Target Survival Workshop
December 6, 2002
Naval Research Laboratory
Washington, D.C.

A target survival workshop was held on December 6, 2002 as part of the HAPL Project Review at NRL,Washington D.C. The goal of the workshop was to refine our understanding of direct drive target survival during injection and of constraints from the physics, fabrication and engineering communities - and decide what can be done to improve our position on this subject during the next 3 years. The format encouraged informal discussion guided and moderated by Dan Goodin and René Raffray. The major points from the discussion are highlighted in the discussion summary section

Background Discussion

The primary sources of target heating include radiation from the hot chamber walls and heating from the chamber gas. A highly reflective outer layer of high-Z and reduced chamber wall temperatures may adequately protect the target from radiation heating. One of the most promising methods to further protect the target DT from heating is an outer foam layer on the target.

In addition, we should critically evaluate the "failure" criteria that we use to define target survival. The failure assumption that we have used for quite some time is that the target starts out at about 18K (because cooling to lower temperature may result in a rough inner DT ice surface and to set the DT gas density inside) and no part of the DT should exceed the triple point during injection (because bubble formation at the outer ice/polymer interface would render the target unstable).

GA and UCSD have taken a "two-pronged" approach to the recent target survival analyses. First, adding an outer layer that could slow the heat pulse into the DT such that the outer DT remains below the triple point. Secondly, we have explored the effects happening at the DT seal coat interface during heating and considered whether the "triple point failure criteria" is overly conservative. Both of these approaches are discussed below. More details can be found in R. Raffray's presentation at the Dec. 5-6, 2002 HAPL review meeting: "Enhancing Target Survival."

First - adding outer layer insulators. Adding a foam as has been suggested (same density as the DT/foam layer with a total mass less than 25% of the DT/foam - which translates to 25% dense 72 μm thick PS foam; the seal coat is 2 μm) results in changing the distance that the target makes it into the chamber (before reaching the triple point) from 2.6 meters to about 4 meters (this is for a condition of ~1.17 W/cm^2 which corresponds to something like vacuum and a wall temperature of ~1500K with a 96% target surface reflectivity - i.e., not very severe conditions). Changing the 2 μm seal coat to 10 μm has a pretty small effect on "survival distance" (the target would make it 4.3 meters into the chamber instead of the 4 meters). Increasing the 25% dense foam layer thickness to 104

µm results in a survival distance of about 6.5 meters (which is what is needed - but this is based on the relatively low heat flux of ~1.17 W/cm^2, i.e., a condition for the "vacuum believers").

Now using a heat flux of about 7.5 W/cm^2(corresponding to a wall temperature of 1500K and about 50 mTorr of gas at 2000K - a more realistic chamber condition for the "gas believers"), a 25% dense foam with a thickness of 104 µm would have a survival distance of only ~2.7 meters but a 10% dense foam with a thickness of about 152 µm would have a survival distance of about 5.9 meters. In other words, this combination is just about getting there!

Second - now considering whether the criteria of remaining below the triple point is appropriate. Our current thinking is that enough heat will enter the DT ice through the seal coat and that one of three things could happen:

1) If the bonding at the DT/foam and plastic seal coat interface is perfect, boiling would only occur through homogeneous nucleations. However, homogeneous nucleation of bubbles on a 0.015 s time scale will be virtually non-existent for DT liquid temperature < ~26 K and would only take off at temperatures > ~34 K (close to the critical temperature of, ~ 39 K). Note that even if a liquid layer is formed around the target which is subject to a decelerating force in the chamber, the inner DT ice layer is pinned by the inner foam and should remain centered in the target.

2) If the DT/foam and seal coat bonding is not perfect then boiling would occur through heterogeneous nucleation requiring defects of the order of ~1 µm. It is still to be determined whether such defects on the surface of the foam or DT ice - or produced by beta particle stopping - will initiate bubbles on the 0.015 second time scale. Since the inner foam will "pin" the inner DT ice layer in the center of the target, the target should still be symmetric. The seal coat is very likely strong enough to contain the pressure (for thicknesses of 1-10 µm). This would mean that quite high heat fluxes could be tolerated.

3) The third scenario is an extension of the previous one and assumes that a micro-gap exists at the DT/foam and seal coat interface either due to original defects or perhaps as an extension of heterogeneous nucleation. This is the more conservative assumption in estimating the amount of DT vapor formed. There would already be DT vapor in the gap and heat fluxes to the interface would result in surface evaporation of DT increasing the pressure in the gap and consequently the thickness of the DT vapor region. This possibility was analyzed in more detail using a thermo-mechanical model including the effect of volume expansion during phase change and expansion of the seal coat. The resulting pressure in the DT region was consistent with the DT saturation temperature. For these initial calculations the DT/foam region was assumed to be rigid and pressure in the DT vapor region was reacted by the stress in the expanding seal coat. Initial results indicate that if a ~3 µm vapor gap is allowed, the maximum allowable heat flux is

~ 4 W/cm^2 for an 8 μm thick seal coat. This maximum heat flux is further increased to ~9 W/cm^2 if a 25% dense, 72μm thick outer insulating foam layer is also included. The effect of the non-uniform heat flux distribution on such a gap has to be further addressed. Assuming DT liquid and vapor formations occur continuously around the target, it remains to be determined whether the deceleration force over 0.015 sec can move a significant amount of the liquid to the front and the vapor to the back of target working against the surface tension of the liquid adhering to the foam walls and the flow impedance of the foam.

Based on this discussion, some target design questions come to mind for discussion at the target workshop, such as whether these options are viable:

a)   an outer (insulating) foam with ~10% density and a thickness of ~152 μm.
b)   a thin liquid region under the seal coat of uniform thickness.
c)   a thin region of mixed vapor and liquid (vapor bubbles no larger than the foam pore size) under the seal coat of uniform thickness.
d)   a thin layer of vapor followed by a thin layer of liquid under the seal coat both of uniform thickness.
e)   a thin layer of vapor followed by a thin layer of liquid under the seal coat, but with a P2 distribution of liquid and vapor (more liquid to the front and more vapor at the back, i.e., caused by the deceleration) but with the thickness of the combined vapor and liquid regions being constant.
f)   each of the above b) through e) but with the total (liquid/vapor) region thickness being non-uniform (caused by non-uniform heating around the target)

Summary of Discussion

The target survival workshop was very well attended and much useful discussion took place helping better appreciate the constraints imposed by target design and parameter changes on the whole spectrum of target-related areas. The discussions are summarized within the context of the two-pronged approach, i.e. (1) design modification to increase thermal robustness of the target, and (2) scenarios leading to phase change at the DT/foam and plastic seal interface which depend on the quality of the bonding there.

1)   Insulating outer foam layer as design modification to increase the thermal robustness of the target

At first, there was a general concurrence that an insulating porous foam layer (down to ~10% density and up to ~150 μm thick) is acceptable from a target physics standpoint provided that such a foam could be manufactured and would survive the injection. However, Steve Bodner remembered that there were results showing how an interface like that could create instabilities because of the sharp variation between the foam and plastic seal densities. The suggestion of Said Abdel-Khalik of making a gradual density change in the foam was thought to provide a solution for target physics but would have to

be compatible with manufacturing techniques. Diana Schroen noted that this had been done before but couldn't remember how strong the gradient was. She agreed to investigate this. This would result in the following layers needed: DT gas, DT solid, DT/CH solid, seal coat gradually diminishing to 10% density foam, then a final seal coat with high-Z on it. Further effort would be required to determine if it is possible and, if so, how to make, to fill and to layer this design.

In the end, Steve Obenschain said that despite what was said, the simple uniformly dense insulating foam target with a seal coat inside and outside the foam layer might still work and that NRL would try to evaluate it over the next 6 months or so before rejecting it.

While the original "radiation preheat" thinking has gone away, the outer high-Z layer will still reduce laser imprints and S. Obenschain suggested that it should be included in the target design. We also discussed how one would make the "outer foam insulated target" - mainly how to keep the outer foam "dry" but still have a smooth outer polymer layer with the high-Z. D. Goodin suggested the obvious way was to make the regular target and then add hemi-shells of dry foam (that would also have a high-Z coat already on it). The concern with that of course is the joint. From discussion during the workshop and after (between D. Goodin and S. Obenschain) it emerged that perhaps one could make the inner seal coat impermeable (at cryogenic temperatures) and try to make the outer seal coat permeable so the DT could be evaporated out of the outer foam at reduced pressure (i.e., during handling). One difficulty is that the high-Z layer must also be permeable at cryogenic temperatures. Andy Schmitt said it should be OK to put holes in the high-Z, but only at the 1 μm size. It was agreed to further think about how to fabricate and fill this modified DT target.

David Harding also reminded us that too good an insulator would hamper removal of the beta decay heat and that it must be determined how cold the outside of the target must be maintained to keep the inside below the triple point. This could also be very good for survival if the outer layer of DT (which is the only one affected in all the calculations done so far about keeping it below the triple point) starts out at substantially lower temperatures.

(2)   Scenarios leading to phase change at the DT/foam and plastic seal interface which depend on the quality of the bonding there.

What clearly came out of the discussion is that the "bond" between the DT/foam and the inner seal coat surface would be poor, i.e., with defects large enough to cause heterogeneous nucleation and possibly vapor-filled gaps leading to surface evaporation as assumed in the conservative scenario presented by R. Raffray at the HAPL review meeting. Although there was a consensus about this, it is not clear how much data there are to confirm this. Related to this, it was pointed out that J. Hoffer's results indicated that a void would be present (at least initially) in each cell of the DT/foam area (the "baby rattle" model of the target); this might substantially reduce the thermal conductivity and heat capacity of the DT and should be included in the thermal analysis. In addition, the

effect of asymmetric heating due to convection/condensation from the chamber gas (with the heat flux decreasing azimuthally over the target surface away from the leading edge) should also be more fully investigated, in particular in regards to local phase change behavior.

Although it seemed to be acceptable to have a uniform layer of DT vapor and/or liquid under the seal coat (which would preserve the density symmetry in the radial and circumferential directions), reservations were noted regarding the possibility of isolated bubbles under the surface which would locally affect the density pattern. The message from target physics researchers was that this would probably be unacceptable even if it can be considered as just a radial displacement (distance) rather than an areal density change.

Given the uncertainties regarding the phase change behavior of DT at the DT/foam and outer seal interface, R. Raffray suggested that this should be addressed experimentally in conjunction with improving the modeling capabilities to better understand the different processes and the ultimate effect on target performance. Experiments with DT or D_2 would be preferable to determine the phase change processes under different interface conditions and heat flux magnitude and profile. However, given the difficulty with performing such experiments it would be worthwhile to consider the possibility of using simulant materials under scaled experiments. There was some agreement on this but such experiments need to be better defined and characterized. A helpful initial step would be to characterize (measure) the compressive strength of DT/foam at relevant temperatures which should be included in the thermo-mechanics calculations (the calculations presented by R. Raffray assumed a rigid DT/foam and only deflection of the seal coat).

Action Items

1) NRL to evaluate the insulating foam target for stability (both uniformly dense and graded) (A. Schmitt, D. Colombant, S. Obenschain)

2) Schafer to look up the data on a "graded density" foams and see if this could be feasible (D. Schroen)

3) NRL to confirm that a uniform DT vapor region thickness below the outer seal (of about 3 microns) is acceptable and, in the actual case of non-uniform heating to provide guidance on how much variation is acceptable between the thickness of the vapor regions on opposite ends of the target (i.e. corresponding to the highest and lowest heat fluxes) (A. Schmitt, D. Colombant, S. Obenschain)

4) GA/UCSD to evaluate how much temperature drop there is to keep the insulated target cold (with beta decay heat) and determine how beneficial this temperature drop is with respect to survival estimates (R. Raffray, R. Petzoldt)

5)   GA/UCSD to evaluate the effect of asymmetric heating in particular on local phase change behavior. A new multi-dimensional model being developed for the thermo-mechanical behavior of the target will help better understand this (R. Raffray, R. Petzoldt)

6)   GA/UCSD to evaluate whether the insulated target with an outer seal that is permeable could actually be filled and "dryed" of DT in the outer foam (R. Petzoldt, R. Raffray)

While not specifically discussed at the workshop, two additional action items came out of subsequent discussions and are listed below:

7)   Measure the compressive strength of DT/foam at relevant temperatures (J. Hoffer).

8)   Investigate possibility of layering at lower temperature (18, 17, 16 K) to provide a means of accommodating higher heat fluxes during injection. (J. Hoffer). The effect of the correspondingly lower gas pressure on the target physics should be assessed (NRL).

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