Targets for the proposed Super-FRS at GSI

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Abstract

To prepare for the high-intensity beams available at the future GSI radioactive-beam facility, development of the production target at the new Super-FRS has to be started. Since the requirements are different for slow and fast extraction from the SIS100/200 synchrotrons, separate solutions for the two cases will be considered. First calculations for both cases, as they have been obtained from the R3B project within the 5^{th} framework of the EU, will be presented.

1 Introduction

In November of 2001, GSI has submitted a proposal to expand its present accelerator complex towards a next-generation facility for research with relativistic beams of ions and antiprotons [1]. A key goal of this facility will be investigations with intense beams of exotic nuclei, that cover hitherto unexplored regions in the field of nuclear structure or nuclear astrophysics (in particular along the r-process path). The instrument to provide these intense secondary ion beams is the Super-FRS [2], a superconducting projectile-fragment separator with a much larger momentum and angular acceptance compared to the present FRS [3]. The aim is, among others, to provide relativistic beams of fission products with at least one order of magnitude higher transmission. The primary-beam intensity from the SIS100/200 synchrotrons will be as large as 10^{12} ions/s, even for the heaviest projectile, ^{238}U.

It is obvious that such high intensities of large-Z ions deposit large amounts of energy in the Super-FRS production targets. As will be shown below, the deposited energy can be handled by conventional technology in the case of **slow** extraction from the synchrotrons. For the transfer of secondary beams to storage rings, a unique feature of the new GSI facility that is nowhere else available worldwide, **fast** extraction has to be applied, i.e. all ions are compressed into a single bunch that hits the target for a duration of about 50 ns. In this case the specific power deposited in the target is larger by about 7 orders of magnitude and will lead to immediate destruction of the target. The latter case constitutes one of the most critical problems in the context of Super-FRS target development.

In the following contribution, calculated temperature distributions of a Super-FRS production target for slow extraction are discussed first. The subsequent section explores the case of fast extraction.

The results presented in this Contribution are largely based on calculations that have been performed within the 5^{th} framework program of the European Union, within the R3B project ("A next-generation experimental setup for Reaction studies with Relativistic Radioactive Beams"). The authors and the results of the R3B-subproject "High-power production target" that are covered in this Contribution [4, 5] can be viewed via the web site of R3B [6].

2 Targets for slow extraction from SIS100/200 (Ref. [4])

2.1 Primary-beam parameters

All calculations in this section have been performed for the "worst-case" beam (the one with the highest energy loss), i.e. ^{238}U. For most cases a high energy, e.g. 1 A GeV, is desirable to optimize Super-FRS transmission. The beam spot must be small to obtain high momentum and spatial resolution in the Super-FRS, therefore we assume a two-dimensional Gaussian beam profile with $\sigma_x = \sigma_y = 1$ mm. In slow extraction, the typical time distribution of the beam is homogeneous with a spill length of 1 s.

2.2 Target properties

A high-energy fragmentation facility needs thick targets (with areal densities of several g/cm^2) of low atomic number to minimize energy deposition and maximize fragment production. Since beryllium is not well suited for complicated and massive designs, carbon is the element of choice, in particular also in view of its high sublimation temperature of about 3900 K. Targets of thicknesses between 1 and 6 g/cm^2 provide interaction probabilities between 18% and 67% for ^{238}U which leads to dissipated energies between 2.9 and 17.4 kJ. Note, however, that the thickest target foreseen (6 g/cm^2) is mostly used in conjunction with light-ion beams, whereas for uranium most likely a 1 g/cm^2 target will be used.

2.3 A rotating graphite wheel design

As will be shown below, the concept of a rotating carbon (graphite) wheel of the appropriate thickness seems to be a technically feasible solution for a Super-FRS production target for slow extraction. Since the bearings at the center of the rotating target can stand only a limited temperature, a thermally insulating core has to be foreseen. A target radius of $R_t = 15$ cm has been chosen. In view of the large energy deposition of the beams and the high temperature that graphite can stand, radiative cooling will be the main heat transfer mechanism. As a first step, the following simplifications have been used in the schematic calculations:

- The rotation speed is assumed to be infinite, i.e. the heat load induced by the beam is evenly distributed over a circular area with a radius given by the point of impact of the beam ($R_{beam} = 14$ cm is assumed).
- The insulating core with $R_{core} = 10$ cm is assumed to have zero heat conductance.
- The target wheel is assumed to have a uniform thickness (between 1 and 6 g/cm^2).

With these simplifying assumptions, the temperature profile of the graphite target wheel as a function of the radius has been calculated (see Fig. 1). The figure demonstrates that even for the highest ^{238}U intensities and the thickest target, maximum temperatures of 1600 K are reached, well below the graphite sublimation temperature. Even if one relaxes some of the simplifying assumptions listed above and calculates the equilibrium temperature distribution for a finite rotation speed of 1/s, the increase compared to the values shown in Fig. 1 is only about 250 K. At the same time, the thermal stress across the target will be tolerable, since the temperature differences are calculated to be below 200 K.

2.4 Technical solutions, future reseach and development

As a first step, a technical solution for a 1 g/cm^2 C target wheel with an outer diameter of 105 mm and a 6 mm thick central part with holes to reduce heat conductance has been calculated [7] (see Fig.2). The calculated temperatures vary between 620 K at the contact with the bearing to 1350 K at the outer surface. In the near future, more realistic target designs have to be calculated. The modifications to be explored are the following:

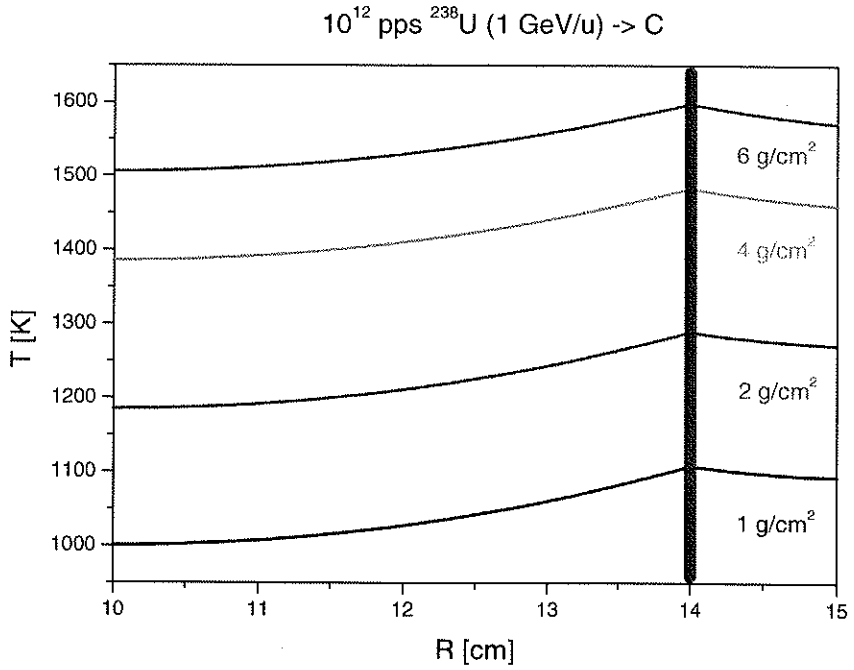

Figure 1: Temperature distribution as a function of radius R for rotating graphite target wheels of different (uniform) thicknesses. Infinite rotation speed and an insulating core with zero heat conductance (R_{core} = 10 cm) has been assumed (from Ref. [4]). The beam impinges at R_{beam} = 14 cm.

- The target wheel must consist of adjacent graphite rings with several steps in areal thickness (e.g. 1, 2, 4 and 6 g/cm^2) to accommodate the wide variety in atomic number Z of the incident beams.
- A technical solution for the bearing and motor must be found and its heat tolerance must be explored.
- Depending on the maximum temperature tolerable at the bearing, the inner (insulating) part has to be redesigned.

It is foreseen to attack these problems in a joint R&D effort with the French groups involved in designing the converter target for the proposed SPIRAL II facility [8].

3 Targets for fast extraction from SIS100/200 (Ref. [5])

One of the unique features of both the present and the future GSI facilities is the fact that high-energy synchrotrons are coupled with storage rings that allow bunched beams of exotic fragments to be transferred to and cooled in storage rings. This allows unique experiments, e.g. mass and half-life measurements over wide areas of the chart of nuclides, or reactions in inverse kinematics with in-ring gas targets [1]. At the new facility up to 10^{12} ^{238}U ions will hit the Super-FRS production target within ca. 50 ns, leading to maximum specific power depositions of up to 4 TW/g. Experience with calculations in the framework of plasma physics experiments tells us that for small beam spots (which are required if the ultimate momentum resolution of the Super-FRS is to be attained) this leads to immediate sublimation of the graphite target material. The hydrodynamic expansion of the sublimated material slows down this process somewhat (with a time constant of a few 100 ns). That means that within the first 50 ns, the target material is largely unaffected and can serve as a production target. After ca. 100 ns, however, the central target density is reduced considerably, which leads to different energy losses together with lower production rates. Ultimately the target will be destroyed and has to be replaced after each beam pulse.

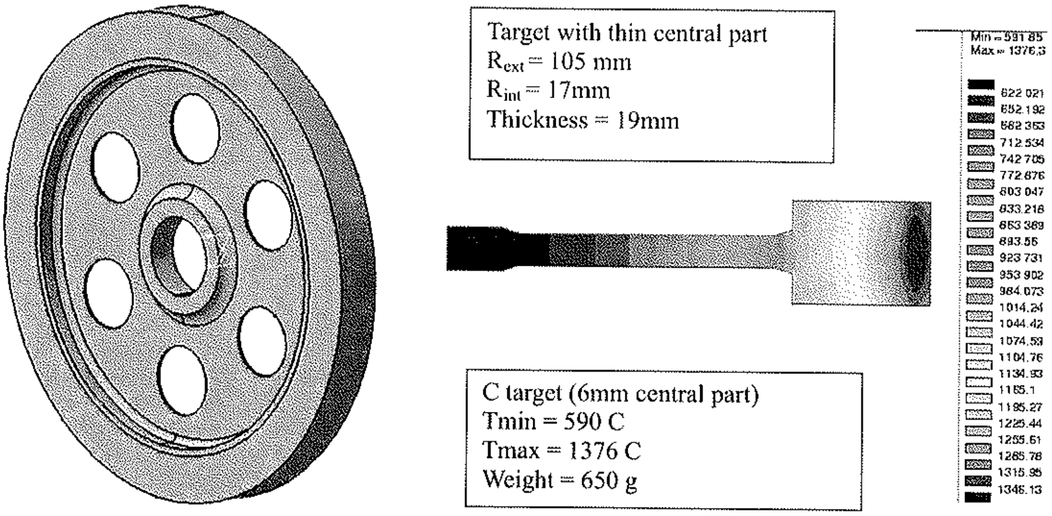

Figure 2: Example of the temperature distribution in a technically feasible C target wheel of 1 g/cm^2 thickness. The calculated temperatures range from 620 K at the contact with the bearing to 1350 K at the outer surface [7].

Two options are being considered as a way out of this situation: (i) a continously flowing target, e.g. in the form of a liquid lithium film, that replaces the evaporated target material immediately; this allows to maintain a tiny beam spot required for high resolution; (ii) a conventional target (such as the one discussed above for slow extraction) with a wider beam spot that allows to reduce the specific heat load to below the sublimation point; this is necessarily accompanied by a loss in ion-optical resolution. Since the use of windowless liquid Li films that are hit by high-intensity heavy ion beams in vacuum may cause a host of severe problems, we consider here only the second option.

3.1 Simulations for fast-extracted ^{238}U pulses

We have mentioned above that the small beam spot envisaged for slow extraction (with $\sigma_x = \sigma_y = 1$ mm) leads to an explosion of the C target within a few 100 ns. When trying to reduce the specific power deposited in the target one should keep in mind that for obtaining the required resolution a narrow beam spot is more critical in the bending plane (x) than perpendicular to it (y). Consequently, simulations have been performed with elliptical beam spots with $\sigma_y = 1.2$ cm and with various (small) values of σ_x (see Fig. 3). It can be shown that for a combination of $\sigma_x = 1$ mm and $\sigma_y = 12$ mm the central temperature stays below 2500 K and would thus not destroy the C target, while at the same time the ion-optical resolution is 65% of its otimum value. This seems to be a tolerable solution. More elaborate calculations have to be performed in the future that study the effect of repeated irradiations with short beam pulses to see if also the equilibium temperature can be kept below the target limit.

4 Outlook

It is clear that the questions of thermal stability of the Super-FRS targets are only one aspect of many that have to be adressed before the separator can be built. Others concern the activation of the targtes and their environments, the longterm mechanical and electrical stability of the target assemblies, and the handling of these assemblies in case of failures. It is hoped that technical solutions for other high-intensity facilities, some of which were discussed in the present Workshop, can be used also in conjunction with the Super-FRS.

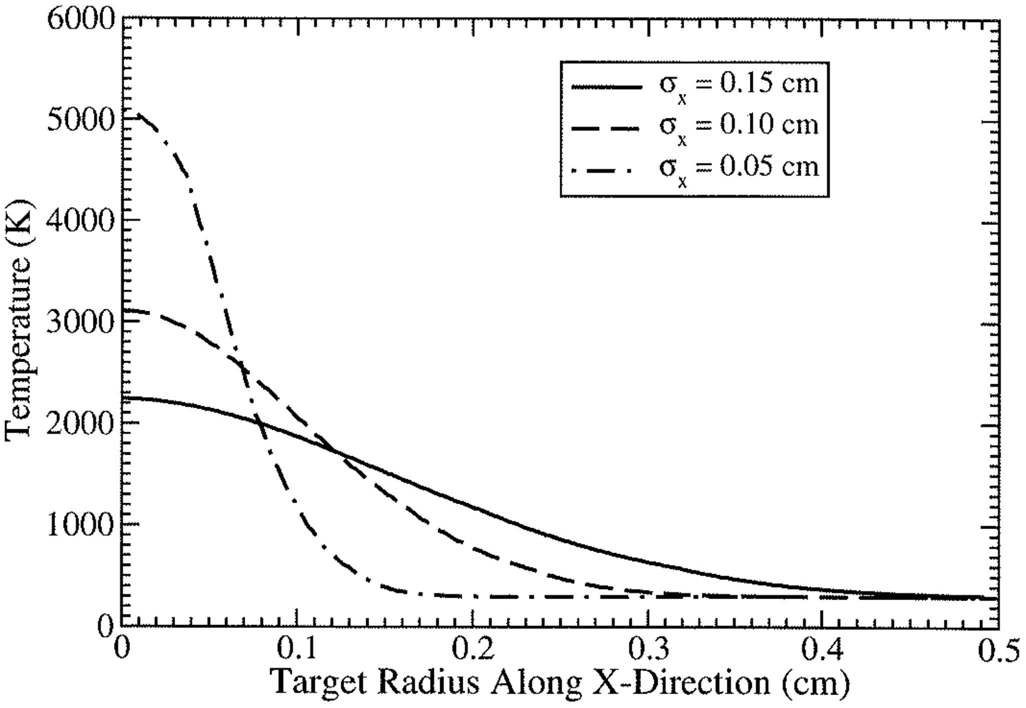

Figure 3: Temperature *vs.* target radius for a fast extracted ^{238}U beam impinging on a 4 g/cm^2 graphite target within 50 ns. An elliptic beam spot with $\sigma_y = 1.2$ cm and σ_x as indicated in the figure was chosen (Ref. [5]).

5 Acknowlegdements

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