Cryogenic recovery panel area required for fast recovery. **DRAFT** D. Shuman 6/17/2011

Thermal conductivities and heat capacities; from: Lanzanou, arxiv1103.1841v3.pdf, fig 3

$$K_{T\_Xe\_80K} := .005W\cdot cm^{-1}\cdot K^{-1}$$

$$K_{T\_Xe\_160K} := .002W\cdot cm^{-1}\cdot K^{-1}$$

$$C_{p\_Xe\_80K} := 200J\cdot kg^{-1}\cdot K^{-1}$$

$$C_{p\_Xe\_160K} := 250J\cdot kg^{-1}\cdot K^{-1}$$

all these values are fairly linear in this range

Heat removal required, assuming we cool a copper panel with LN2:

We need to bring (most of the) Xe from RT to an average temperature of

$$T_{c\_avg} := 0.5(77K + 161K) \qquad T_{c\_avg} = 119\,K$$

$$K_{T\_Xe\_avg\_s} := 0.5\left(K_{T\_Xe\_80K} + K_{T\_Xe\_160K}\right) \qquad K_{T\_Xe\_avg\_s} = 0.35\,W\cdot m^{-1}K^{-1}$$

$$C_{p\_Xe\_avg\_s} := 0.5\left(C_{p\_Xe\_80K} + C_{p\_Xe\_160K}\right) \qquad C_{p\_Xe\_avg\_s} = 225\,J\cdot kg^{-1}K^{-1}$$

Heat of fusion $H_f := 2.26kJ\cdot mol^{-1}$ $\quad C_{fus} := \frac{H_f}{M_{a\_Xe}}$ $\quad C_{fus} = 16.618\,kJ\cdot kg^{-1}$

Heat of vaporization $H_v := 12kJ\cdot mol^{-1}$ $\quad C_{vap} := \frac{H_v}{M_{a\_Xe}}$ $\quad C_{vap} = 88.235\,kJ\cdot kg^{-1}$

Heat capacity, at constant volume, in mass units: $\quad M_{a\_Xe} = 0.136\,kg\,mol^{-1}$

$$C_{v\_Xe} := \frac{1.5R}{M_{a\_Xe}} \qquad C_{v\_Xe} = 0.092\,kJ\cdot kg^{-1}\cdot K^{-1}$$

Total heat removal required (assume 14/15 of all gas needs to be solidified and brought to avg. solid temp to bring vapor press. to 1 atm)

Total Xenon mass $M_{Xe} := 150kg$ $\quad \rho_{Xe\_s} := 3gm\cdot cm^{-3}$

Total Xenon volume $V_{Xe} := \frac{M_{Xe}}{\rho_{Xe\_s}}$ $\quad V_{Xe} = 0.05\,m^3$

Total heat removal required

$$Q_T := \frac{14}{15}M_{Xe}\cdot\left[C_{p\_Xe\_avg\_s}\cdot\left(161K - T_{c\_avg}\right) + C_{fus} + C_{vap} + C_{v\_Xe}\cdot(293K - 161K)\right]$$

$$Q_T = 17.7\,MJ$$

Heat flux equation

$$q := K\cdot A\cdot\left(\frac{d}{dx}T\right)$$

Since dx is equal to thickness, which builds up over time, flux is an inverse function of Xenon thickness, and integrating over time will yield a log function of some sort (for thickness and flux as a function of time). Putting this formulation aside for now, in order to get a rough estimate of area required, we consider using an average value for thickness:

let thermal conductivity of solid layer be;

$$K_T := K_{T\_Xe\_avg\_s} \qquad K_T = 0.35\,W\cdot m^{-1}\cdot K^{-1}$$

If we assume a steady state heat flow over an average thickness, and we need to bring pressure down in:

$$\tau := 15s$$

We need an average heat removal rate of

$$q_{avg} := \frac{Q_T}{\tau} \qquad q_{avg} = 1.18\,MW$$

We have two equations in two unknowns, thickness and area of frozen Xenon

$$t \cdot A := V_{Xe}$$

$$q_{avg} := \frac{K_T \cdot \Delta T \cdot A}{t}$$

$$q_{avg} := K_T \cdot \frac{\Delta T}{t} \cdot \frac{V_{Xe}}{t} \qquad \Delta T := 161K - 77K$$

$$t_{Xe\_s} := \sqrt{\frac{K_T \cdot \Delta T \cdot V_{Xe}}{q_{avg}}} \qquad t_{Xe\_s} = 1.116\,mm$$

$$A_{Xe\_s} := \frac{V_{Xe}}{t_{Xe\_s}} \qquad A_{Xe\_s} = 44.794\,m^2$$

This is clearly infeasible for a panel, but maybe feasible using cooled charcoal or molecular sieve. So, we need to think about what our requirements are here, if we need to bring pressure down very quickly, for instance, if a feedthrough insulator fractures, (calculate choked flow here) then we are going to need an evacuated recovery tank. We also need to size a vent port on the vessel for a choked flow condition.