GENERAL ATOMICS
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Los Alamos
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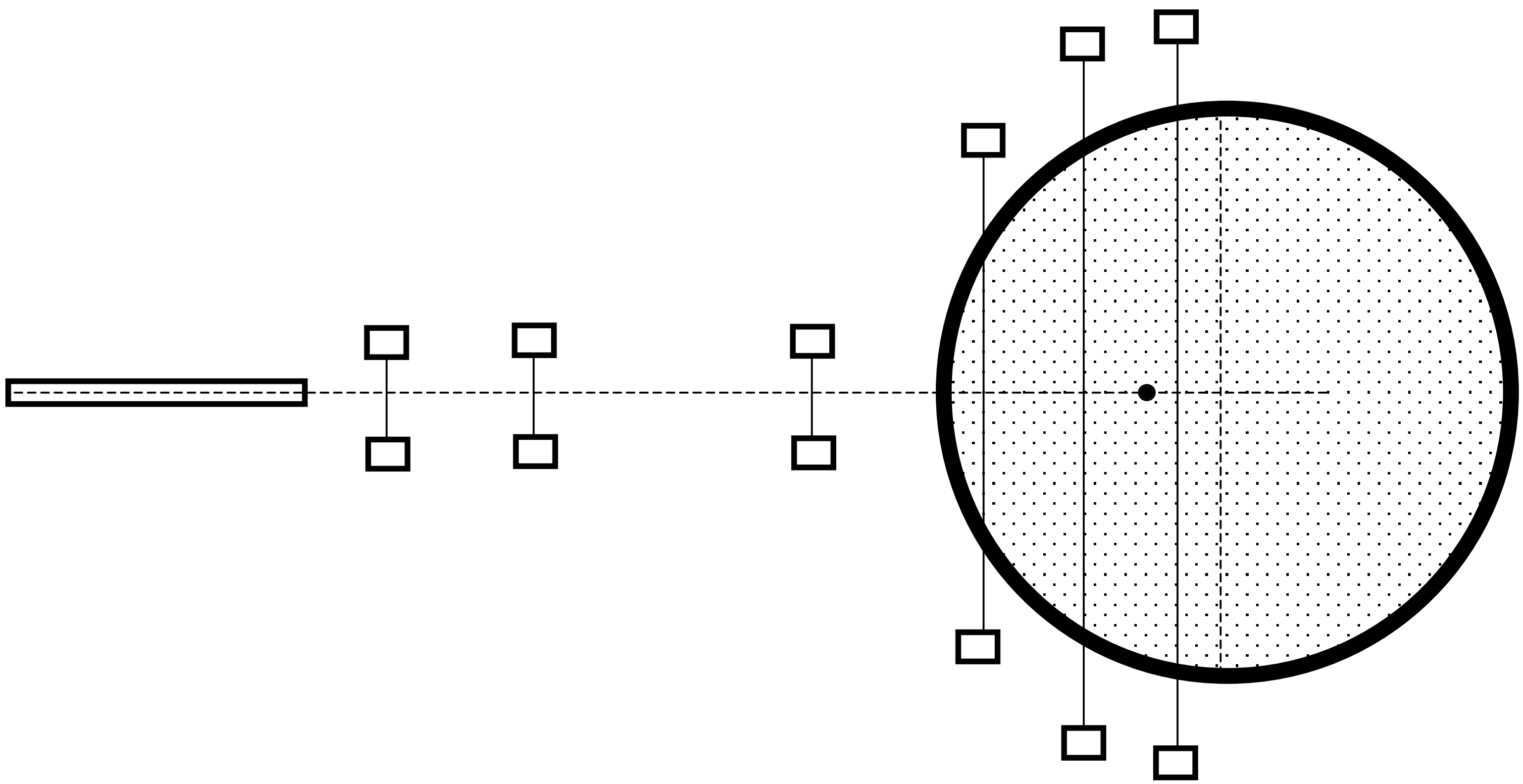
Aerosol Limits for Target Tracking



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Outline

Review effects of aerosols on direct drive targets

Review effects of aerosols on indirect drive targets

Light absorption, scattering, and extinction

Effect of particle size on extinction efficiency

Particle number and mass density limits vs particle radius based on light extinction

Single particle size limit based on tracking accuracy

Direct drive target fabrication specifications affect acceptable aerosol size and density

Target Fabrication Requirements:

- **The final target surface finish is required to be <50 nm RMS over lengths of 20 to 100 μm.**
- **The deviation from uniformity for the high-Z layer must be less than 10% of its thickness (10% of 32 nm for gold).**

Resulting Aerosol Requirements:

- **The 50 nm RMS surface finish requirement suggests aerosols shouldn't be larger than ~50 nm (~10^{-15}g) (larger droplets may flatten on impact)**
- **High Z surface buildup should not exceed a few nm (low Z is less critical)**

3 nm buildup in 6 m corresponds to ~5×10^{-10} relative density

(~5 mg/m^3 for Pb)

If droplet density and size are not excessive, in-chamber tracking should not be necessary for indirect-drive targets

Calculate maximum acceptable single droplet size near edge of 3 m chamber

$$\Delta R = \frac{\Delta v}{v_0} R_c = \frac{m_d}{m_t} R_c \Longrightarrow m_d = \frac{\Delta R}{R_c} m_t = \frac{0.3 \text{ mm}}{3 \text{ m}} 2 \text{ g} = 0.2 \text{ mg}$$

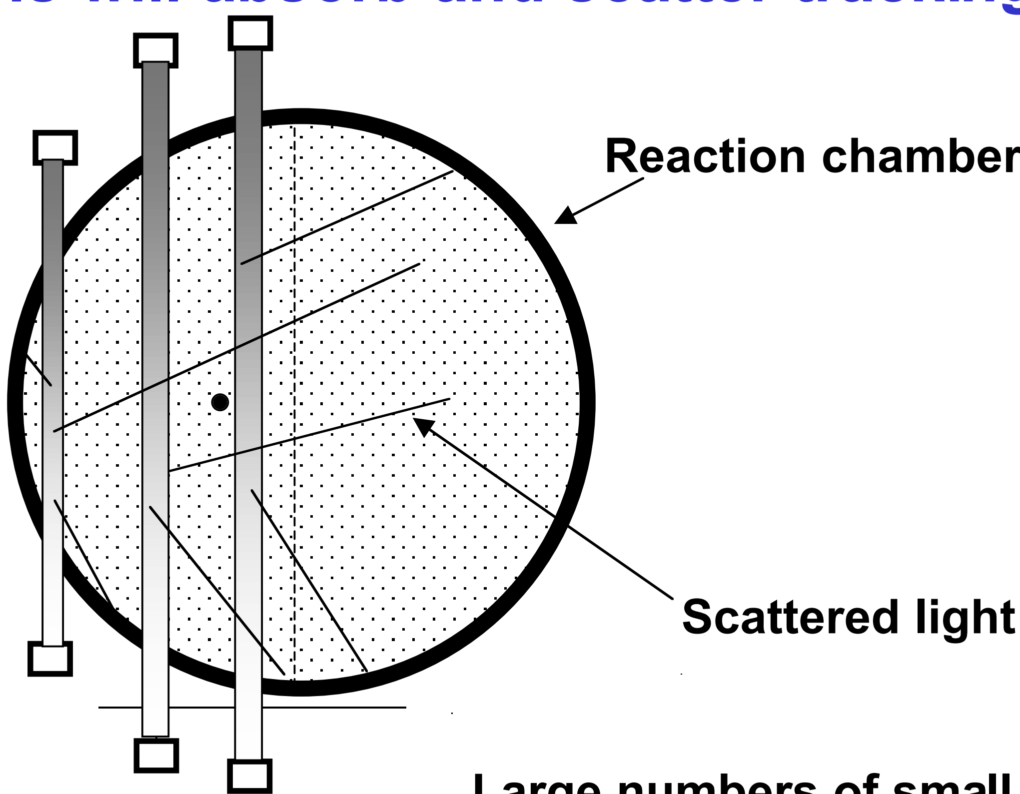
Droplet radius is 0.29 mm (assuming 2 g/cc liquid density).
Chamber density is limited to about 1 g/m^3 for numerous smaller droplets.

1 g/m^3 could cause 0.3 mg/cm^2 accumulation on target passing through a 3 m radius chamber

$$\frac{\rho}{A} = \rho R_c = \left(1 g / m^3\right)(3m) = 0.3 mg / cm^2$$

This is roughly 1% of ion beam range for 3.5 GeV Pb ions so energy loss is acceptable (<1%) for HIF targets.
Scattering of beam by droplets in chamber may cause more losses

Aerosols will absorb and scatter tracking light



Large numbers of small particles reduce tracking intensity

A single large particle could affect position measurement accuracy

Extinction = Absorption + Scattering

$$\frac{I_t}{I_i} = \exp(-\alpha_{ext} h)$$

$$\alpha_{ext} = N(C_{abs} + C_{sca}) = NC_{ext}$$

$$Q_{ext} = C_{ext} / A$$

$$= 0 \text{ for very small particles}$$

$$= 2 \text{ for large particles}$$

N = number density of particles
C = Cross section
Q_{ext} = Extinction efficiency
α_{ext} = Extinction coefficient

Thus, we must estimate C_{ext} and Q_{ext} to know light absorption in the chamber

Scattering and absorption efficiency drop quickly with size for small particles (size much less than wavelength)

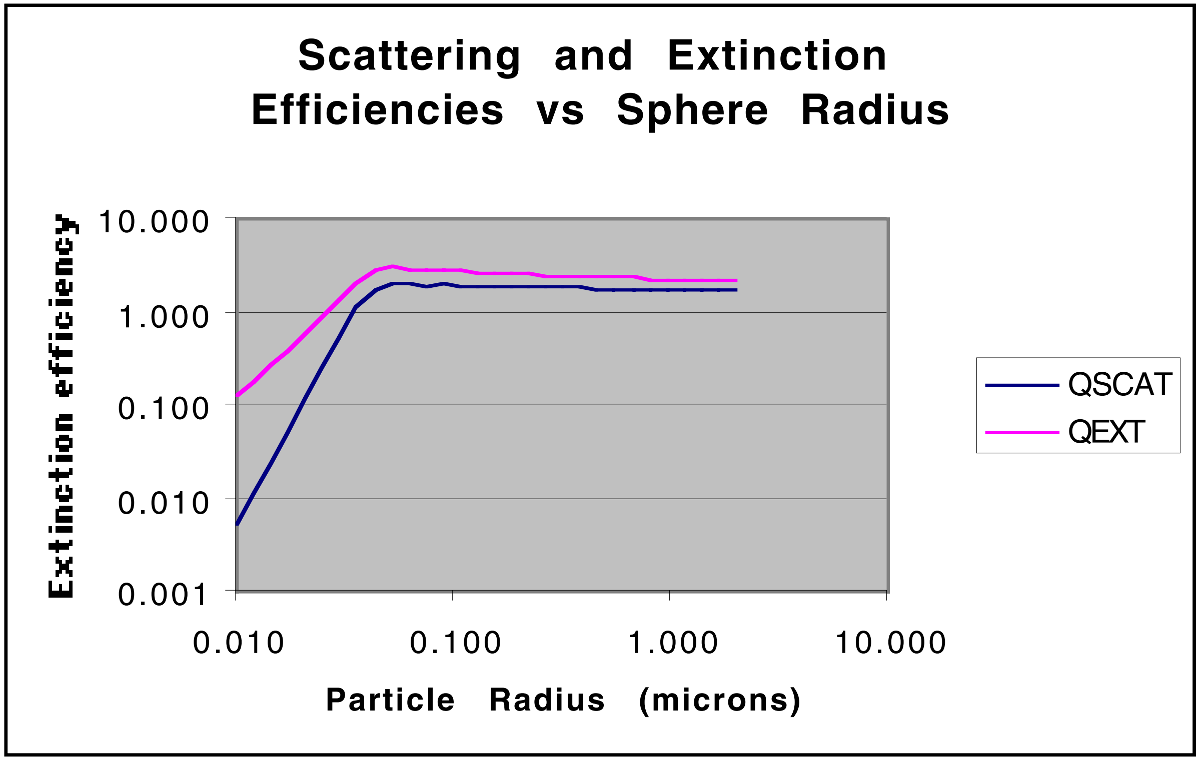
Size parameter x = ka = 2πna/λ
n = index of refraction
m = relative index of refraction
a = particle radius

$$Q_{sca} = \frac{8}{3}x^4\left|\frac{m^2-1}{m^2+2}\right|^2 \quad \text{so, for small x, } Q_{sca} \propto \frac{1}{\lambda^4}$$

$$Q_{abs} = 4x\,\mathrm{Im}\left\{\frac{m^2-1}{m^2+1}\right\}\left[1-\frac{4x^3}{3}\mathrm{Im}\left\{\frac{m^2-1}{m^2+1}\right\}^2\right]$$

$$\approx 4x\,\mathrm{Im}\left\{\frac{m^2-1}{m^2+1}\right\} \quad \text{so, for very small } x,\ \mathrm{Q}_{\mathrm{abs}} \propto \frac{1}{\lambda}$$

Calculated extinction and scattering for Pb and 0.3 micron light

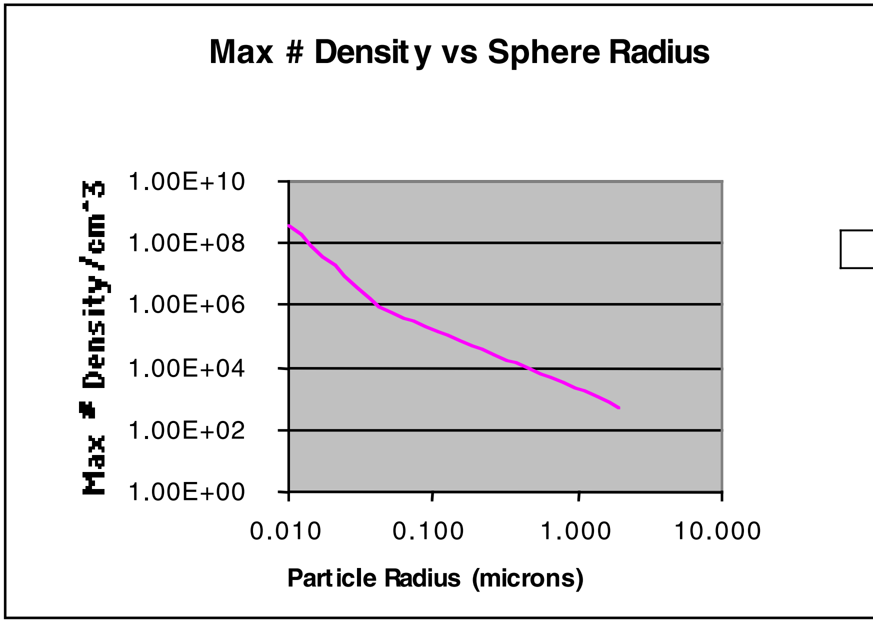


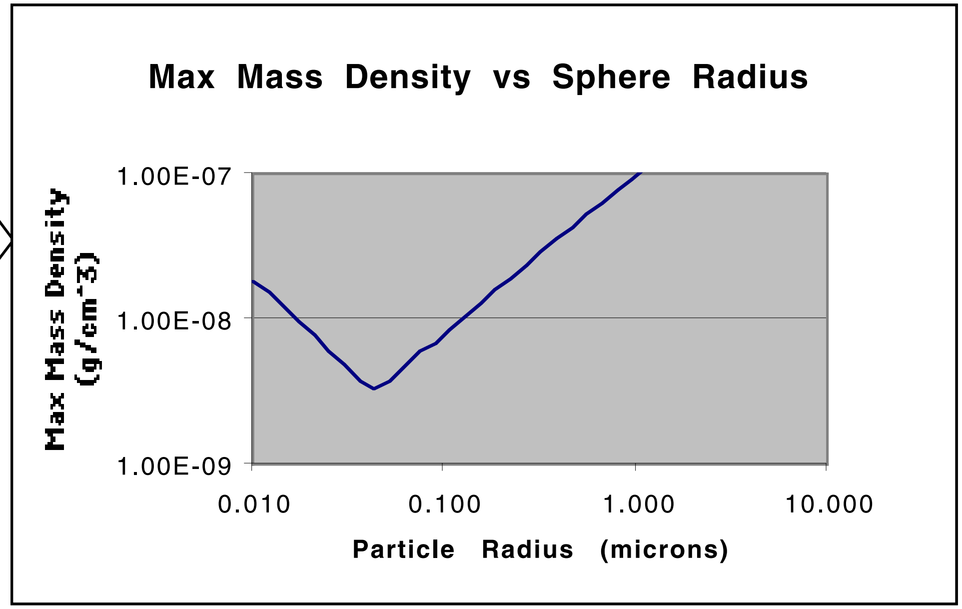
n = 4.4, k = 3.9

$$C = Q\pi r^2$$

Thus, for a particle radius 10X smaller than the wavelength, Q drops and more particles are allowed.

Beam extinction places limits on particle number and mass density





These calculations may also be useful for driver beam aerosol limits

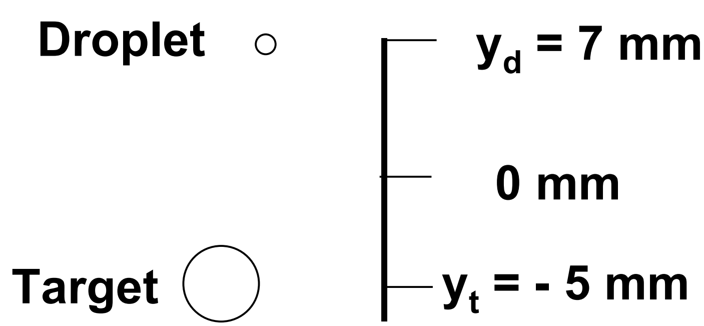
Assumes Pb particles and 0.3 micron wavelength and 90% beam propagation through 6.5 m

Single particles size is limited by effect on measured target position

Measured target position y is effected by droplet

Field of view 7 μm × 14 mm

(assumes pixel width w_p = 7 μm)



$$y_m = \frac{A_t y_t + A_d y_d}{A_t} = \frac{2 r_t w_p y_t + \pi r_d^2 y_d}{2 r_t w_p}$$

$$\Delta y = y_m - y_t = \frac{(y_d - y_t)\pi r_d^2}{2 r_t w_p}$$

Maximum allowed measurement error sets max droplet radius.

$$r_d = \sqrt{\frac{2 r_t w_p \Delta y_{\max}}{\pi (y_d - y_t)}} \approx \sqrt{\frac{2(2{,}000\,\mu\text{m})(7\,\mu\text{m})(2\,\mu\text{m})}{3.14(12{,}000\,\mu\text{m})}} = 1.24\,\mu\text{m}$$

Multiple droplets in beam path would reduce this limit further
Changes in position computing algorithm may reduce the measurement error

Conclusions:

Rough approximate aerosol size and density limits are shown in table

Target type	Particle size limit and basis	Density limit and basis
Laser direct drive	50 nm (~10^{-15} g) Assumes particles stick & degrade surface finish	5 mg/m^3 High Z material thickness (low Z material may have higher limit)
Ion indirect drive	0.2 mg (~0.3 mm) External tracking	1g/m^3 External tracking & Beam energy absorption
Tracking system limit	~1µm Position measurement error	~ 10 mg/m^3 (Depends on particle radius) Tracking and driver beam absorption