INTRODUCTION

For the R&D of the direct SPES target, we consider a 40 MeV proton beam impinging on a UC_x target with an isotopic ratio equal to U:C=1:4 and a density of 2.5 g/cm^3.

In a thick UC_x target, the proton has a range of about 1.2 cm. With a MCNPX [1] calculation it is possible to estimate the maximum fission rate available at this proton energy and also to analyze how the fission rates and the power deposition change when the target thickness is lower than the proton range. The total fission rate in the thick target turns out to be 9.1×10^{12} fissions per second and the total power deposition about 8 kW (=40 MeV*0.2 mA) [2].

TARGET CONFIGURATION

The target configuration has been set considering some main purposes, such as the high number of fission reactions, the fission fragment distribution with a high number of atoms in the whole mass range 80<A<160 and a low power deposition in the materials (both window and target). The most exploited solution in the RIB projects is the 2-step configuration: a proton or a deuteron beam impinges on a converter target used to emit fast neutrons, that induce the fission in the uranium target. We choose the 1-step target configuration: it consists of a proton beam that directly impings on the fission target [3]. The main problem of the 1-step configuration concerns the high power deposition of the incident beam in the production target, mainly due to the electromagnetic interactions. However, a solution to this drawback has been conceived: only the protons with higher fission cross-section are used to induce fission in the thin target and the outgoing lower energy beam is driven towards a passive dump. This possibility is possible because the 238U fission cross-section and the stopping power have opposite dependency on the proton energy, as shown in Fig. 1.

It is clear that low energy protons (for example, with energy below 25 MeV) are less efficient for the in-target production: they have lower fission cross-section and higher values of stopping power. For this reason, we choose to drive them towards a passive dump. In this way the power deposited in the target is considerably lowered and the number of fission reactions is kept high.

Even if with a higher energy proton beam the dissipated energy per length is lower, it would increase sensitively the apparatus cost. Moreover, the 238U fission cross-section does not increase considerably for energies higher than 40 MeV (as shown in Fig. 1). For these reasons we chose is energy value for the primary proton beam.

In order to optimize the heat dissipation, a good solution is to use a target made of multiple disks. In this way its cooling is strongly simplified: due to the void environment, the heat dissipation is fully entrusted to the thermal radiation and this mechanism is directly proportional to the body surface. The use of several thin disks of equal mass increases the total surface and allows for a better cooling.

All these considerations lead to the system configuration shown in Fig. 2.
After an entrance window made by a thin Carbon foil of 400 µm and necessary to separate the beam line and the target void region, it’s placed the target divided in several disks of about 1 mm thickness. They are followed by a carbon dump, in which the protons with low production rate and high stopping power are driven.

In this study, we consider a target of 5 disks. Their material is pure UC₂ (with a density of 2.5 g/cm³), leading to a total mass of about 40 g. The disks have a radius of 3 cm and thicknesses varying from 1.3 mm to 0.9 mm. In order to optimize the power deposition, the disks thicknesses decrease to compensate the increasing values of the stopping energy per length. These thicknesses are a compromise between the need of low energy deposition (thinner target are preferred) and mechanical resistance of the material (thicker target are preferred).

RESULTS

The Monte Carlo calculations done for our target were performed considering a proton beam with a gaussian shape, an energy of 40 MeV and a current of 0.4 mA.

The results show that a power of about 0.4 kW is deposited in the window, 3.4 kW in the whole target material and about 12 kW into the dump. The power deposition in each disk is shown in Table 1: the average value is about 0.7 kW. This corresponds to an average power density in the whole target mass of less than 100 W/g.

Table 1. Thicknesses and power deposition in the target disks.

<table>
<thead>
<tr>
<th></th>
<th>Target #1</th>
<th>Target #2</th>
<th>Target #3</th>
<th>Target #4</th>
<th>Target #5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (mm)</td>
<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
<td>1.0</td>
<td>0.9</td>
</tr>
<tr>
<td>Power (kW)</td>
<td>0.74</td>
<td>0.71</td>
<td>0.70</td>
<td>0.65</td>
<td>0.63</td>
</tr>
</tbody>
</table>

The outgoing proton energy distribution is shown in Fig. 3. The proton beam impinges on the first disk at about 39 MeV and leaves the last disk with an energy of about 28 MeV.

Fig. 3. Energy of the proton beam coming out of the target disks.

The calculated fission rate for all the target is about 9·10¹² fissions per second and 1.8·10¹³ atoms per second are thus produced. They are not uniformly distributed in the 5 disks because of the decrease of the disk thickness and of the beam energy: the fission reactions in the last disk are 40% less than those of the first disk.

The fission reactions due to neutrons have also been calculated and it appears to be negligible (<1%) with respect to those induced by protons.

CONCLUSIONS

A possible solution for producing exotic nuclei is a configuration with a proton beam with energy of 40 MeV and a current of 0.4 mA impinging directly on a UC₂ target. In this way about 700 Watt per disk are deposited and 2·10¹³ s⁻¹ fission fragments are obtained as a result of high energy fissions in ²³⁵U.