DEVELOPMENT OF A PROTON-TO-NEUTRON CONVERTER FOR RADIOISOTOPE PRODUCTION AT ISAC-TRIUMF

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Abstract

At ISAC-TRIUMF, a 500 MeV proton beam is impinged upon “thick” targets to induce nuclear reactions to produce reaction products that are delivered as a Radioactive Ion Beam (RIB) to experiments. Uranium carbide is among the most commonly used target materials which produces a vast radionuclide inventory coming from both spallation and fission- events. This can also represent a major limitation for the successful delivery of certain RIBs to experiments since, for a given mass, many isobaric isotopes are to be filtered by the dipole mass separator. These contaminants can exceed the yield of the isotope of interest by orders of magnitude, often causing a significant reduction in the sensitivity of experiments or even making them impossible.

The design of a 50 kW proton-to-neutron (p2n) converter-target is ongoing to enhance the production of neutron-rich nuclei while significantly reducing the rate of neutron-deficient contaminants. The converter is made out of a bulk tungsten block which converts proton beams into neutrons through spallation. The neutrons, in turn, induce pure fission in an upstream UCx target. The present target design and the service infra-structure needed for its operation will be discussed in this paper.

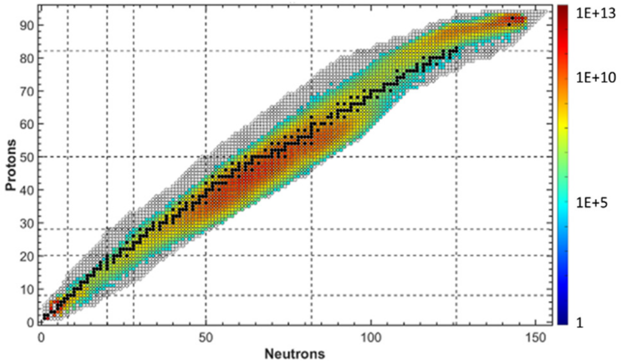

Figure 1: In-target production from an ISAC UC_x target irradiated with 10 μA - 500 MeV proton beam.

INTRODUCTION

The ISAC-TRIUMF Facility [1] applies the ISOL Method [2] to produce radioisotopes for a wide range of experiments. Like at most ISOL facilities world-wide, at ISAC-TRIUMF, one of the most used target materials is uranium carbide (UC_x) since its interaction with a 500 MeV proton beam induces the production of a broad variety of radioisotopes as shown in Fig. 1.

Over the last three years, 39% of the beams requested from UC_x targets were neutron rich [3]. Most of those beam proposals point out the requirement for low isobaric iso-tope contamination produced by spallation-fission reac-tions of protons on uranium atoms, a reaction channel com-peting with pure fission [4]. However, some of these re-quests have never been satisfied because of the presence of isobaric surface ionized neutron-deficient contaminants.

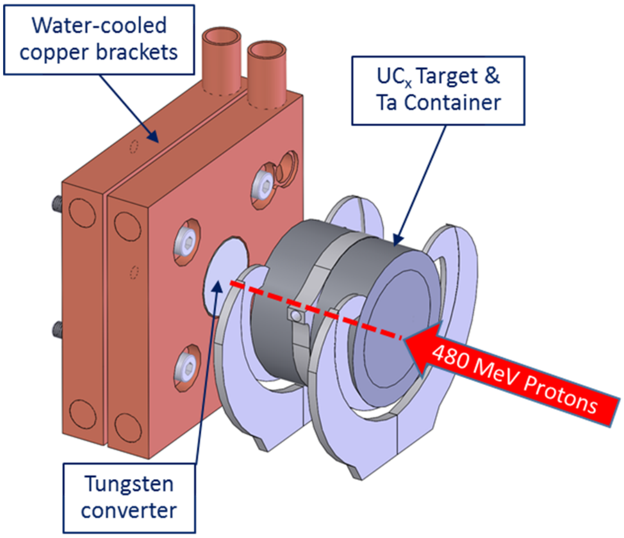

Figure 2: p2n converter, hollow UC_x target and tantalum container.

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The introduction of a p2n converter for ISOL beam production was proposed by J. Nolan [5] [6] and it is currently successfully used at the ISOLDE facility at CERN [7] [8].

The ISAC-TRIUMF proton-to-neutron (p2n) target, under development by a joint collaboration between TRIUMF, CERN and SCK-CEN, aims at delivering neutron-rich RIBs with intensities comparable to ISAC-TRIUMF standard UC_x targets, while reducing the isobaric neutron-deficient contaminants by two orders of magnitude. The following sections describe the target-converter assembly design and justifies it according to technical and licensing constrains.

P2N TARGET-CONVERTER DESIGN

The proton-to-neutron geometry is shown in Fig. 2 where the concept is explained: the incoming 500 MeV proton beam from the main cyclotron is directed through the centre of a hollow actinide target onto a solid tungsten cylinder in contact with two water-cooled copper brackets. The interaction of protons with the tungsten cylinder induces spallation reactions, which, in turn, generate a nearly isotropic neutron flux. Some of these neutrons will interact with the upstream annular target material made up of uranium carbide rings and induce fission reactions in them. The reaction products then effuse through the transfer line and are ionized in a standard surface ion source coupled with the TRIUMF Resonance Laser Ion Source (TRILIS). The fission target is placed upstream of the converter in order to further reduce neutron-deficient nuclear reaction products via protons that are scattered by the converter.

A tungsten collimator, currently under development, might be added inside the heat shield before the target. It is optimized to suppress the protons scattered away from the beam axis by the beam windows present in the upstream part of the beamline.

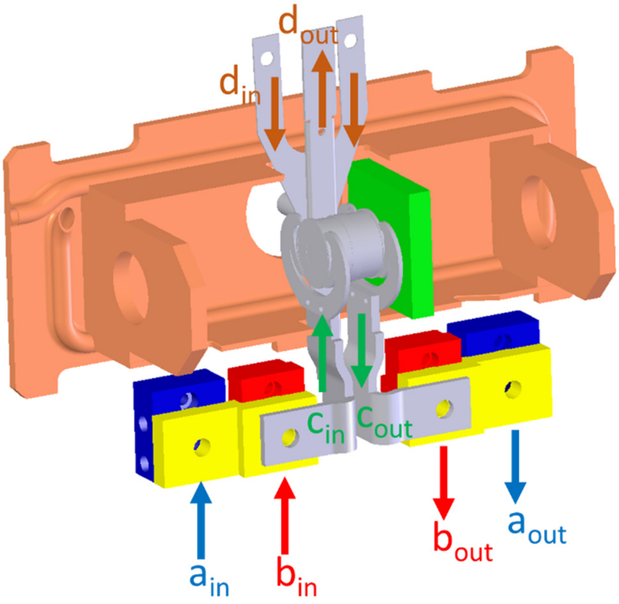

Figure 3: p2n target inside the heat shield, connected to the electrical connections.

Target Design

Figure 3 shows the latest design of the p2n target within the standard ISAC copper heat shield, where significant modifications with respect to the standard ISAC target geometry are highlighted [9].

The extraction of atomic species from the target container represents one of the main challenges for producing high-intensity RIBs. The target temperature homogeneity at 2000 °C has to be prioritized to avoid cold spots and allow for release of radioactive isotopes. In order to reach those temperatures in the UCx target material, the ISAC target containers are heated by ohmic heating with currents up to ~600 A. Since the p2n UC_x target has a bigger diameter which needs a higher current to be heated, a different heating architecture has been adopted. The ISAC target heating current is usually sent from a power supply in the electrical room through several meters of water-cooled copper pipes to a copper block (blue body on the left of Fig. 3) where the target legs are bolted on. A similar, separate, parallel circuit provides the current to an electromagnet, allowing the operation of a FEBIAD [10] ion source through the red blocks in Fig. 3. A picture of the "source tray" including the current connectors is shown in Fig. 4.

The p2n prototype target does not require the operation of a FEBIAD ion source, therefore the FEBIAD magnet and target heater "inlet" blocks will be short-out by means of a copper block indicated in yellow in Fig. 3, so that the effective current available across the target is c = a+b. A symmetric connection is made on the "outlets" as well. This connection enables currents of up to 1600 A to be delivered to the target, which is sufficient to heat the target above 2000 °C. Such heating is required to aid the release of radioisotopes of interest. The hot target container radiates to the heat shield which is cooled by the water lines shown in Fig. 5.

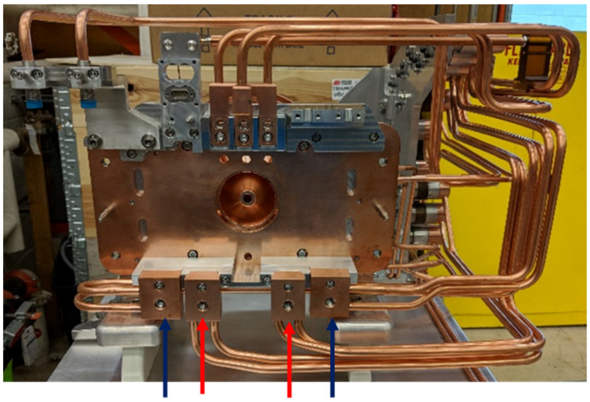

Figure 4: ISAC target module source tray including the electrical target (blue arrow) and FEBIAD (red arrow) connectors.

OVERALL COOLING CONSIDERATIONS

To efficiently produce an isotropic neutron flux, the 500 MeV beam from the main cyclotron is impinged upon a ~2 cm long tungsten converter where the spallation reactions take place. The power deposited by the proton beam in the tungsten cylinder is conductively transferred to two water-cooled copper brackets (see Fig. 5).

The converter bracket is connected to the cooling loop of the heat shield to remove the power deposited by the proton beam in the tungsten inner converter.

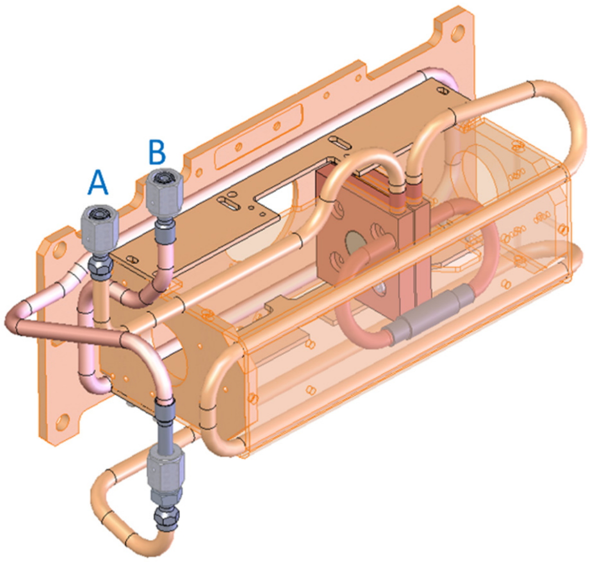

Figure 5: Converter body connected to the water services in the heat shield

The major limitation on the incoming proton beam power is therefore determined by the maximum outlet water temperature which, for regulatory requirements, must not exceed 55 °C at the position B in Fig. 5. Assuming a maximum flow in the water lines of 8 L/min and an inlet water temperature of 28 °C, the maximum power which can be dumped in this water line is:

$$P = \dot{m}\, C_p\, \Delta T = \frac{8}{60} * 4.186 * 27 = 15\ kW.$$

The power emitted by the thermal radiation from the target can be estimated from:

$$P = \epsilon * A * \sigma * (T^4 - T_0^4)$$

where $\epsilon = 0.2$ is effective emissivity assumed for a target shielded with tantalum foils, $A = 130\ cm^2$ is the surface area of the target, $\sigma = 5.67 * 10^{-8}$ is the Stefan-Boltzmann constant, $T_0^4 = 400\ K$ is the average temperature in the inner side of the copper heat shield and $T^4 = 2373\ K$ is the average target temperature. The resulting power emitted exclusively through thermal radiation from the target is therefore ~5 kW. Based on initial calculations on beam power deposition in the converter, it seems reasonable to estimate that the proton beam deposits ~8 kW in the converter body at maximum beam current (100 µA) and that therefore the total power to be removed is <15 kW. Correspondingly, the p2n target converter should be able to be irradiated with the full proton beam power if efficient heat transfer into the water is achieved.

CONCLUSION

The proposed initial design of a high-power proton-to-neutron converter for ISAC-TRIUMF was discussed along with some key considerations concerning the services infrastructure such as water and electrical supplies. The proposal for operating this target has been accepted with high priority and the authors will ask to schedule the target for online irradiation during December 2018.

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