.66	2.45
M_{liq} (kg)	58.8	14.8	5.7
$M_{aer,min}$ (kg)	31.2	31.6	32.4

Xe gas @ 0.5 T+Pb film

P_+ / P_-	10	10^3	10^6
X_{bp} (μm)	5.1	3.6	2.3
X_{tot} (μm)	2.03	1.90	1.65
M_{liq} (kg)	16.0	8.3	2.6
$M_{aer,min}$ (kg)	129.4	131.4	135.0

Conclusions and Future Work

- Interaction of the target X-rays with first surface can be studied separate from other products from the micro-explosion
- The volumetric model has been used to predict the primary-vaporization depth and evaporated mass from Li & Pb liquid films using the direct-drive and indirect-drive target spectra
- The volumetric energy deposition from the direct drive spectrum was always less than the cohesion (total phase transition) energy. However in some cases the local volumetric energy deposition was greater than the sensible heat required to raise the temperature to the vaporization temperature.
- The indirect drive spectrum showed high mass evaporation rate (per shot) for all cases studied.

Conclusions and Future Work

- The after-X-rays-blast pressure has a negative effect on the total evaporated mass from the liquid film.
- Increasing the cavity initial pressure relative to the film vapor pressure helps to decrease the evaporated mass
- In future work, the impulse caused by the reaction (rocket effect) will be evaluated
- Mass transfer will be considered in detail to investigate both of the aerosol formation and vapor condensation