Liquid Jet Lithium Target for Super-FRS Fast Extraction Scheme: Comparison Between 2D and 3D Simulations *

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Abstract

Previously we have shown [1] that using the highest intensity uranium beam with 10^{12} ions delivered in a single bunch with a duration of 50 ns, a solid graphite target will be destroyed in a single experiment if one uses a small focal spot size necessary to have good ion optical resolution and sufficient transmission of the secondary particles. It is therefore essential to develop novel target designs like a windowless liquid jet target. In Ref. [1] we presented first calculations of interaction of the beam with a liquid lithium target using a two–dimensional computer code, BIG-2 [2]. This computer code uses a semi-empirical equation-of-state model to simulate the target physical conditions [3]. In the meantime we have carried out three-dimensional calculations of this problem and in this contribution we present more detailed calculations together with a comparison between 2D and 3D results.

Introduction

The new heavy ion synchrotron, SIS100 that will be built at the future **F**acility for **A**ntiprotons and **I**on **R**esearch (**FAIR**) [4], will generate a very intense uranium beam with an intensity of 10^{12} ions that will be delivered in a single bunch, 50 ns long. A wide range of particle energy between 400 MeV/u–2.7 GeV/u will be available to the experimentalists. The beam intensity in transverse direction will be Gaussian while the focal spot geometry could be circular or elliptic. Super-FRS will be one of the important experiments that will be carried out at FAIR. Calculations have shown [1] that if one uses a focal spot with dimensions required for reasonable ion optical resolution and tolerable transmission of the fragments, a solid carbon target will be destroyed in a single experiment whereas one needs to use the same target over an extended period of time. Using a two-dimensional computer code, BIG-2, calculations have been reported [1] in which a novel target design, namely a windowless liquid lithium jet target has been used. Recently, we have performed calculations using a three-dimensional hydrodynamic code and a comparison between the results obtained from the two codes shows excellent agreement.

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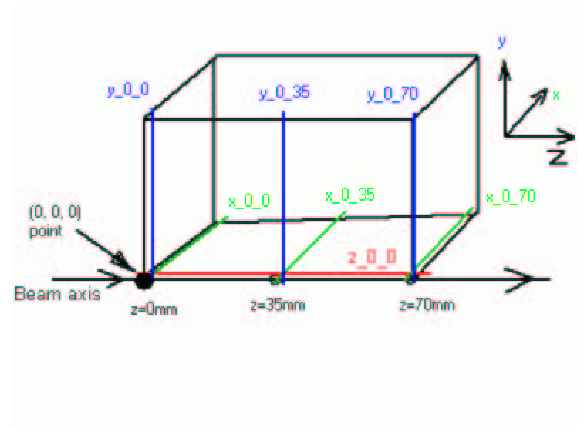

Figure 1: A quater of the target in plane geometry, length = 7 cm, height = 1.5 cm, thickness = 1 cm, beam is directed along Z-axis.

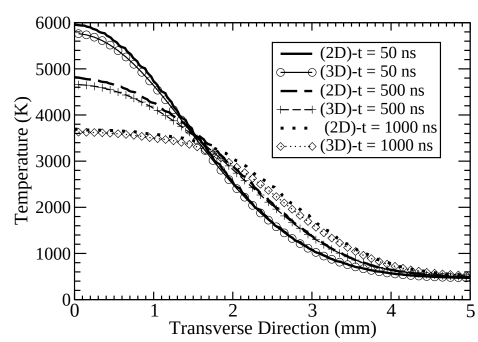

Figure 2: Temperature vs transverse coordinate (Y–axis) at different times, circular focal spot with σ = 1.414 mm, 2D and 3D results

Simulation Results

The target initial conditions are shown in Fig. 1 which is quarter of a target in plane geometry. The beam is incident along the Z-axis and target length, height and thickness are 7 cm, 1.5 cm and 1 cm respectively. It is advantageous to use an elliptic focal spot instead of a circular one in these experiments. This is because the ion optical resolution of the fragments is determined by the X–dimensions whereas the transmission is controlled by the Y-dimensions. One can therefore increase the focal spot area to reduce the target temperature while keeping reasonable levels of resolution and transmission. However, for a comparison between 2D and 3D results we assume a circular focal spot with a standard deviation, σ = 1.414 mm that is equivalent to an elliptic focal spot with σ_x = 1 mm and σ_y = 2 mm. An initial temperature of 460 K is required to keep lithium in liquid state.

In Fig. 2 we plot temperature along transverse direction (along the height) at three different times using 2D and 3D codes respectively. It is seen that at t = 50 ns when the beam has delivered its total energy, the temperature at the maximum of the Gaussian distribution is of the order of 6000 K and the 2D and 3D results agree very well. At later times the temperature decreases because of the low density caused in the beam heated region as a result of the shock wave moving outwards, but the level of agreement between the 2D and 3D results remains excellent. Corresponding pressure nd density profiles are plotted in Figs. 5 and 6 respectively. It is again seen that the 2D and 3D results show excellent agreement which means that it may be sufficient to use two–dimensional code to study most aspects of this problem.

One of the most important conditions required for the survival of a liquid jet target is that the target temperature remains well below the boiling temperature of the material. The boiling temperature of lithium is 1343 K which means that the target will be destroyed if irradiated with above beam parameters. It has been shown [1] that if one uses an elliptic focal spot with a two-dimensional Gaussian intensity distribution in X–Y plane with standard deviation, σ_x = 2 mm and σ_y = 12 mm along X and Y directions respectively, sufficient resolution and transmission can be achieved. In order to study this problem with a 2D code, one can consider a circular focal spot which has an equivalent area that leads to $sigma$ = 4.9 mm. The BIG-2 code has been used to carry out these calculations and the results are plotted in Figs. 5 – 7 respectively. It also to be noted that in this case we consider a cylindrical target that has a length of 7 cm and a radius of 1.5 cm while the beam is incident along the cylinder axis. The results are plotted along the transverse coordinate (radius).

We note that it has been shown that if one uses the full intensity of the uranium beam (10^{12} ions per bunch), a solid carbon target will survive only if one uses a beam spot with σ_x greater than 4 mm and σ_y = 12 mm. Such a value of σ_x would decrease the resolution to a value that will not be acceptable. Using a liquid jet target one can operate with a focal spot that has σ_x = 2 mm, which is a substantial gain. It is therefore very likely that one would use such a liquid jet target for the Super-FRS.

Figure 5 shows that at t = 50 ns (at the end of the ion pulse), a maximum temperature of 970 K is generated in the target that leads to a maximum pressure of 0.7 GPa, as seen from Fig. 6. The high pressure launches a compression wave outwards in transverse direction that leads to a 15 % reduction in the density at t = 2000 ns (see Fig. 7). Figure 6 shows that at t = 2000 ns the pressure t the target center decreases to almost zero while in the outer part of the target in the compressed part of the target the pressure is of the order of 0.2 GPa. These calculations show that the target may be used with the above beam parameters, however more work is needed in order to come to a final conclusion concerning this problem. For example it is important to calculate the minimum height of the target so

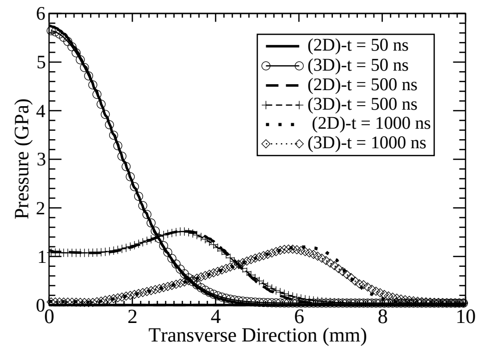

Figure 3: Pressure vs transverse coordinate (Y–axis) at different times, circular focal spot with σ = 1.414 mm, 2D and 3D results.

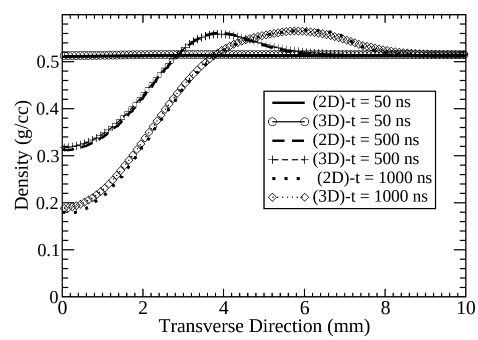

Figure 4: Density vs transverse coordinate (Y–axis) at different times, circular focal spot with σ = 1.414 mm, 2D and 3D results.

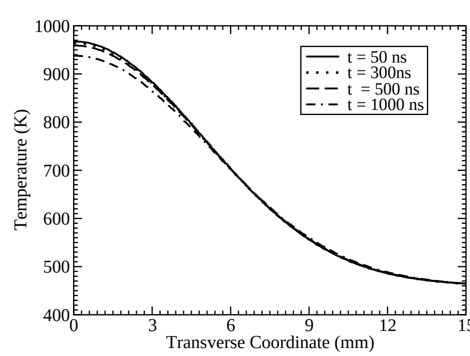

Figure 5: Temperature vs transverse coordinate (cylinder radius) at different times, circular focal spot with σ = 4.9 mm, 2D calculations using BIG-2 code.

that the amplitude of the pressure wave decreases to a level that it does not destroy the jet nozzle.

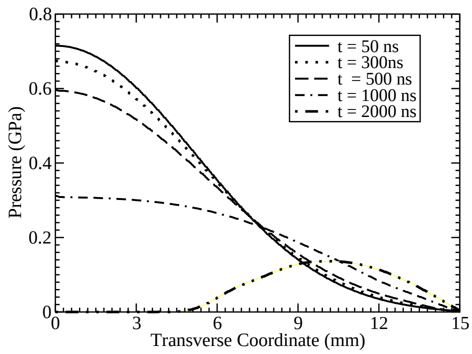

Figure 6: Pressure vs transverse coordinate (cylinder radius) at different times, circular focal spot with σ = 4.9 mm, 2D calculations using BIG-2 code.

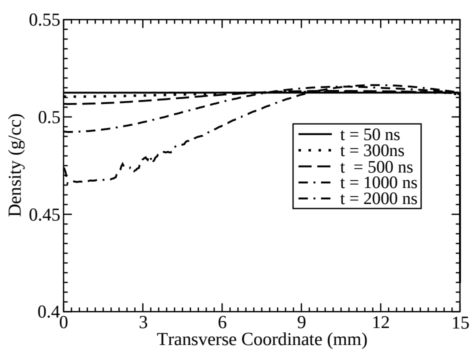

Figure 7: Density vs transverse coordinate (cylinder radius) at different times, circular focal spot with σ = 4.9 mm, 2D calculations using BIG-2 code.

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