BEAM ENERGY DEPOSITION FROM PS BOOSTER AND PRODUCTION RATES OF SELECTED MEDICAL RADIOISOTOPES IN THE CERN-MEDICIS TARGET

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Abstract

CERN-MEDICIS uses the scattered (ca. 90%) 1.4 GeV, 2μA protons delivered by the Proton-Synchrotron Booster (PSB) to the ISOLDE target irradiating it , and then continues on to irradiate the MEDICIS target which is positioned behind the ISOLDE target. After irradiation, the MEDICIS target is transported back to an offline isotope mass separator, where the produced isotopes are mass separated, and are then collected. The required medical radioisotopes are later chemically separated in a class A laboratory. The radioisotopes are transported to partner hospitals for processing and preparation for medical use, imaging or therapy for cancer treatment . Production of isotopes strongly depends on the design and core materials of both the ISOLDE and MEDICIS targets. The MEDICIS target unit is a configurable unit, allowing for variations in target material as well as ion source for the production of selected medical radioisotopes. The energy deposition on both targets is simulated using the Monte Carlo particle transport code FLUKA [1, 2], along with the in-beam production of some medical isotopes of interest. Diffusion and effusion efficiencies can then be applied to estimate the extracted activities.

INTRODUCTION

The MEDICIS (MEDical Isotopes Collected from ISOLDE) facility is a new research facility planned to start operations in spring 2017, attached to the ISOLDE facility at CERN, Switzerland, with the aim of producing medical radioisotopes.

The MEDICIS process starts with the MEDICIS target unit receiving protons, while the proton beam irradiates the ISOLDE target unit creating various isotopes. The MEDICIS target unit is then transported to an adjacent facility, where the isotopes released from the target are ionized, mass separated offline and then collected. After this, there is chemical purification and shipping, to the university hospitals of Lausanne and Geneva, and to other partners.

Figure 1 shows the components of the new MEDICIS facility involved in the extraction and collection of medical isotopes. The main isotopes of interest are not those commonly available from hospital cyclotrons, but would benefit the research community in the development of new medical isotopes. These isotopes can be used for PET, SPECT, Beta therapy and Auger therapy. There are also isotopes which are alpha emitting e.g. ^{149}Tb [4], ^{225}Ac, ^{213}Bi etc, which can be used for targeted alpha therapy.

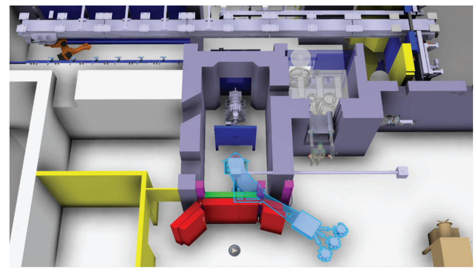

Figure 1: Top view of MEDICIS Facility showing front end, separator and collection chambers.

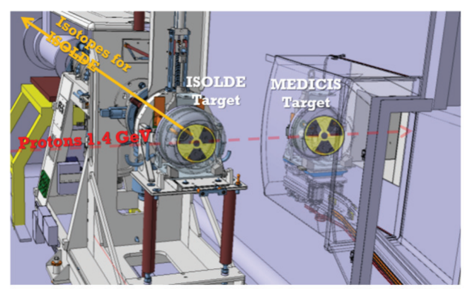

Figure 2: MEDICIS target in the ISOLDE irradiation area receiving protons that would otherwise be lost in the beam dump.

Construction of a radiation-hard monorail allows for transportation to a decay point and then further transportation to the front end, where the extraction process can take place. Figure 2 shows the irradiation point, with the MEDICIS target on the monorail in a position where it would receive protons.

METHOD

The Monte Carlo code FLUKA [1, 2] is used in this investigation. The geometry of both targets was drawn in FLAIR [5], the advanced graphical interface of FLUKA. The target material used in the ISOLDE target was uranium carbide, the most commonly used target material for ISOLDE.

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For MEDICIS, the target core chosen was tantalum. In Figure 3, image A. represents the ISOLDE target and image B. represents the MEDICIS target. The geometry, dimensions and material properties are shown in Table 1.

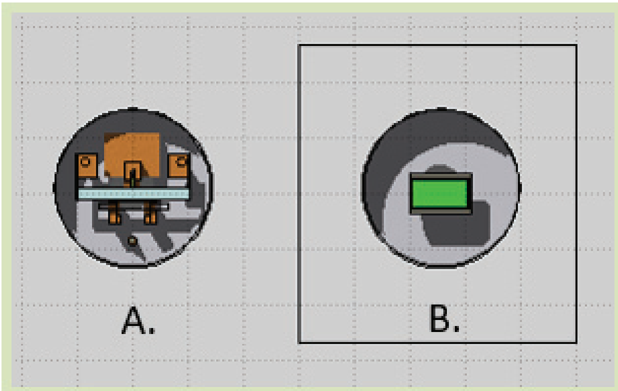

Figure 3: Geometry of both targets in FLAIR.

Table 1: Parameters used in FLUKA Geometry

Parameter	Description
MEDICIS core	Ta cylinder (radius = 25mm, length = 100mm); density = 6 g/cm^3
ISOLDE core	UCx cylinder (radius = 10mm, length = 200mm); density = 3.5 g/cm^3

In-target production of the selected isotope was simulated with FLUKA. Production rates were obtained by Resnuclei scoring. The isotope decay curves were obtained by Dcyscore scoring.

ENERGY DEPOSITION SIMULATIONS

Energy deposition of a proton beam is defined by the Bethe-Bloch formula, and for a proton beam, the energy deposition increases as a function of distance until we reach the Bragg peak, which is the maximum after which it drops down to zero.

In Figure 4, we have a proton fluence plot through 3D geometry showing how the beam passes through both targets. The beam from the PS Booster has a Gaussian profile before hitting the ISOLDE target, but after passing the ISOLDE target does scatter; hence the profile we see in Figure 4.

The beam from the PS Booster delivers short high intensity pulses at low repetition rate. Each pulse is 1.25 µs long and consists of a microstructure of 4 bunches of 230 ns spaced by 100 ns in a standard ISOLDE configuration [7]. About 50% total pulses of 14.4s are available for isotope production at ISOLDE. This is equivalent to a dc proton current of about 2.1 µA.

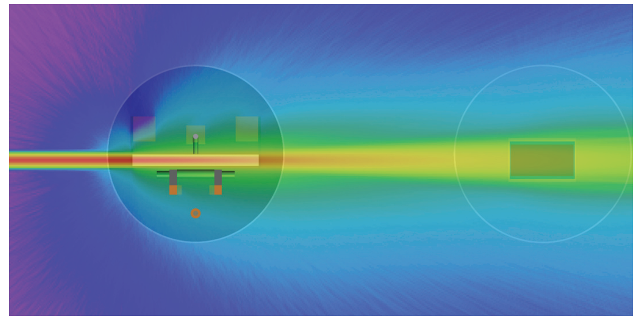

Figure 4: Proton beam passing through ISOLDE and MEDICIS targets.

Table 2: Power Deposition

Target core	Power deposited (W)
MEDICIS	93
ISOLDE	260

In Figure 5, we can see that the energy deposition of the proton beam is far greater on the ISOLDE target as compared to the MEDICIS target. This can be explained by the fact that the beam from the PS Booster gets scattered after hitting the ISOLDE target (see Figure 4), meaning that it does not hit the MEDICIS target as effectively as it hits the ISOLDE target.

Close inspection of Figure 5 reveals the maximum value of energy deposition seen at the ends of the ISOLDE target container. This is because it is made of Ta of nominal density i.e. 16.65g/cm^3 , which is very dense when compared to the MEDICIS target core. One must also bear in mind that for the ISOLDE target container, the beam windows (i.e. plugs) are quite thick leading to the higher energy deposition. The maximum energy deposition is seen in Figure 5 by the darker red colour. This is further confirmed in Table 2, where we can see about a factor 3 difference in the power deposition between the MEDICIS and ISOLDE targets. We also see some energy deposition in air, which we report at 0.01% . It also mirrors regions of higher fluence in Figure 4 as higher fluence leads to higher energy deposition. We do not observe this in regions where vacuum is defined (e.g. inside a vacuum vessel)

In these simulations, an irradiation profile of approximately 5 days (i.e.planned irradiation time for the MEDICIS target) with a beam intensity of 1.3E13 particles per second (i.e. 2µA) and proton beam energy of 1.4 GeV was specified.

PRODUCTION OF MEDICAL ISOTOPES

The production of isotopes at MEDICIS is different to cyclotron based systems. Although large number of isotopes can be produced due to the highly energetic beam from the PS Booster, in the MEDICIS target one has to take into account the various efficiencies to extract a beam.

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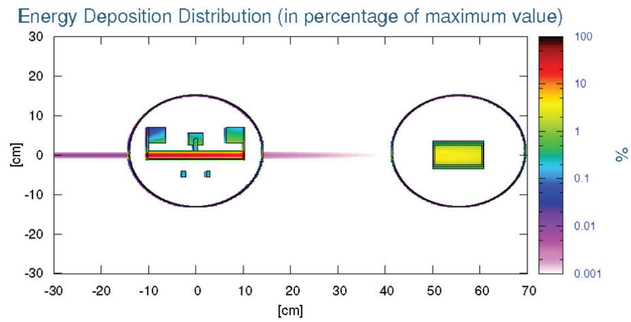

Figure 5: Energy deposition on ISOLDE and MEDICIS targets.

$$i = \Phi.\sigma.N.\epsilon \tag{1}$$

The beam intensity i (ion/s) can be expressed as seen in Equation 1 [8] in terms of the production in target $\Phi.\sigma.N$, where Φ (ion/s) is the flux of the primary particle; σ (cm^2) is the cross section to produce the desired isotope; and N is the number of target nuclei per cm^2 multiplied by the extraction efficiency ϵ, which can have a great impact on the extracted activity.

In Figure 6 some of the key isotopes of interest that can be produced using the MEDICIS tantalum target were selected, and the in-target production rates were compared against those produced by using the ISOLDE uranium carbide target. Although uranium carbide is a popular target material at the ISOLDE facility, it is not normally used to produce these isotopes.

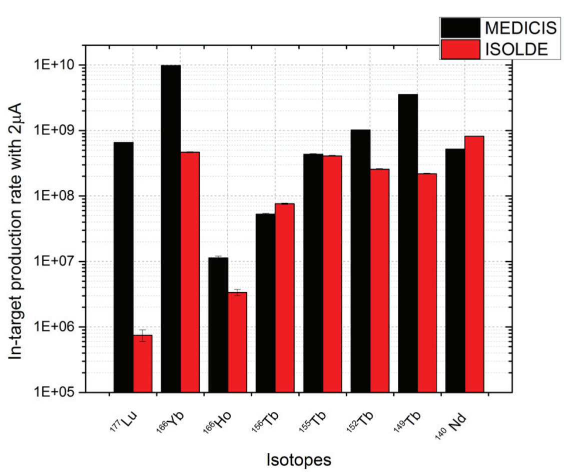

Figure 6: Selected isotope production rates for MEDICIS tantalum target.

In Figure 7, we see the decay curves of the simulated isotopes ranging from 1 second after production to 1 day after production. An extraction efficiency after the end of beam (EOB) of 20% is chosen [3]. The isotope decay curves give valuable information on activity as a function of time, allowing one to plan use and logistics. Error bars are included, but however are too small to be readily seen.

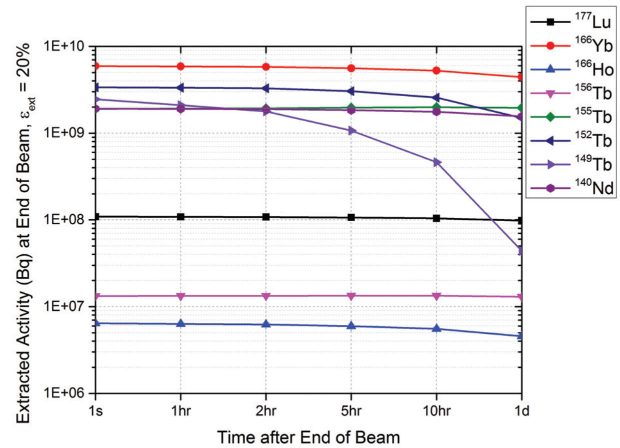

Figure 7: Decay curves for selected isotopes; activities obtained considering maximum possible gain.

CONCLUSION

As part of the development of the new CERN-MEDICIS target for fabrication and commissioning, studies were undertaken by FLUKA to calculate the energy deposition of the proton beam from the PS Booster on the new target. It was found that approximately 260 W on average was deposited in the ISOLDE target core. This is a reasonable number as about 90% of the proton beam is deposited in the beam dump [6]. The power deposition in the MEDICIS core was simulated to be approximately 93W.

Studies were also undertaken to determine in-target production rates by FLUKA of eight medical radioisotopes produced by a MEDICIS tantalum target and compared against those produced by the standard ISOLDE uranium carbide target. Subsequently, extracted activity was calculated for the isotopes produced by the MEDICIS target by applying an extraction efficiency factor. These simulations provide an estimate of the yields one can expect from the selected isotopes, which will be supplemented by experimental measurements once the MEDICIS facility is ready.

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