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NUCLEAR AND MECHANICAL BASIC DESIGN OF TARGET FOR Mo-99 PRODUCTION USING HIGH POWER ELECTRON LINAC

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Abstract

Today providing enough supplies of ^{99m}Tc / ^{99}Mo as a most applicable radioisotope in diagnostic nuclear medicine for the world demand is an important challenge. One of the proofed ways to access reliable source of this radioisotopes is the production using e-Linac [1]. In this investigation it has been tried to find the simple and the optimized design of ^{99}Mo production target based on photoneutron reaction using e- Linac. Based on the Monte-Carlo calculation for radiation transport and finite element thermal analysis, 9 thin plates of enriched ^{100}Mo has been suggested. Equal distance between plates has been considered for cooling to prevent target melting. The main target includes only ^{100}Mo in one-stage approach method to increase production rate in comparison with two-stage approach [2]. Applying 2.5 m/s for inlet velocity of cooling water provides suitable cooling process with maximum temperature of target about 900 ˚C.

INTRODUCTION

The most widely used diagnostic radioisotope in clinical practice of nuclear medicine is ^{99m}Tc, which covering 35 million diagnostic imaging process annually [3]. Its short half-life limits the distribution process to long distances, so suppliers generally try to produce ^{99}Mo, which transforms into ^{99m}Tc nucleus in β decay mode ($t_{1/2}$= 66 h).

Production of ^{99}Mo using e-Linac is a common method with two main approaches. Two-stage approach is a general method (W target as a photon converter and ^{100}Mo as a photoneutron target). In one-stage approach, the Mo target is electron-photon converter as well as the photoneutron target simultaneously, so self-absorption of photons in electron-photon converter will be prevented and produced photons participate directly in photoneutron reactions. In this study, the one-stage approach has been selected.

The maximum cross section of ^{99}Mo production reaction is on 14 MeV and by considering of logarithmic bremsstrahlung spectrum, the beam with energies between 30 to 45 MeV is desired. So 30 MeV e-beam has been selected for irradiation the target. It should be mentioned that this energy is edge of commercial high power e-Linacs abilities [4].

The different geometries for target has been investigated that reported in ref. [5]. According to it, the hemispherical target is efficient than other geometries. But due to the thermal and mechanical challenges in construction, it is decided to use simplest geometry. To achieve better results of cooling, the scanning e-beam on long ^{100}Mo plates has been considered.

NUCLEAR SIMULATION

Molybdenum is a dense metal that can be used as an electron-photon converter. Of course the photon flux of molybdenum is not as high as the produced photon flux in tungsten, but in two-stage approach, some portion of photons are absorbed in tungsten before they can be able to participate in photoneutron reaction in ^{100}Mo target. So using ^{100}Mo target as an electron-photon converter and an isotope production target simultaneously, resolves this problem.

The peak forward direction of bremsstrahlung photons are in the limited conical shape area [2], but since these photons creation happen rarely in the angles of 0, 90 and 180 degrees (relative to e-beam direction), photons population is minimum in these areas. Figure 1 shows the distribution of particles in volume of massive cylindrical target.

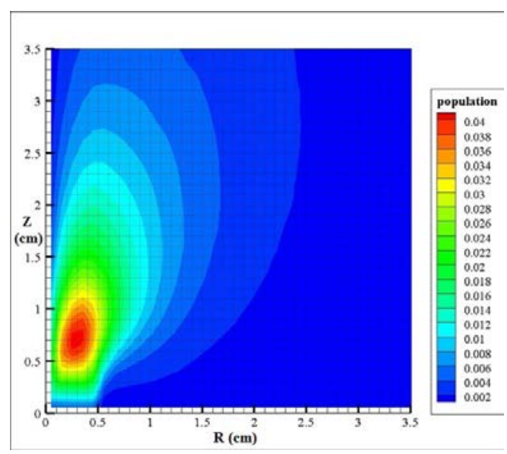

Figure 1: Distribution of photons population in volume unit of each mesh, per one incident electron.

In ^{100}Mo(γ,n)^{99}Mo reaction, the created photoneutrons during this reaction, is corresponded with produced ^{99}Mo. So the photoneutron production rate is equal to ^{99}Mo production rate. The distribution of neutrons population is shown in Fig. 2.

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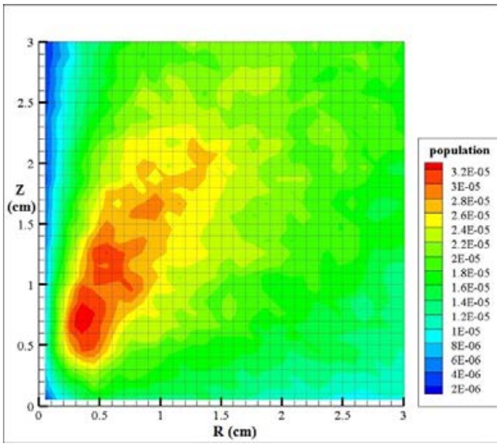

Figure 2: Distribution of photoneutrons population in volume unit of each mesh, per one incident electron.

From Fig. 2, the optimized dimension has been obtained about 1.5 cm in radius and 1.8 cm in thickness. But to decreasing heat flux, it has been decided to apply beam scan system on the long metal target (Fig. 3). The target has been divided to 9 plates (gray sections in Fig. 3) by thickness of 0.2 cm, and 0.2 cm free space between each plate. Also to avoid contacting of water and plates (because of corrosion), the copper clamps (brown sections in Fig. 3) has been considered as water cooling pipes.

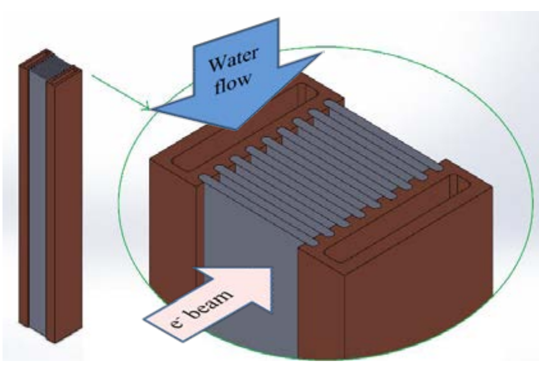

Figure 3 : Schematic view of target and cooling ducts.

THERMAL CALCULATION AND COOLING SYSTEM DESIGN

Based on Newton's law of cooling, Eq. 1, the heat transfer coefficient is related to heat transfer rate [6].

$$Q=h.A.(T_w-T_\infty) \quad (1)$$

where Q is the heat transfer rate (W), A is the cross-sectional area (m^2), h is the heat transfer coefficient ($W/m^2.K$), T_w is the object's surface temperature and T_∞ is the fluid temperature (K). According to heat transfer coefficient changes in corresponding by flow regime, the turbulent flow is a desired regime [6]. Therefore the Reynolds number (Eq. 2), has been considered more than 10000 to be sure about the regime type (turbulent) [7].

$$Re = \rho v D_H/\mu \quad (2)$$

where ρ is the fluid density (kg/m^3), μ is the dynamic viscosity of the fluid (kg/m.s), D_H is the hydraulic diameter (m) and v is the velocity of the fluid (m/s).

Finite Element Analysis

Melting point of molybdenum and copper is 2623 and 1085 ˚C, respectively. It should be noted the temperature must keep low enough to avoid recrystallization of target [8]. During recrystallization, cracks, surface roughening, and swelling may occur and affect the mechanical and thermal properties of the material. Recrystallization happens at 50-70% of the melting point temperature [9]. So the assurance temperature of target has been considered 1300 ˚C.

First, a target with 5 cm height has been simulated by Fluent software. The deposited energy of the target plates is shown in table 1 (for 1mA current at 30 MeV of continues e-beam). The related temperature distribution is shown in Fig. 4.

Table 1: The Deposited Energy in Target

^{100}Mo plates	Energy (MeV)
Plate 1	2.867
Plate 2	3.619
Plate 3	4.013
Plate 4	3.598
Plate 5	2.752
Plate 6	1.637
Plate 7	0.856
Plate 8	0.508
Plate 9	0.369

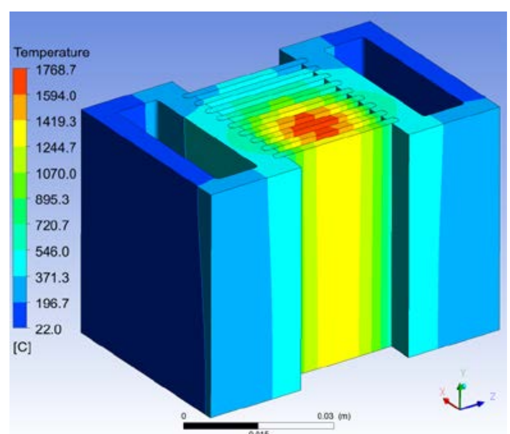

Figure 4: The temperature distribution in target with 5 cm in height (D_H = 15.65 × 10^{-3} m, v = 2.5 m/s).

In this case, the maximum temperature of target is more than 1700 ° C that clearly exceeds the assurance temperature. For the next step, a target with 10 cm in height has been tested. Figure 5 shows the related temperature distribution as well as Fig. 6 shows the water temperature profile.

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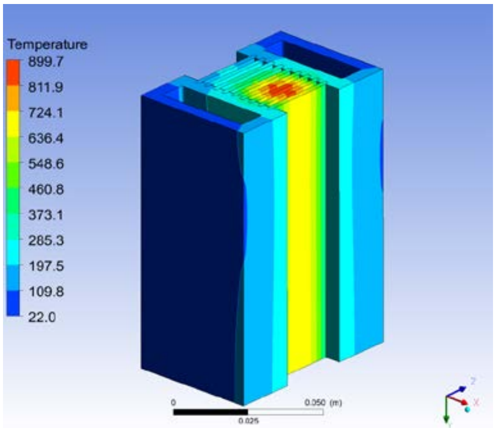

Figure 5: The temperature distribution in target with 10 cm in height ($D_H = 15.65 \times 10^{-3}$ m, v = 2.5 m/s).

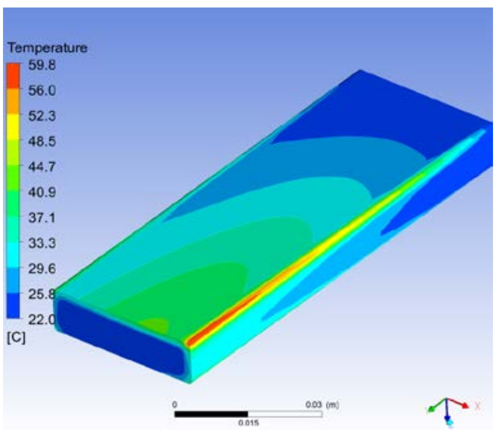

Figure 6: The water temperature profile in target with 10 cm in height.

As shown in Fig. 5, the maximum temperature is about 900 ˚C, which is below than assurance temperature. Also Fig. 6 illustrates that the maximum temperate of water does not exceed 60 ˚C.

CONCLUSION

In this investigation, simulation of ^{99}Mo production target based on using e-Linac has been performed, also the appropriate cooling system has been designed as well.

Molybdenum-99 production system including 9 ^{100}Mo plates with 3 cm in width, 10 cm in height and 0.2 cm in thickness has been designed. The reaction rate for such target is about 1.24×10^{13} event per second (for 1mA current at 30 MeV of continues e-beam). Also two copper ducts with internal cross section of 3.6 cm × 1 cm have been considered for cooling tube and target clamps. By applying 2.5 m/s of inlet velocity for cooling water, the maximum temperature will be about 900 ˚C. Therefore, the designed cooling system performance is acceptable.

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