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Disk converter target

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Abstract

It is cylindrical converters that are generally considered for the purpose of changing the ion beam energy into X rays, with their irradiation to be provided through the cylinder end. This article studies a target having a disk-shaped converter to be irradiated sideways. It may be practical when one fails to overcome difficulties with the focusing of ion beams into a spot of a diameter smaller than a few millimeters.

Keywords: Cylindrical converters; Ion beam energy; X-rays

There are several options of the indirect–drive targets (Lindl, 1995; Callahan-Miller & Tabak, 1999), in which the energy of laser beam or accelerated heavy ions is converted into that of X rays at a temperature below 0.4 keV. In general, they all incorporate an outer shell of high-*Z* material, such as gold, and a spherical capsule having the outer wall made from beryllium or carbon with high-*Z* alloy. The X rays that result from the conversion should be absorbed by both the target outer surface and the inner surface of the gold shell. There would be a considerable portion of the energy to go back into the hole used to put in a laser or heavy ions beam.

As was indicated by A.D. Sakharov, the flow of X rays Q into the wall is related to the wall path length L as $Q \sim L^{+1/3}$ (Kholin, 1997).

Experimental data are given in Kholin (1997) and Eliseev *et al*. (1986), which show for a temperature of 0.3 keV that the radiation path length into gold is 65 times smaller than it is into carbon. This is consistent with the calculated values for the radiation path length, given a small amount of higher-*Z* alloy existing in the carbon.

For equal surface areas, the energy flow into carbon has been found to be 4 times that into gold. As a limitation of the laser target, there is a loss of X-ray energy that occurs through an open hole that lets the laser light move into the target. A limitation of the heavy ion fusion target is that some X-ray energy remains within the converter and the film of the injection hole. Such loss is approximately equal to the energy going into the capsule. The expectation for NIF is that there may be about 12% of the driver energy going into the capsule. The NIF capsule has a surface area that is 4% of the outer gold shell surface, and the hole for light beam injection is 30% larger than the capsule surface area. It is desirable that the same parameters should be kept in mind when designing the targets in heavy ion fusion science. The heavy ion fusion target has the energy of accelerated ion beam converted into X rays within a cylinder-shaped converter. Normally, the flow of ions in the current designs is directed as the cylinder axis, and the cylinder length is larger than its diameter.

We now look into the possible use of a disk-type converter (Nechpai *et al*., 1994), whose length is smaller than its diameter, with the ion beams to irradiate it radially around through the disk side.

The main advantage of such a design is that wide-angle beams can be used, thus allowing each converter to be irradiated by four beams of the cross sections shaped as a 2-mm × 6-mm oval. Along with this, there is a higher energy concentration near the converter axis due to overlap of the beams. Each beam has energy of 1.25 MJ, and its intensity on the target surface is 1000 TW/ cm^2.

To consider such a target in detail, a calculation was done on the design as given in Figure 1. Thus, there is a capsule, its outer layer made of carbon, which has a radius of 2.3 mm and it is positioned centrally into a cylindrical shell of gold having a 6-mm radius and being 16 mm long. At each end of the cylinder inside, a converter 2 mm thick and 8 mm in diameter is placed. They are isolated from the capsule sec-

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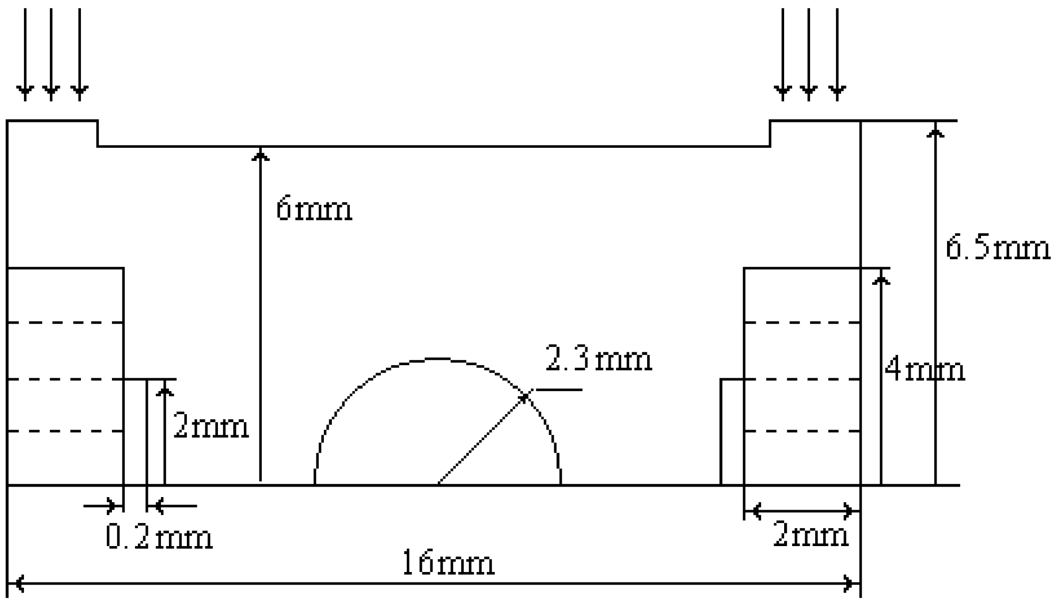

Fig. 1. Disk converter target.

tion by a gold disk of 0.2 mm thickness and 4 mm diameter. The window for transmitting the ion beam, being against the disk side, is 6.5 mm in radius, 2 mm long, and 0.02 mm thick. Each ion beam is a 6-mm-wide stretch passing across the converting disk of 6 mm diameter, with the ions having stopping length a little more than the disk diameter.

The converter is broken radially into four segments of 1, 2, 3, and 4 mm outer radii having average densities of 0.5, 0.4, 0.3, and 0.2 g/ cm^3, respectively. The converter material is a mixture of gold (10% by mass) and water. In fact, hydrogen is good as having a smaller path length on the ions stopping, while gold and oxygen are to facilitate the ions to X-ray energy conversion.

The following procedure was used to estimate the stopping length. First, the relationship $dE/dx = f(E)$ was obtained from the curves in Ziegler (1977), and the function $f(E)$ was interpolated through analytical relation. Then, the function $x(E)$ was found numerically as the solution to the equation $x(E) = \int_E^{\max E} dE/[f(E)]$;where $x(0)$ is the stopping length. With this equation solved, the $E = E(x)$ relationship can be found. As a result, we can have $dE/dx = f(E(x))$ for $T = 0$. Peter and Meyer-ter-Vehn (1991) give the relationship $(dE/dx)(x)$ for the stopping of iodine ions having an initial energy of 30 MeV per nucleon in gold at 2 g/cm^3 density and temperature of 0 and 0.3 keV. These curves were used to generate the interpolation function to transform dE/dx for $T = 0$ keV into dE/dx for $T = 0.3$ keV. The above procedure was useful to estimate the stopping length of mercury ions at 30 MeV energy per nucleon in a converter of water (90%) mixed with gold (10%) at a temperature of 0.3 keV. Thus, the stopping length was found to be near that in the case of oxygen. Figure 2 illustrates the $(dE/dx)(x)$ relationship for stopping length in the oxygen case as obtained for $T =$ 0 keV and $T = 0.3$ keV. The same figure also includes the original relationship $(dE/dX)(E)$ from Kholin (1997), as well as $(dE/dx)(x(E))$, the relationship that was arrived at with the procedure used. Their agreement suggests the credibility of the procedure.

For the converter of interest having a diameter of 8 mm, calculation was made on three overlap variations of the four beams in the converter. The ion energy of bismuth in the beam was varied as follows: 7.9 GeV, 8.5 GeV, and 11.7 GeV. The overlap patterns are shown in Figure 3a,b. The ion energy of 8.5 GeV comes out as optimal. Here, the peak of energy deposition intensity is near the converter axis.

A photon at a velocity of 30 cm/ns can cover a distance of 30 cm in 1 ns. Therefore, if the target is about 1 cm in size, it can impinge on the walls 30 times. This implies that the diffusion method should be reasonably effective for a first approximation.

The beam energy was deposited within the converter uniformly during 10 ns, by which time 14.5% of the energy was still remaining in the converter, 5.1% in the vacuum, 3.4% having gone back into the beam injection hole, 15.5% into the capsule. 56.5% into the target shell of gold, and 5% having been deposited into the 0.02-mm gold film of the injection hole.

On the target surface, the peak pole temperature reached 0.2887 keV, and the lowest temperature value was 0.2852 keV, so that the temperature ratio was 1.013, which is regarded as reasonable. With the energy increase of 20% in the calculation, the peak temperature value grew to

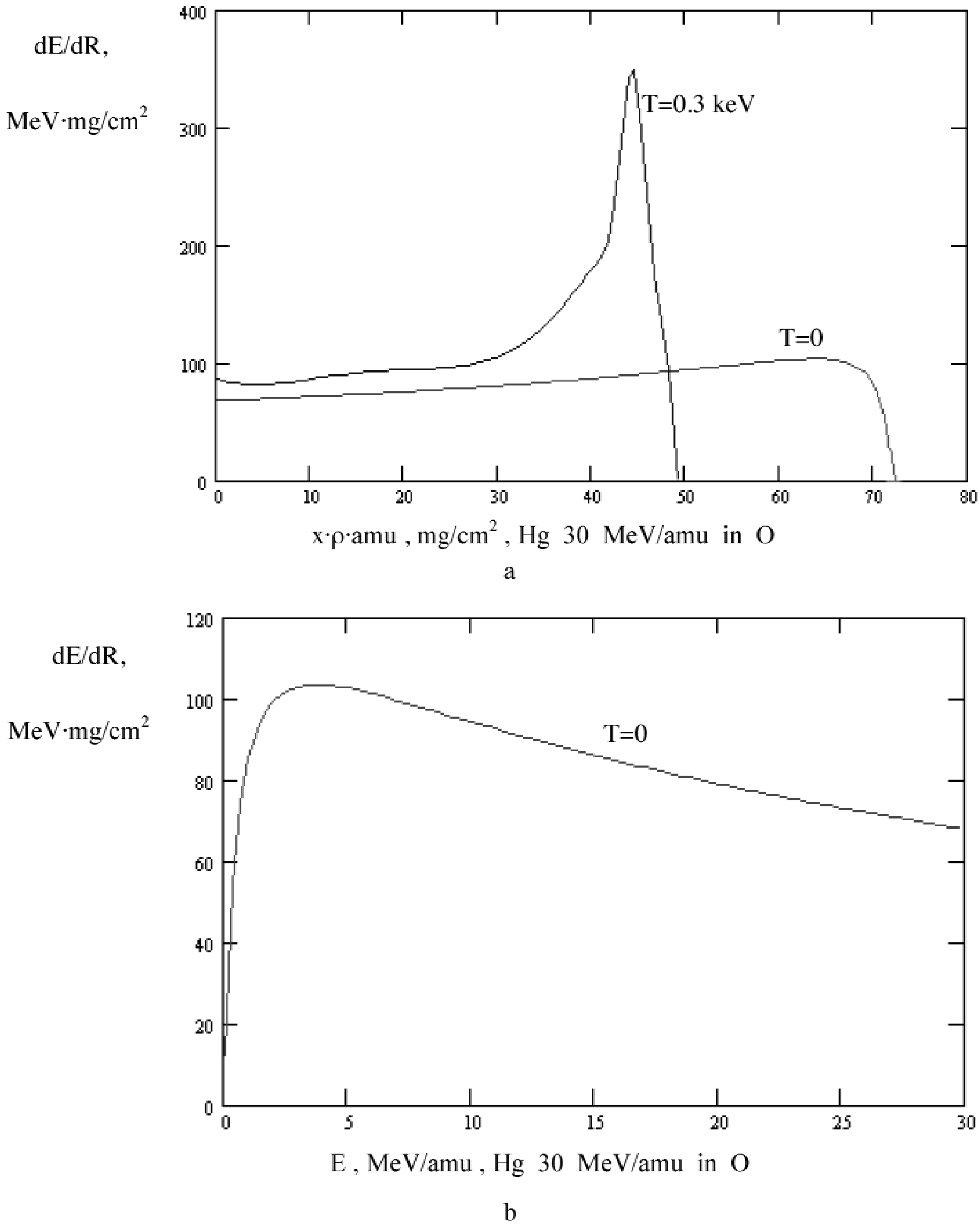

Fig. 2. Energy loss at the Hg ions stopping in oxygen depending on distance (a) and depending on the ion energy (b).

0.3109 keV. When the energy was decreased by 25%, the maximum of temperature in the capsule went down to 0.2688 keV.

A one-dimensional calculation with a temperature of 0.28 keV found a one-dimensional energy value of 5 MJ without burn consideration, while the best optimization analysis by the SND code with the account of fusion fuel burn in the capsule (Dolgoleva, 1983) obtained the energy deposition value of about 200 MJ.

This early study indicates potential use of the disk converter concept. However, to proceed on a real disk-converter design, it would still require more than one iteration with detailing of both the calculation geometry and the physics models in use.

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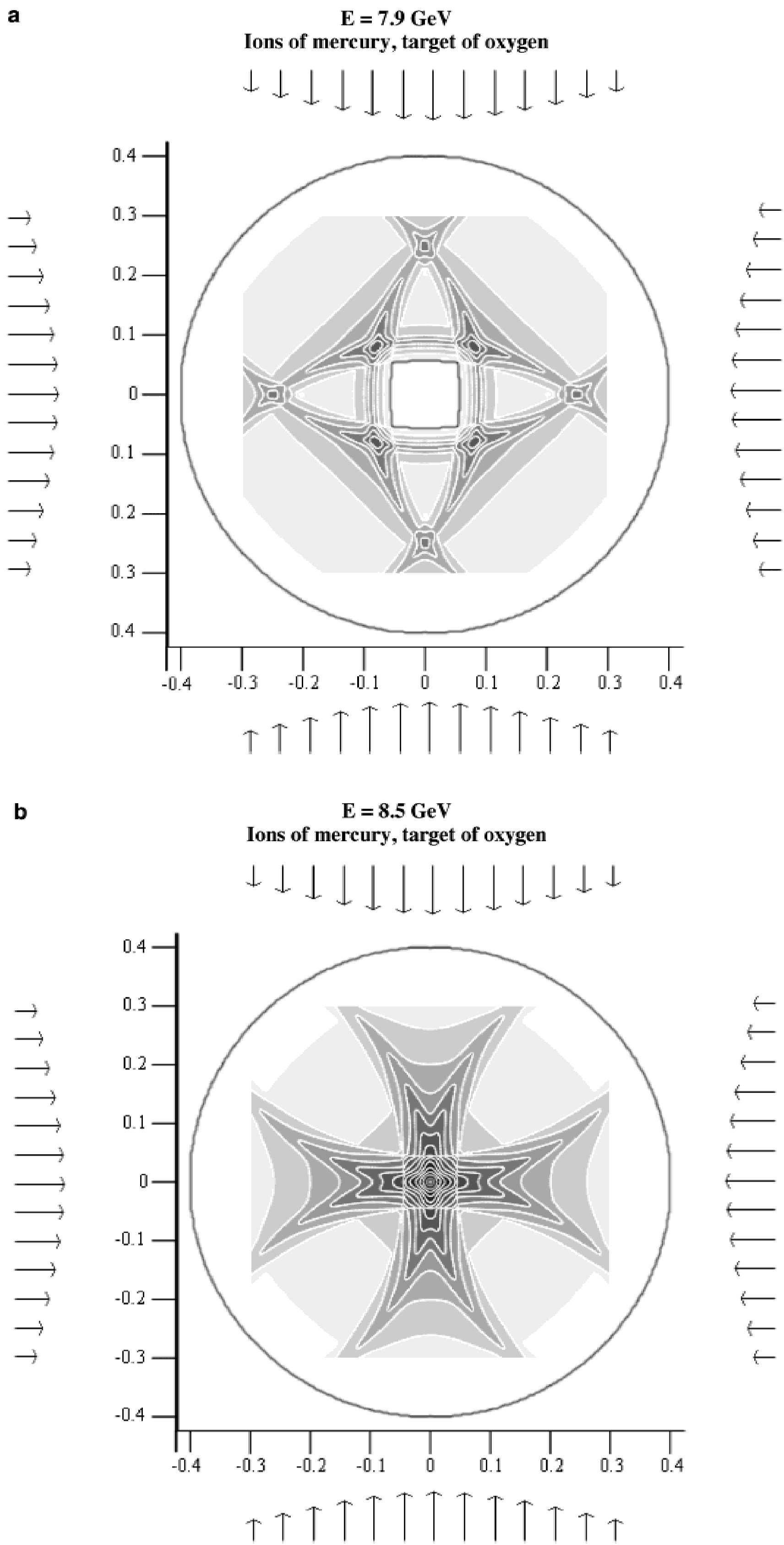

Fig. 3. a: Relative intensity patterns for four-beam disk irradiation. Ions have 7.9 GeV energy and a stopping length smaller than the disk radius. **b:** Relative intensity patterns for four-beam disk irradiation. Ions have 8.5 GeV energy and a stopping length a little more than the disk radius. (*Figure continues on facing page.*)

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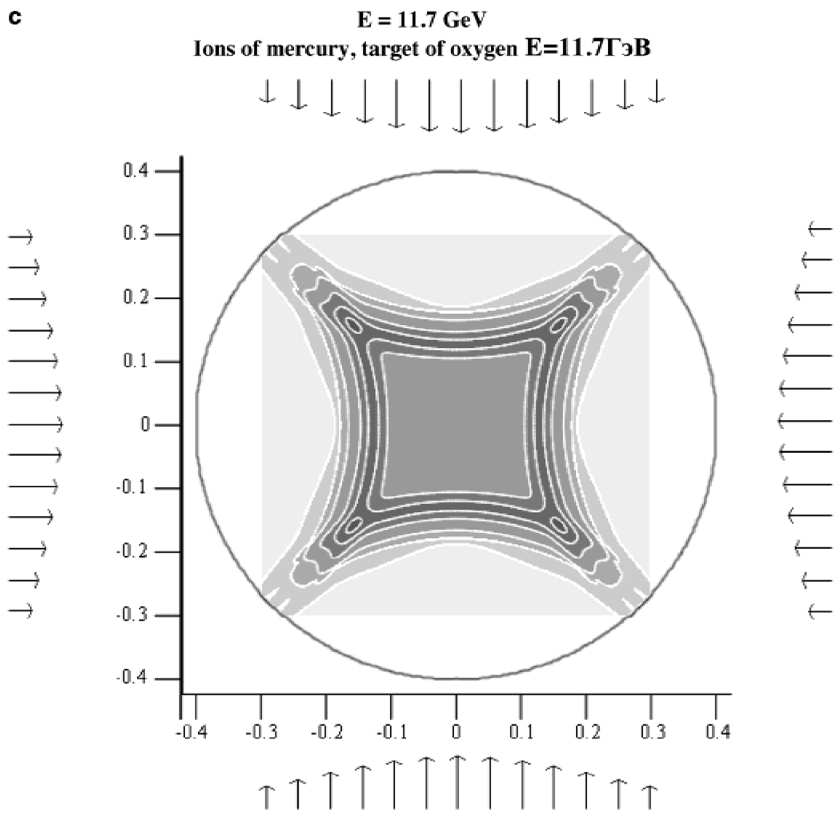

Fig. 3. (*continued*). **c:** Relative intensity patterns for four-beam disk irradiation. Ions have 11.7 GeV energy and a stopping length-markedly larger than the disk radius.

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