# Laser IFE Systems Modeling Progress Report

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**HAPL Meeting**
**Sept. 24-25, 2003**
**Madison, Wisconsin**

Work performed under the auspices of the U. S. Department of Energy by University of California Lawrence Livermore National Laboratory under Contract W-7405-Eng-48

# Activities since July 11 e-meeting

## Other progress and next steps

- Began developing general systems model structure, starting from target gain curve G(Ed). Then target yield = Y(Ed), so wall temp will be found as a function of driver energy, a more fundamental plant design variable than target yield.
- Next steps
  - develop steel temperature scaling as function of Y, Rw, P, and W thickness
  - Start on blanket modeling with UCSD
  - Start on target injection constraint modeling (vs Rw, P, possibly target size as a function of yield) with GA
  - Develop code logic for chamber sizing under multiple constraints
- Need additional detailed calculations for different target yield (e.g, 300, 400 MJ), thick W layers (~1 mm), and perhaps extended pressure range > 20 mtorr.

Model structure is taking shape

Not yet – just got info on how blanket/coolant effects limits

Started

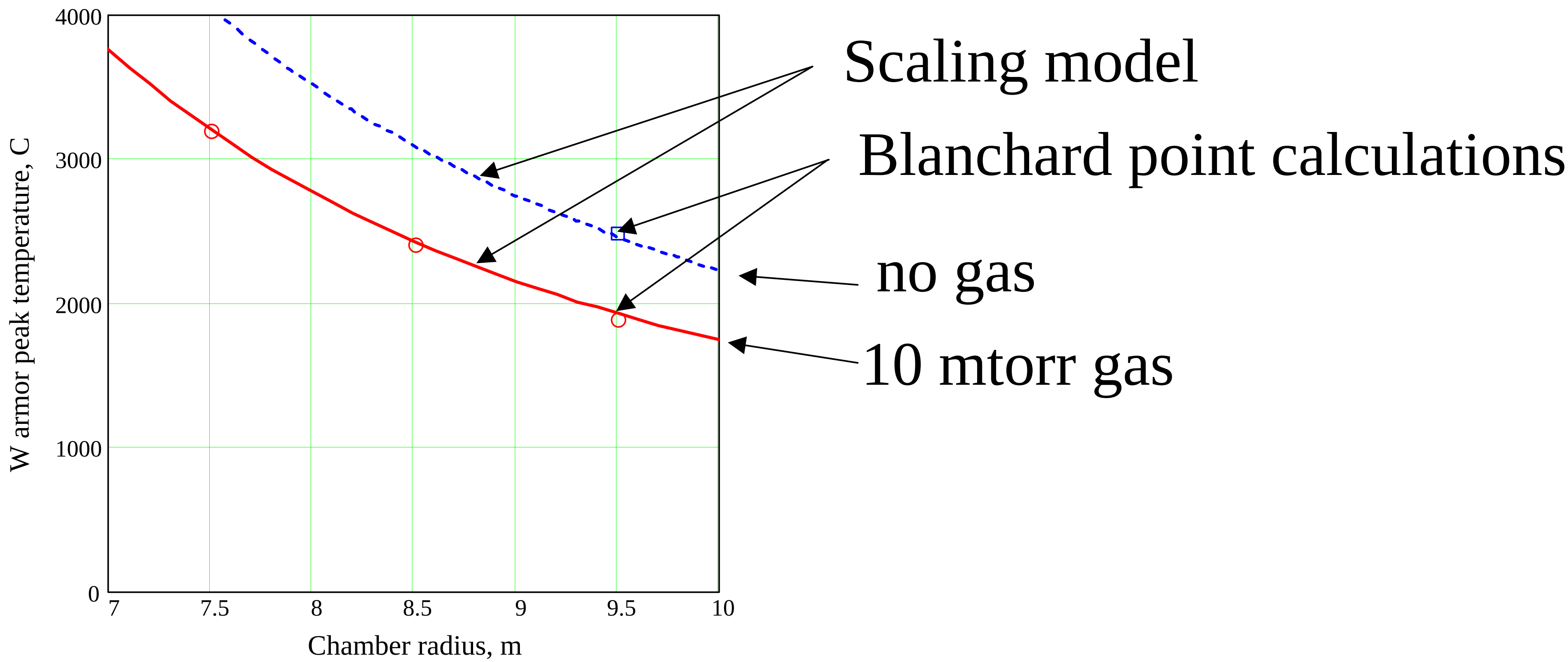
Preliminary model complete

Yes, for constraints to date

Input received from UW and UCSD

# New results from UW confirm wall radius scaling previously presented

Results for 300 MJ yield target




$$Tw(Y, Rw, p) := \left[ \Delta To(p) \cdot \frac{Y}{154} \cdot \left( \frac{6.5}{Rw} \right)^{2.5+0.02 \cdot p} \right] + Twss$$

T in C, Y in MJ, Rw in m, p in mtorr

# Systems code is being developed in Mathcad - example pages shown

Mathcad Professional - [LIPPS0918.mcd]

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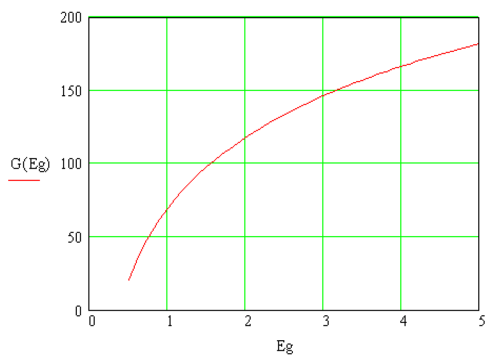
**Laser IFE Power Plant Systems Code**

**Target Gain**

Target gain increases with increasing driver energy. The form of this fit follows published gain curves for direct drive targets. The constants are selected to give a gain equal to the average of Perkins' 1D gain (170 at 2.4 MJ) and unoptimized 2D gain (110 at 3.1 MJ) as of 12/02. Want G = 140 at 2.75 MJ. This will be updated soon with new curves from Perkins and eventually for 1/3 and 1/4 mircon options.

$G(E) := 69.0 + 70.2 \cdot \ln(E)$ $\qquad G(2.75) = 140.014$

$Eg := 0.5, 0.6 .. 5$




**Target yield, MJ**

$Y(E) := G(E) \cdot E$

Examples for 154, 300 and 400 MJ yields

$Y(1.546) = 154.0 \qquad Y(2.335) = 300.1 \qquad Y(2.821) = 400.0 \qquad Eo := 1.546$

**Fusion Power, MW**, as a funcion of chamber rep-rate, RR in Hz

$Pf(E, RR) := Y(E) \cdot RR$

Mathcad Professional - [LIPPS0918.mcd]

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**Chamber Design Constraints**

Peak temperature in W armor = function of chamber radius, target yield, and chamber pressure

Reference point W temperature rise per pulse (for Yo = 154 MJ, Rwo = 6.5m)
This is a fit to Blanchard points at 6.5 m: ΔT = 2600, 2040, 1570 C at p = 0, 10, and 20 mtorr on top of a base of about 500C. (Ref. Blancard, Dec 2002 HAPL talk)

$\Delta To(p) := 2600 - 560 \cdot \left(\frac{p}{10}\right)^{0.88}$ $\qquad$ p is chamber pressure in mtorr

$Twss := 500$ $\qquad$ Quasi steady state W temperture, C (may want to make this a function of coolant temperature based on Raffray blanket design)

W armor peak temperature

$$Tw(E, Rw, p) := \left[\Delta To(p) \cdot \frac{Y(E)}{154} \cdot \left(\frac{6.5}{Rw}\right)^{2.5 + 0.02 \cdot p}\right] + Twss$$

The temperture rise on each pulse scales with the target yield, inversely with wall area (1/Rw^2) and inversely with heat load pulse width which goes as (1/Rw^0.5) but modified by chamber pressure (emprical fit to Blancahard results).

Set a maximum allowed W armor temperature (C) and then solve for the minimum wall radius (m).

$Twmax := 2400$

Solve for the minimum wall radius (m)

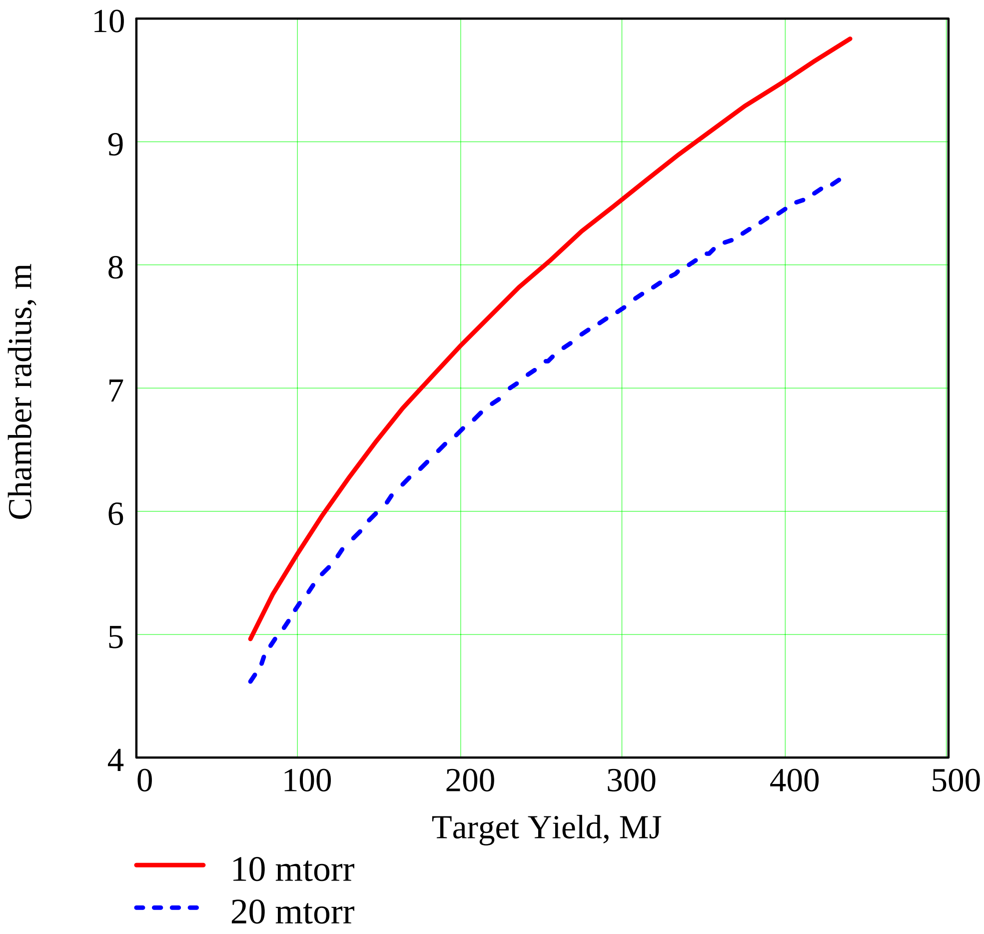
$Rwgv := 5$ $\qquad$ guess value

$Rwmin(E, p) := \mathrm{root}(Twmax - Tw(E, Rwgv, p), Rwgv)$

For 154 and 400 MJ yield:

$Rwmin(Eo, 10) = 6.673 \qquad Rwmin(2.821, 10) = 9.504$

# Minimum chamber radius vs target yield and chamber pressure for $T_{Wmax}$ = 2400 C



# Model for target heating during chamber transit has been added

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Normal Arial 10

**Target Heating in Chamber**

Calculate maximum target time vs heat rate.
This uses Raffray target heating scaling.

$$vmol(T) := 872\cdot\left(\frac{T}{6000}\right)^{0.5}$$ "molecular" velocity, m/s

$$a(vinj,T) := \frac{vinj}{vmol(T)}$$ ratio of target injection velocity to vmol

$$\gamma(vinj,T) := 0.7684\cdot a(vinj,T)^2 + 1.8768\cdot a(vinj,T) + 0.99545$$ Velocity and T scaling parameter

$$\Delta E(T) := 158.3\cdot(T-18) + 9.62\cdot 10^4 + 1.75\cdot 10^4$$ Heat absorbed due to cooling, condensing, solidifying Xe on target, J/kg

Heat rate, W/cm2 (scaled from result at 400 m/s, Tgas = 6000K, p = 10 mtorr)

$$HR(vinj,T,p) := 3.69\cdot\frac{\gamma(vinj,T)}{\gamma(400,6000)}\cdot\frac{\Delta E(T)}{\Delta E(6000)}\cdot\frac{p}{10}\cdot\frac{T}{6000}\cdot\left(\frac{6000}{T}\right)^{0.5}$$

check results- OK --->

$$HR(400,6000,10) = 3.69$$

$$HR(400,4000,10) = 2.401$$

$$HR(100,6000,10) = 2.232$$

Allowable in-chamber time limited by target heating

$$\tau tar(h) := 0.035775\cdot\left[0.8\cdot\left(\frac{2}{h}\right)^{0.8} + 0.2\right]$$ This is a fit to Raffray curve of allowable heating time vs heat rate

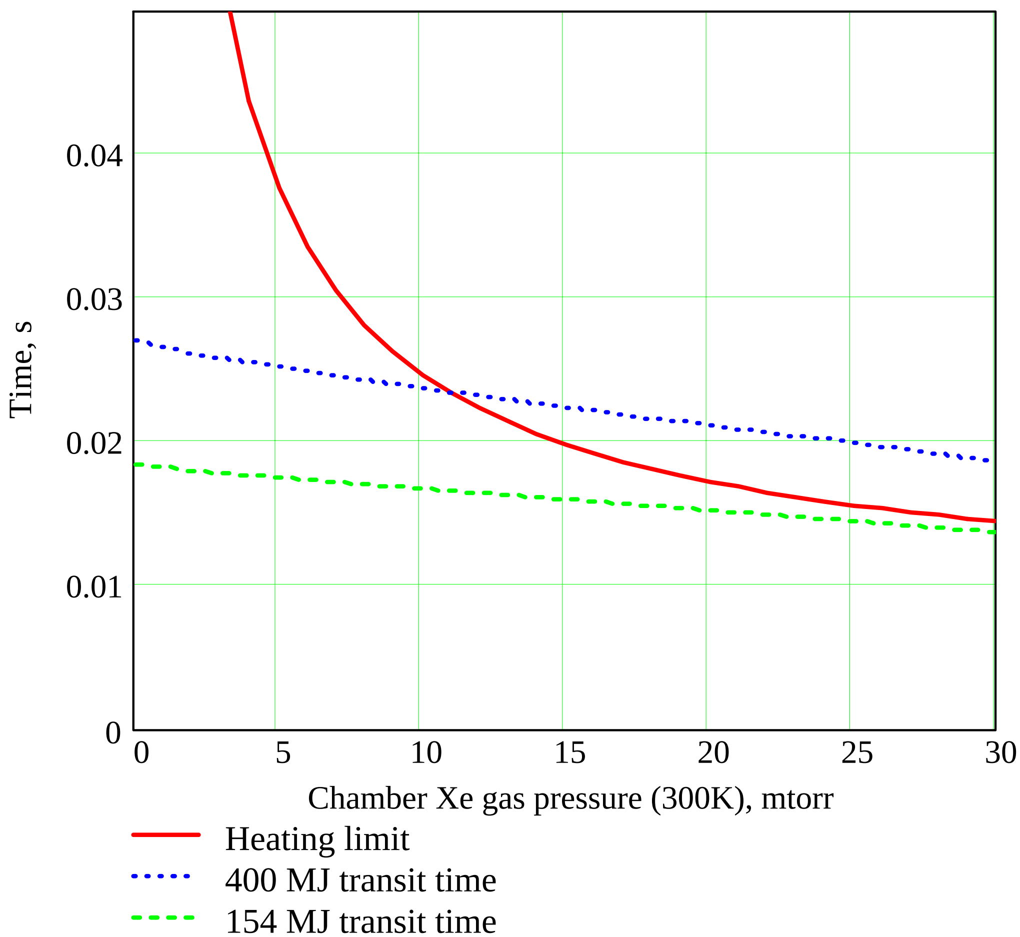
Insert HR equation from above

$$\tau tarmax(vinj,T,p) := 0.035775\cdot\left[0.8\cdot\left(\frac{2}{HR(vinj,T,p)}\right)^{0.8} + 0.2\right]$$

- Based on Raffray's Excel model for foam insulated target
- Heat rate ($W/cm^2$) is function of injection velocity, temperature and pressure of Xe gas
- Allowable transit time is calculated as function of these same parameters.

# Target heating could limit chamber pressure

$V_{inj} = 400$ m/s, $T_{Xe} = 6000$ K

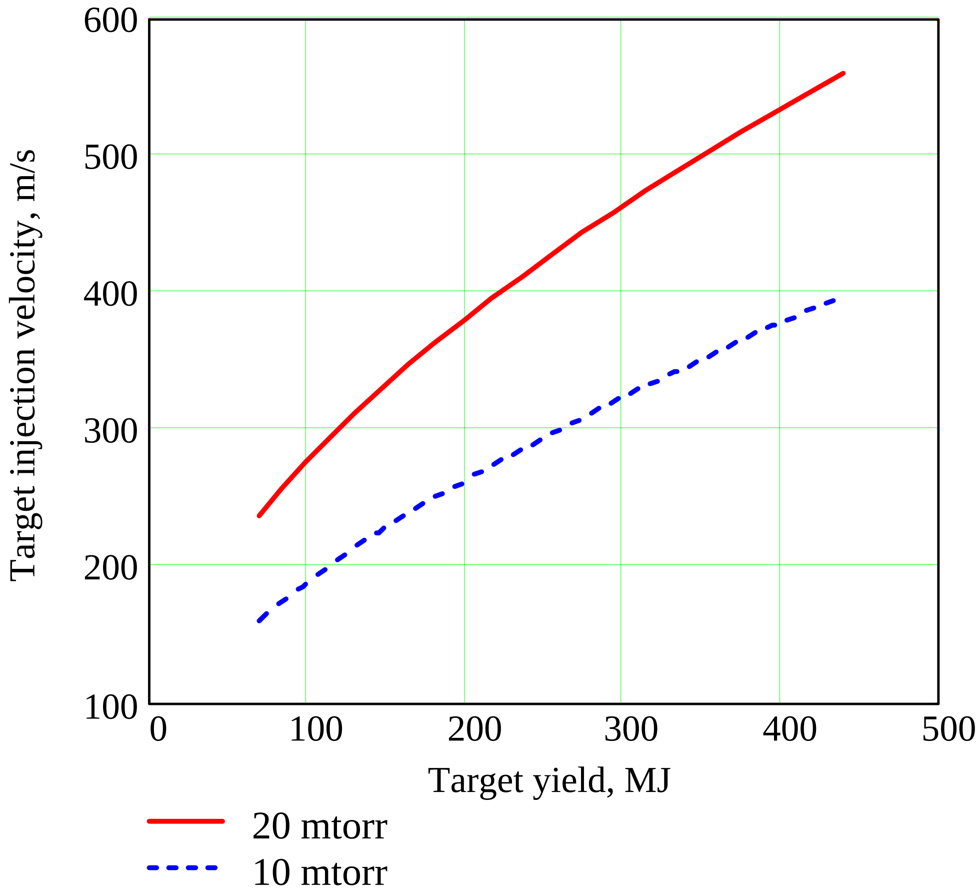



- For 154 MJ target, chamber is small enough that transit time at 400 m/s in less than allowable heating time.

- For 400 MJ target, transit time at 400 m/s exceeds allowable heating time for $P_{Xe} > 11$ mtorr.

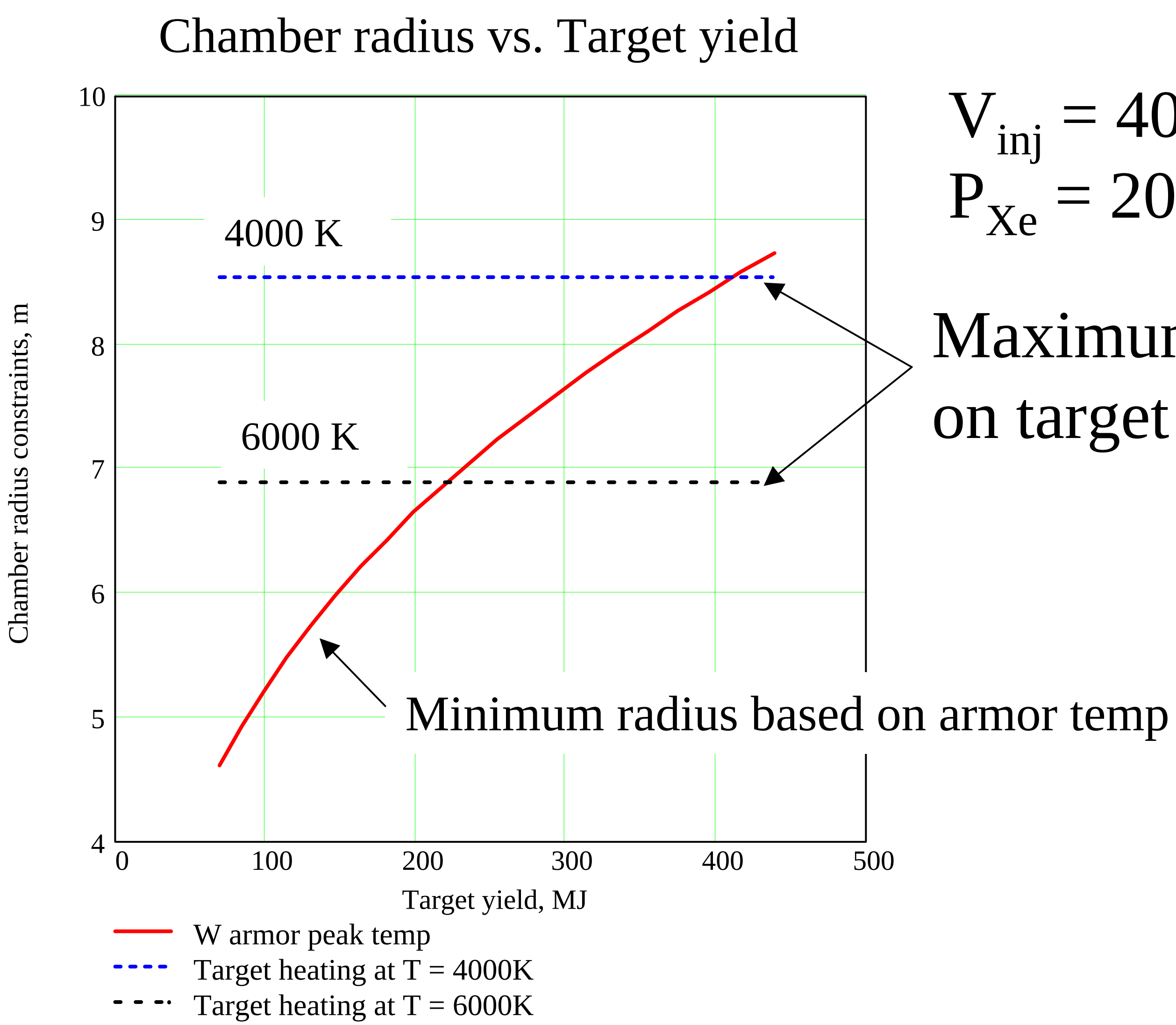
- Allowable time increases with decreasing Xe temperature, relieving this constraint (e.g., $P_{Xe} < 20$ mtorr at $T_{Xe} = 4000$ K)

# Many design aspects can be explored – e.g., required injection velocity for target survival




Although higher Xe pressure gives a smaller chamber, shorter allowable heating time demands higher target injection velocity.

# Example of multiple constraints – W armor max temp and target heating in chamber




$V_{inj}$ = 400 m/s
$P_{Xe}$ = 20 mtorr

Maximum radius based on target heating

# Next steps

- Continue work on incorporating FW/blanket design info
  - For thick W armor, steel temp based more on steady conditions (power flow) than pulse effects (yield)
  - Add thermal stress constraint
  - Need to calculate pulsed stress due to isochoric heating of Li in coolant channel and determine if it is a problem
  - Add conversion efficiency scaling (dependence on radius, power, coolant parameters). Eventually optimization will pick radius to minimize COE subject to constraints.
- Other target injection constraints (e.g., What fraction of inter-pulse time is useable, perhaps to allow settling of turbulence, cooling of gas?)
- Update gain curve based on Perkin's work