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Thermal Simulation of a Water-Cooled ThO_2 Target for Actinum-225 Production at IRIS

Bum-Sik Park[a*], J. H. Kim[a,b]
[a]*Institute for Rare Isotope Science (IRIS), Institute for Basic Science (IBS), Daejeon, Korea*
[b]*TOPTIER Project, Institute for Rare Isotope Science (IRIS), IBS, Daejeon, Korea*
[*]*Corresponding author: bspark@ibs.re.kr*

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1. Introduction

Targeted alpha therapy (TAT) employs radiopharmaceuticals that bind to disease-specific biomolecules, and the short range of alpha radiation limits damage to surrounding healthy tissue. Actinium-225 (^{225}Ac) is a particularly attractive alpha emitter for TAT because of its favorable half-life ($t_{1/2}$ = 9.9 d) and the emission of four alpha particles in its decay chain. Although clinical studies have demonstrated the therapeutic potential of ^{225}Ac-labeled radiopharmaceuticals, further development is hindered by the limited availability of this radionuclide. In response to this demand, several research facilities have demonstrated the feasibility of thorium-based target systems for ^{225}Ac production [1-3].

This study focused on defining design requirements based on the characteristics of a 70 MeV cyclotron proton beam, evaluating engineering considerations related to thorium oxide powder, and performing thermal finite element analysis to assess heat deposition and cooling performance under expected beam conditions.

2. Water-Cooled ThO_2 Target

To achieve high-yield production, the target system must withstand proton beam currents of up to 100 µA during extended irradiation periods of up to 48 h. Under these conditions, the expected production yield of Ac-225 is estimated to reach the order of 100 mCi for a two-day irradiation [4]. These conditions define the key thermal requirements for the engineering design presented in the following sections.

2.1 Geometry of Target

The conceptual design of the target system was developed based on the isotope production facility at iThemba LABS [2]. Its dry target configuration was considered more suitable for the operational environment at IRIS. The conceptual layout of the targetry system is illustrated in Fig. 1. The target stack consists of a ThO_2 target dedicated to ^{225}Ac production, encapsulated in stainless steel cladding, followed by a dummy aluminum disk designed to fully absorb the residual proton beam and reduce unwanted activation of structural components. The target assembly is cooled by circulating water, while helium gas is purged through the gap between the beamline window and the target stack window. Helium purge was introduced to reduce window heating and prevent activation products from accumulating in the beamline gap. The ThO_2 material is encapsulated in stainless steel cladding with an outer diameter of 60 mm, an inner diameter of 50 mm, and cover plates with a thickness of 0.5 mm. The cladding dimensions were selected to accommodate the relatively large proton beam spot size available at the IRIS cyclotron, thereby reducing localized heat deposition within the target.

During target loading and post-irradiation collection, ThO_2 handling will be performed inside a hot cell. Target loading and unloading operations will be carried out remotely using a robotic handling system similar to that employed at iThemba LABS. The pusher assembly secures the target in position while simultaneously connecting the cooling water inlet and outlet lines.

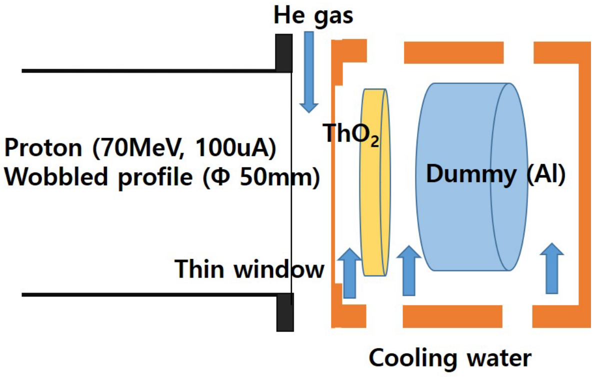

Fig. 1. Schematic diagram of the ThO_2 target.

2.2 Material Properties of ThO_2

To estimate the thermal behavior of the target system, the relationship between thorium dioxide powder density and thermal conductivity must be considered, since the pore volume in ceramic materials plays a critical role in heat transport. The theoretical density of thorium dioxide is 10.0 g/cm³, while the maximum achievable pellet density is approximately 9.79 g/cm³ after milling, drying, pressing, and sintering. In contrast, the tap density of loose ThO_2 powder is about 3.0 g/cm³ [5]. In general, ThO_2 targets are more difficult to cool than metallic targets and are less suitable for high-intensity beam irradiation. Practically, the corresponding thermal conductivity is approximately 0.7 W/m·K for the tap-density case and about 8.0 W/m·K for sintered material at 95% of the theoretical density [6]. The thermal properties used in this study are summarized in Table 1.

Table I: Material Properties for the Target

	Stainless Steel	ThO_2 (sintered 95% TD)
Specific Heat Capacity	500J/kg-K	234J/kg-K
Density	7.79 g/cm3	9.5 g/cm3
Thermal Conductivity	16.2 W/m-K	8.0 W/m-K
Melting Point	1400℃	3390℃

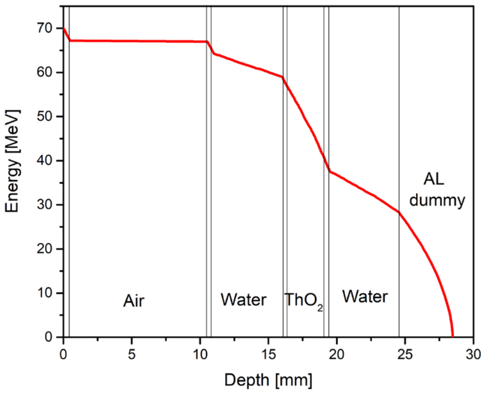

Fig. 2. Power deposition profile for the target.

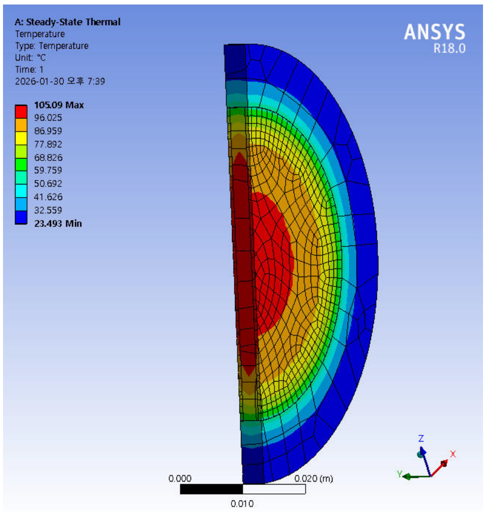

Fig. 3. Thermal analysis for the 100uA uniform irradiation. The maximum temperature is 105°C with 20°C ambient temperature.

2.3 Thermal Analysis of the Target

For proton energies in the range of 40–70 MeV, the production ratio of ^{227}Ac relative to ^{225}Ac can be effectively suppressed below 0.07%; however, this ratio increases with higher proton energy and longer irradiation times [4]. To minimize the production of long-lived ^{227}Ac ($t_{1/2}$ = 21.8 y), the energy deposition and target thickness were optimized using SRIM simulations [7]. The optimized ThO_2 thickness was selected to degrade the incident proton energy from 70 MeV down to approximately 40 MeV, thereby reducing Ac-227 co-production. Based on these calculations, the ThO_2 thickness is determined to be 2.5 mm and the resulting power deposition profile is shown in Fig. 2.

Figure 3 presents the thermal analysis results, showing a substantial safety margin below the melting points of stainless steel and ThO_2 when the convection heat transfer coefficient of 7000 W/m²·K is assumed.

3. Conclusions

The present work provides a preliminary engineering design of thorium oxide (ThO_2) targets for accelerator-based production of ^{225}Ac at the IRIS 70 MeV cyclotron. A key motivation of this study was to establish a target concept that enables efficient ^{225}Ac generation while suppressing the co-production of long-lived ^{227}Ac impurities. In particular, the target thickness was optimized to degrade the incident proton energy from 70 MeV down to approximately 40 MeV, a range known to minimize the $^{227}Ac/^{225}Ac$ production ratio.

Thermal finite element analyses indicate that the target concept remains within the safe operational limit under the expected irradiation condition. For a 100 μA proton beam and forced water cooling, the peak temperature remained below 105 °C assuming a convection coefficient of 7000 W m^{-2} K^{-1}. This result provide a substantial thermal margin compared with the melting points of stainless steel cladding and ThO_2, confirming the feasibility of the proposed target geometry for initial irradiation campaigns.

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REFERENCES

[1] Robertson, A. K. H., Ramogida, C. F., Schaffer, P., & Radchenko, V., Curr. Radiopharm. 11 156–172 (2018).
[2] G. F. Steyn et al., Instruments, vol. 2, no. 4, article 29, Dec. 2018, doi:10.3390/instruments 2040029.
[3] Cunmin Tan et al., Separation and Purification Technology 354 (2025) 129371.
[4] Yeon, Y.-H. et al, Alpha Emitter Radioisotope Development Plan from Natural Thorium Target at IRIS, Proc. Cyclotrons 2025, Chengdu, China (2025).
[5] T. Shiratori, and K. Fukuda, J. Nucl. Mater. 202, 98 (1993)
[6] J.H. Yang, K.W. Kang, K.W. Song, C.B. Lee, Y.H. Jung, Nucl. Technol. 147, 113 (2017)
[7] J. F. Ziegler, M. D. Ziegler and J. P. Biersack, SRIM – The stopping and range of ions in matter (2010), Nucl. Instrum. Methods Phys. Res. B 268 (2010) 1818–1823.