FERMILAB **ENGINEERING NOTE**	SECTION PPD/ETT	PROJECT BTeV/C0	SERIAL - CATAGORY	PAGE 1
SUBJECT Estimate of Cryopanel Regeneration Rate		NAME Mayling Wong		
		DATE Sept, 2002	REVISION DATE	

Problem: The gas load of the 5% model was measured to be a rate of 5e-4 torr-L/sec at room temperature. Assume the gas load of the pixel detector is 20 times the measured rate for the 5% model. This would make the gas load for the detector 0.01 torr-L/sec. Two cryopanels will be used as a primary water pump for the pixel vacuum vessel. Assuming the entire source of the gas load is outgassing of water (a conservative assumption), how thick can the ice build up on the cryopanel before the panel must be regenerated?

Given: Two cryopanels are placed inside the vacuum vessel, each with dimensions 13-inches by 50-inches. Both sides of each panel act as water pumps.

Cryopanel total surface area	$A := 1.7$	m^2
Cryopanel temperature	$Tp := 80$	K

Snow has a thermal conductivity ranging from 0.049 W/m-K to 0.190 W/m-K. [Incropera, F.P., et al, Fundamentals of Heat Transfer, 1981] For this analysis, the lower value will be used for the thermal conductivity of the frost. Water cryodeposits have been reported to have a density of 810 kg/cm^3. [Wood, B.E., et al, “Spectral Infrared Reflectance of Water Condensed on Liquid Nitrogen-Cooled Surfaces in Vacuum,” AIAA Journal, Vol. 9, No. 9, September, 1971]

Snow density	$\rho := 810$	kg/m^3
Snow emissivity	$\varepsilon := 0.92$	
Snow thermal conductivity	$k := 0.049$	W/m-K
Molecular weight of water	$M := 18$	kg/kmol
Diameter of water molecule	$d := 0.46 \cdot 10^{-9}$	m
Stephan-Boltzmann constant	$\sigma := 5.6697 \cdot 10^{-8}$	W/m^2-K^4

The vacuum has an ambient temperature of 300 degrees K.

Vacuum ambient temperature	$Ta := 300$	K
Detector gas load	$Q := 0.01$	torr-L/sec

Solution: The assumption is made that the source of the gas load is water outgassing from the detector. The outgassing rate of water can be interpreted as a quantity of 0.01 torr-L of water for every second. The quantity is calculated in terms of number of molecules following the ideal gas law.

Universal gas constant	$R := 8.314$	kJ/kmol-K

Number of molecules in a 0.01 torr-L

$$n := \frac{Q \cdot 133.32 \cdot 0.001}{R \cdot 1000 Ta}$$

$n = 5.345 \times 10^{-10}$ kmol

$n := n \cdot 1000$

$n = 5.345 \times 10^{-7}$ moles

$n := n \cdot 6.023 \cdot 10^{23}$

$n = 3.219 \times 10^{17}$ molecules

Thus, water molecules are outgassing from the detector at a rate of 3.2e17 molecules per second. Assuming the rate remains constant, how many molecules have outgassed in a year?

Number of water molecules outgassed in a year

$$nyear := n \cdot 60 \cdot 60 \cdot 24 \cdot 365$$

$$nyear = 1.015 \times 10^{25} \quad \text{molecules}$$

Now, let all of the water molecules that outgas from the detector stick to the cryopanel. How thick would the frost layer be on the cryopanel, assuming it is characteristic of snow?

Thickness of frost

$$x := \frac{nyear \cdot M}{A \cdot \rho \cdot 6.02 \cdot 10^{23} \cdot 1000}$$

$$x = 2.205 \times 10^{-4} \quad \text{m}$$

The frost thickness that builds up on the cryopanels is 0.22 mm in a year. In order to estimate the performance of the cryopanel with such a frost thickness on it, it is assumed that the heat transfer by radiation through the vacuum is equal to the heat transfer by conduction through the frost layer. The temperature of the frost surface can be calculated as a function of the frost thickness.

Initial guess of frost surface temperature $Ts := 100$ K

Given

$$\varepsilon \cdot \sigma \cdot \left(Ta^4 - Ts^4\right) = k \cdot \frac{(Ts - Tp)}{x}$$

$$\text{Find}(Ts) = 81.89 \quad \text{K}$$

The pumping speed of the cryopanel is not readily quantified for a given frost thickness. However, in the 5% model, the cryopanel had a pumping speed of 19,000 L/sec when it was at a temperature of 113K.

In summary, after one year of operation with a water-outgassing rate to be 0.01 torr-L/sec, a frost layer that is 0.22 mm thick is expected to build up on the cryopanels. For such a thickness and having the panel temperature at 80K, the frost surface temperature would be 82K. It is expected that the cryopanel with a 0.22 mm thick frost layer will operate as well as the cryopanel did in the 5% model test, where its temperature was 113K. Thus, the cryopanel can operate for a year without regeneration. It is likely that the vacuum system will be opened up more often than a year, so the cryopanel can be regenerated during each experimental shutdown.