High Power Heavy-Ion Beam Interactions in Matter

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R&D for Fragment Separation

The heavy-ion beams available from RIA will have to be stopped at the front end of the Fragment Separator after losing 10-30% of its energy in a transmission target. The unreacted beam and unwanted secondary beams will represent difficult problems because the will have very high power densities and short ranges. Uranium at 400 MeV/A has a range of about one centimeter (12 mm in carbon), so the volume where the power is deposited is quite small. Additional problem areas will be in the Linac where lower energy, but still high power, beams may need to be stopped in emergency beam dumps. In all of these dumps, the damage in the leading surface of the stops will be extremely high. Normally, after ~5 displacements per atom materials will have suffered significant damage so that structural integrity can be lost; although for materials such as structural steel the sustainable damage can be much higher [1]. The mechanisms for this loss can be any of several sources or a combination of them. Swelling, fracture, loss of thermal conductivity, evaporation, embrittlement and reduction in sheer or compressive moduli are some of the standard problems associated with radiation damage [2].

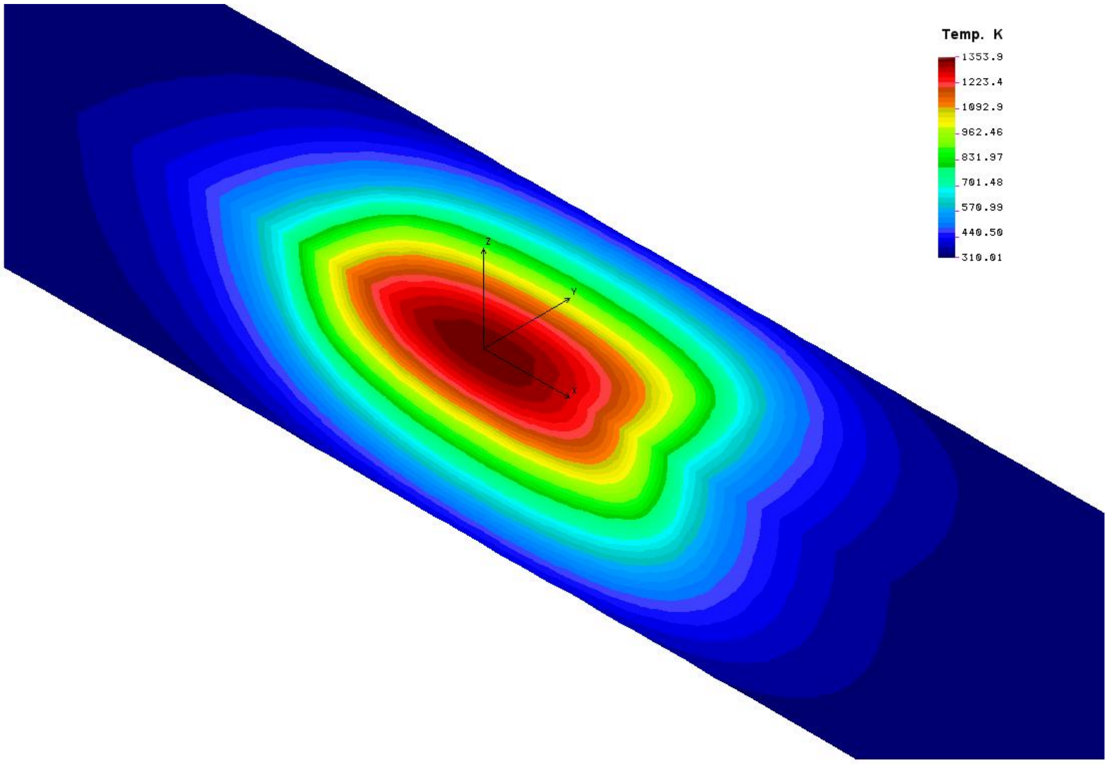

Figure 1. 400 kW of U on a water-cooled copper target. Spot size is 2 cm by 1 cm. Only one half of the target is shown.

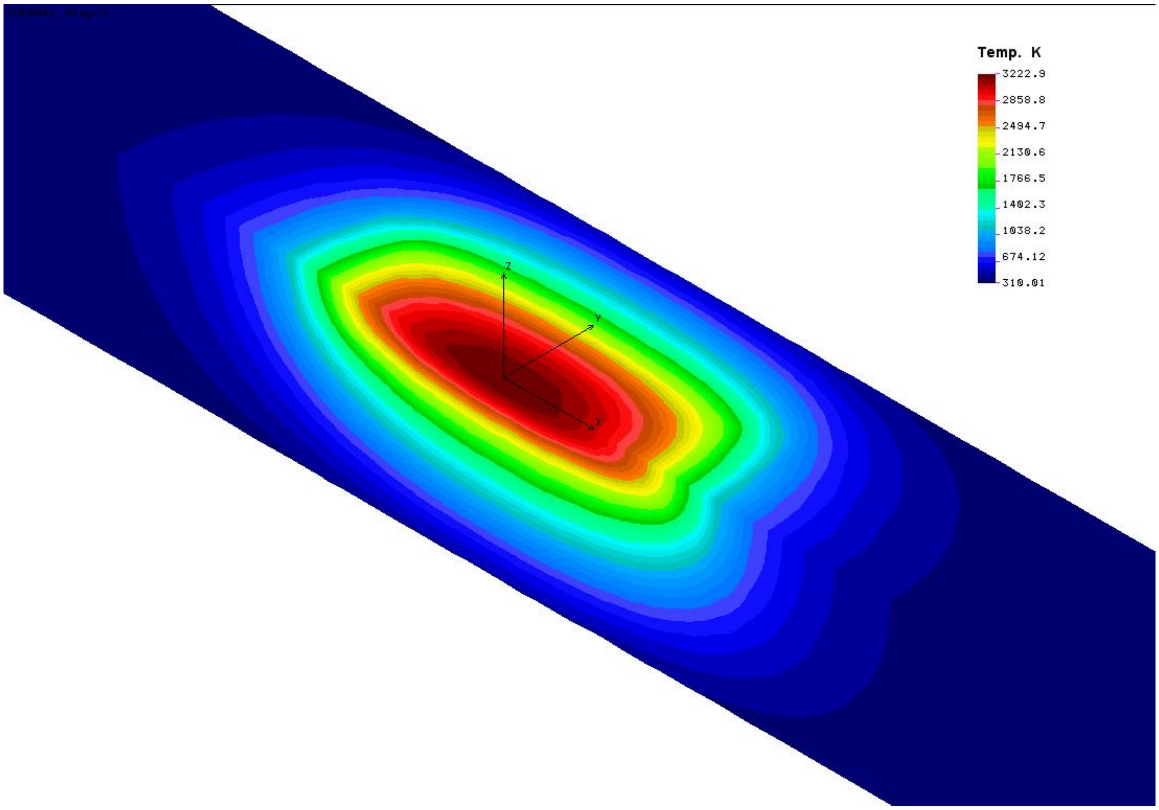

Figure 2. As figure 1, but for a tungsten target.

If we have a copper beam dump and 400 kW of ^{238}U incident beam, the range is only 4.1 mm. Since it takes about 50 gal/min of cooling water with a 30 C temperature rise to take out the heat, there will be extreme temperature differences across the beam area. But this is a relatively minor problem. Finite element calculations suggest the maximum power density that copper can accommodate is about 25 kW/cm^3. This says that the beam needs to be 40 cm^2 in area to keep the copper from melting. Going to tungsten gives a factor of two increase in the possible power density; however, this doesn't provide a large decrease in the required beam area because the range decreases and the thermal conductivity also decreases. The higher thermal radiation possible because of the increased melting point has been taken into consideration. The two cases are shown in figures 1 and 2 for copper and tungsten, respectively.

It should be noted that rotating targets can be made to survive this power level (~1 MW/cm$^{3)}$, but a rotating beam dump is not fail-safe and should not be considered for an emergency device.

On a less acute scale, the long-term survivability of materials subjected to undesired secondary particles needs to be studied. Many different fragments come out of the target at beam powers close to the NSCL's primary beam. Because these fragments are more diffuse than the primary beam, more conventional beam dumps can handle their local power densities. The solution for 4 kW beams in the NSCL's A1900 is shown in figure 3. It is likely such a solution could be adapted for RIA.

Damage to materials from the high neutron fluxes is also a major problem. Considerable work has gone into studying this problem from the fusion community [3,4], although only for neutron energies below 14 MeV. One difference between the exposures of structural materials to neutron fluxes is seen in the heavy fragment irradiation of the front surface of the material and the local hot spots from the Bragg Curve. Structural material may undergo lattice changes in that part facing the beam that are not induced in the more distant parts. This could lead to local stresses and ultimately premature failure.

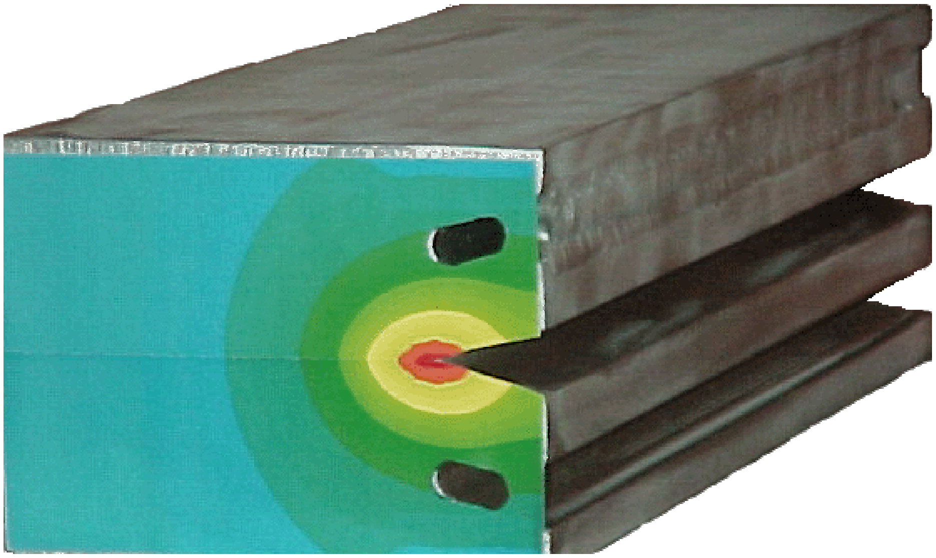

Figure 3. A1900 beam catcher-bar for 4 kW. The two oblong holes are water cooling channels.

The proposed R&D would be directed to understanding the problems that high energy density beams present to materials exposed directly to the beam and what can be done to mitigate those problems. Solutions need to be found that let one chose the best materials, which have both the longest lifetime and the greatest reliability. By definition, these materials will be in the most radioactive areas and will, therefore, be the most difficult to work on.

The high-energy beams at the NSCL, while of lower energy and power than RIA, will, nevertheless be useful in this study. The Coupled Cyclotron Facility can supply 80 MeV/A Uranium in spot sizes of ~ 0.5 mm diameter. This beam, and others such as Xe beams, provides high power densities for studying material properties under high power heavy ion irradiation. The MSU community has significant facilities for studying material properties, where irradiated samples can be tested.

Specific goals of the proposed R&D are:

- Study the interaction of high-power density heavy ion beams with possible beam dump material to determine how the material is damaged
- Examine possible material failure mechanisms
- Study materials to determine best for specific purposes (e.g. dumps, beam tubes, etc)
- Examine ways to try to spread out the energy deposition
- Test materials with high dE/dx beams

References

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