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Re-assessing the Maximum Allowed Infrared (IR) Power for Enhanced Layering in a Conduction Dominated Cryogenic NIF-Scale Hohlraum

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MEMORANDUM

TO: Distribution

FROM: Bernard Kozioziemski

SUBJECT: Re-Assessing the maximum allowed infrared (IR) power for enhanced layering in a conduction dominated cryogenic NIF-scale hohlraum.

I. SUMMARY

Recent measurements of the infrared (IR) absorption coefficient of CH and CD capsules differ significantly from earlier estimated values from thin flat samples. The optimum wavelength for IR enhanced layering of DT and D_2 ice layers inside of a NIF scale hohlraum depends on the relative ice and capsule absorption coefficients. This update of a previous memo shows the maximum ice heating with IR as a function of ice and capsule absorption instead of at discrete wavelengths. Also discussed is the leverage of other parameters, such as the IR absorption of the hohlraum wall, and thermal conductivities of the support rods and exchange gas. The most likely capsule and ice absorption values limit the IR heating to between 2 - 7 Q_{DT}. We find most leverage of the IR heating comes from increasing the ice to capsule absorption ratio. As before, this is the conduction only limit to IR, with convection potentially playing a large role.

II. INTRODUCTION

The amount of IR power that can be used for heating a solid hydrogen ice layer inside plastic shell for NIF ignition hohlraums is limited by the extraction of that heat. The capsules are ideally cooled by conduction, as convection introduces asymmetries in the shell temperature leading to deformations in the ice layer. The relatively low thermal conductivity of helium gas at cryogenic temperatures limits the total power that can be deposited in the capsule and ice layer to a few milli-watts. Thus, the ice heating is limited by any capsule absorption. Similarly, the total heat deposited in the hohlraum must be extracted through the cooling rods to the cryostat cold head, further limiting the IR heating of ice layers.

The calculational results described in this memo extend the range of parameters compared to the previous memo[1]. The goal is to determine the best region to search in order to maximize IR heating. The details of the calculation are the same as those described in the previous memo. Briefly, the capsule consists of an 80 μm thick ice layer inside of a 2 mm diameter, 150 μm wall plastic shell. A NIF scale-1 hohlraum surrounds the capsule and has a roughened gold surface to scatter and symmetrize the IR. The absorbed IR power in the ice, shell, and hohlraum are found by raytracing. These powers are then used in a spherical, one-dimensional analytical calculation to determine the temperature difference between the inner ice surface and the hohlraum wall. The total IR power must be extracted by two sapphire rods from the hohlraum to the cryostat cold head. Finally, the IR power is scaled to find the maximum amount of IR power into the ice consistent with the inner ice surface at 1.5 K below its melting temperature (T_m = 19.7 K for D-T) and the cryostat cold head at 7.5 K. Maximizing the IR power requires the hohlraum wall be kept as cold as possible and the tamping gas thermal conductivity be as high as possible. Hence, the tamping gas is assumed to be pure helium rather than a helium-hydrogen mixture. The temperature dependence of both the helium and sapphire thermal conductivities are included since both are a strong function of temperature over the range of interest of this problem.

Where as the previous memo examined the maximum IR heating for discrete wavelengths using the best known capsule and hohlraum parameters, this memo looks at how the maximum Q_{DT} changes with physical parameters that we may have limited control over. Improving the capsule absorption, hohlraum wall absorption, and the support rod conduction would each require significant investment of resources. Thus, knowing the relative gain in Q_{DT} helps to make the case for pursuing one area over another.

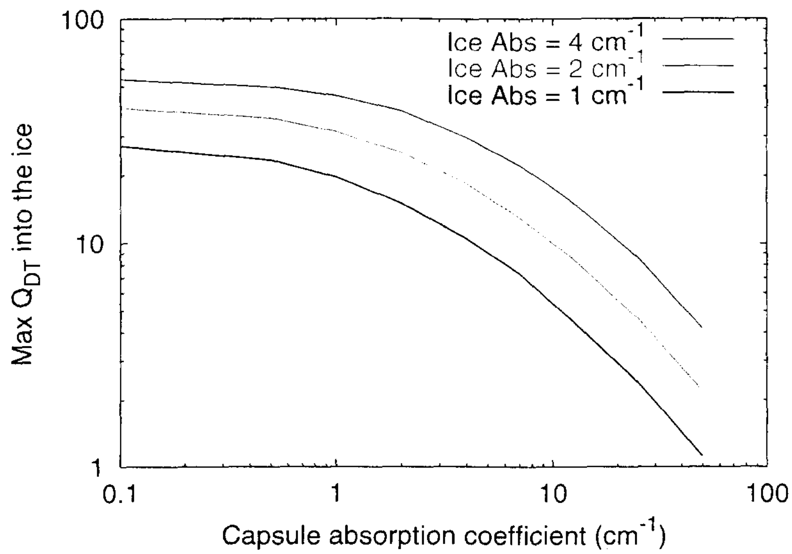

FIG. 1: Maximum Q_{DT} of IR heating into the ice with $\alpha_{ice} = 1$ cm^{-1}, 2 cm^{-1}, and 4 cm^{-1} as a function of the capsule absorption coefficient.

III. RESULTS

Figure 1 shows the maximum ice heating as a function of the capsule absorption coefficient, α_{cap}. The range of α_{cap} includes values much lower than current materials, but is useful in showing the limits of IR heating. The current best candidate shell materials have absorption coefficients in the range of 5 cm^{-1} to 30 cm^{-1}, limiting the D-T heating to 2-10 Q_{DT} for the nominal ice absorption of α_{ice} = 1 cm^{-1}. For comparison, α_{ice} values of 2 cm^{-1} and 4 cm^{-1} are also shown, where the former is maximum expected value for the strongest D-T line and the latter is the D_2 absorption value. The hohlraum wall was defined in the raytrace model to be consistent with our current experimental system, namely a 4 μm RMS surface with approximately 10% absorption for each ray bounce.

Heating of the hohlraum limits the Q_{DT} in the ice when α_{cap} is very low. Figure 2 shows that the Q_{DT} into the ice can be increased when the hohlraum absorption is removed, but only gains a substantial amount when α_{cap} is small. The absolute best case is when the capsule heating is off and the hohlraum is non-absorbing. In this case, the ice heating can reach up to 80 Q_{DT}. However, we see that for more modest α_{cap} the hohlraum absorption has little impact on the problem, buying about 15 to 25 percent increase when the hohlraum absorption

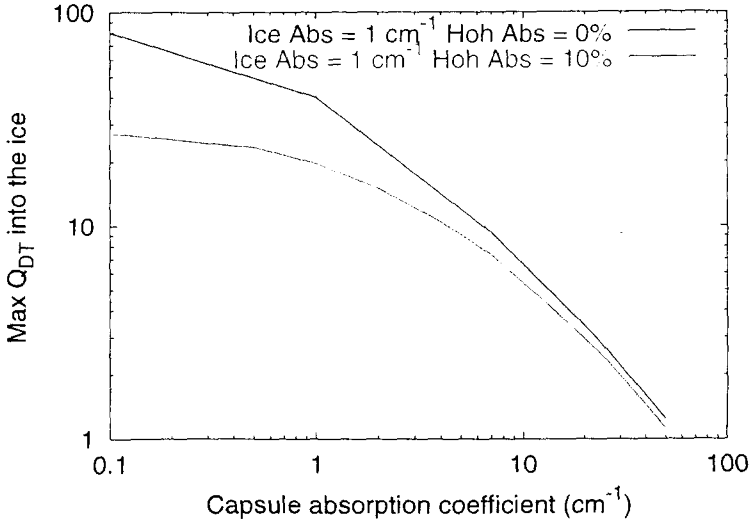

FIG. 2: Maximum Q_{DT} of IR heating into the ice with $\alpha_{ice} = 1$ cm^{-1} for the non-absorbing hohlraum surface and the 4 μm rms surface as a function of the capsule absorption coefficient.

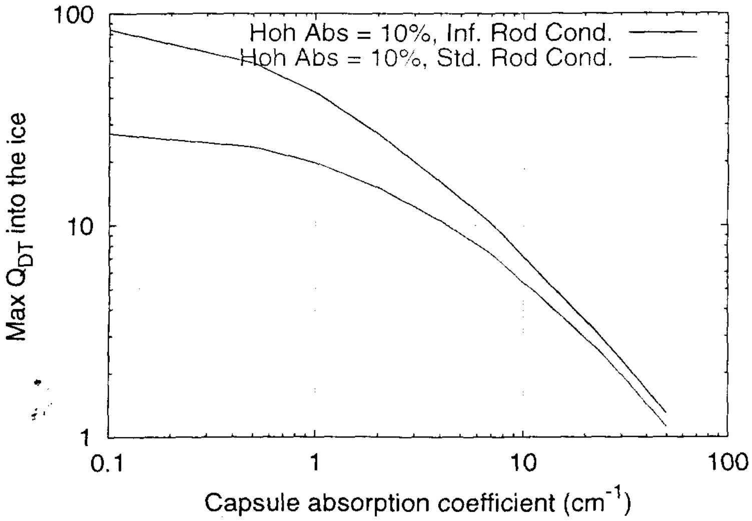

FIG. 3: Maximum Q_{DT} of IR heating into the ice with $\alpha_{ice} = 1$ cm^{-1} comparing the effect of the increased sapphire rod conductivity. The baseline case is shown along with 1000 times larger support rod thermal conductivity.

is turned off completely.

Next, the support rod thermal conductivity was increased. As with the reduced hohlraum wall absorption, a large increase in Q_{DT} of the ice is obtained only when α_{cap} is small. Figure 3

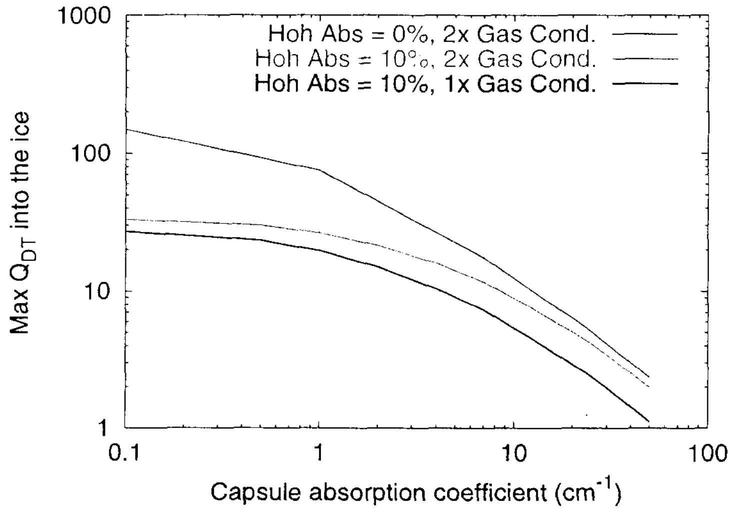

FIG. 4: Maximum Q_{DT} of IR heating into the ice with $\alpha_{ice} = 1\ cm^{-1}$ for two different hohlraum absorptions and gas thermal conductivities compared to the baseline. The most gain in IR into the ice layer occurs for $\alpha_{cap} < 1\ cm^{-1}$.

compares the nominal sapphire rod conductivity with an unrealistic material having 1000 times larger conductivity. For α_{cap} of 1 cm^{-1} to 3 cm^{-1}, the increase in Q_{DT} is between 20% and 28%. As with the hohlraum wall absorption, the majority of the temperature drop from the ice to the cold tip is across the exchange gas for the current best capsule materials.

Convection has so far not been considered in this calculation. The thermal asymmetry generated by convection flows will further limit the IR in the ice layer because the convection cells grow rapidly with temperature gradient. However, it may be possible to tune out the low mode perturbations with the a combination of IR pointing, power balance, and thermal shimming of the hohlraum. Then convection may help since the convective flows increase the heat conduction from the capsule to the hohlraum walls. The benefit convection cooling is estimated by increasing the exchange gas thermal conductivity.

Figure 4 shows the effect of doubling the gas thermal conductivity on the maximum ice Q_{DT}. Simply doubling the conductivity gives a little less than a doubling in the maximum Q_{DT} because the hohlraum heating plays a role, particularly for low α_{cap}. Also shown in the figure is the maximum Q_{DT} for the case with no hohlraum absorption, which doubles compared to the case with 1x gas conduction and a non-absorbing hohlraum.

In summary, the range of possible D-T ice heating has been explored for many cases. When α_{cap} is less than 10 cm^{-1}, the gain in Q_{DT} into the ice starts to become substantial for decreased hohlraum wall absorption and increased support rod conductivity. For a realistic hohlraum wall absorption decrease by a factor of two and increase in support rod conduction of a factor of two, the maximum Q_{DT} can be increased from 4.6 to 5.4 with α_{cap} = 1.2 cm^{-1}. Much more substantial gains are realized by decreasing α_{cap}.

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[1] B. J. Kozioziemski, *LLNL memo, Assessing the maximum allowed infrared (IR) power for enhanced layering in a cryogenic NIF-scale hohlraum.*, Livermore, **2002**.

[2] R. C. Cook, A. Nikroo, S. A. Letts, *LLNL memo, Measurement of Wavelength Dependent Extinction Coefficients for Target Capsule Materials,* Livermore, **2001**.

[3] B. J. Kozioziemski, R. L. McEachern, R. A. London, D. N. Bittner, "Infrared Heating of Hydrogen Layers in Hohlraums", *Fusion Science and Technology,* **41**, pp. 296–302 (2002).

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