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A Simulation on ^{123}I Radionuclide Production Target Performance

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Abstract

^{123}I is radiopharmaceuticals to diagnose thyroid cancer and can be obtained through nuclear reaction by irradiating proton beam (30MeV, 100uA) onto ^{124}Xe gas target in order to produce this medicine. More medicine can be produced under the same condition by irradiation of higher beam current in nuclear reaction energy. However, the higher the beam current is, the more heat is generated and target device may melt. This paper predicts whether production is possible at a higher beam current through heat analysis with modeling of ^{124}Xe target device which is gas target. Geometrical structure modeling was used by 3D CAD SolidWorks and analyzed by using COMSOL. We used modeling in spiral way which is a more spacious surface to increase cooling efficiency of cooling water. We analyzed by simulation that target isn't melted when the beam output of cyclotron 30 is irradiated onto gas target.

Keywords: *Radiopharmaceuticals, ^{123}I, ^{124}Xe, Cyclotron*

1. Introduction

Radionuclide production technology utilized in the latest radio immunotherapy is a very important field since this is utilized in treatment and diagnosis of incurable cancer. Radiopharmaceuticals is a nuclear medicine emitting alpha-ray, beta-ray, gamma-ray, X-ray and positron beam, Radioisotope used in nuclear medicine may be divided into diagnosis and treatment nuclide according to the type of radiation-emitting. If radioisotope with medicine was inserted to the human body cancer, we can figure out where the cancer is distributed in the body by measuring radiation emitted in the body through the radiation detector. One of the radiopharmaceuticals is ^{123}I for diagnosis of thyroid cancer and this can be only produced by using 30MeV cyclotron in Korea Institute of Radiological and medical sciences (KIRAMS). By designing and analyzing gas target chamber which can be resisted to beam output (30MeV, 200uA) generated from cyclotron, this paper intends to produce more ^{123}I by irradiating proton beam onto ^{124}Xe target in the future [1].

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2. Concept, Model and Methodology

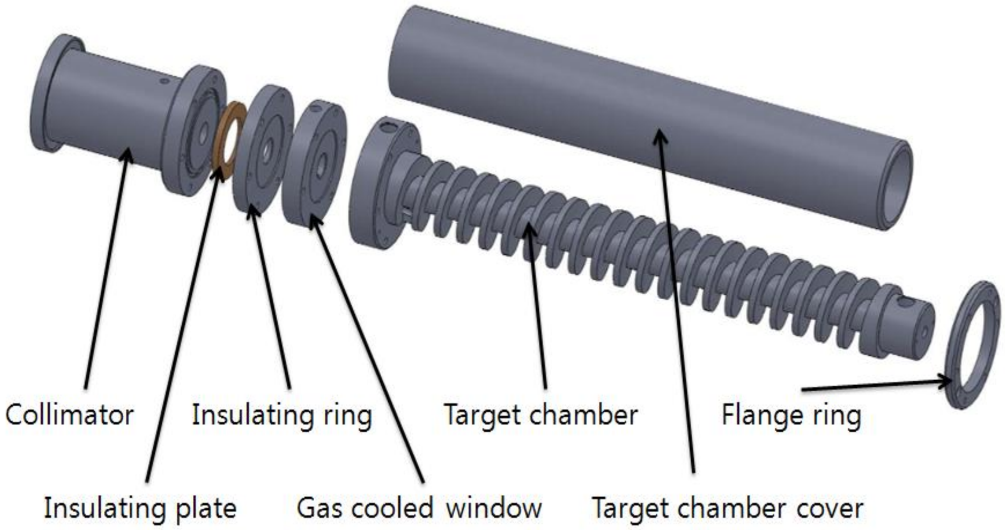
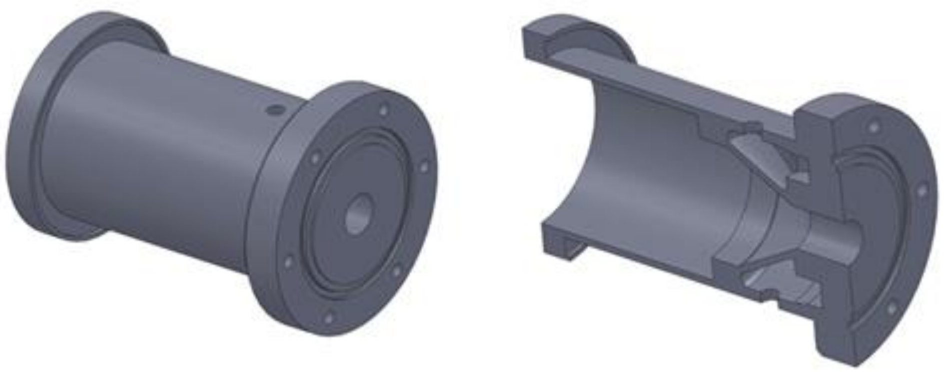


Figure 1. The Disassembling Drawing of Gas Target 3D Modeling

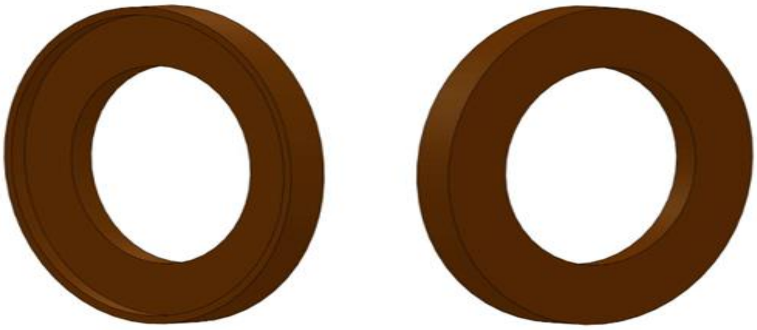
The most complicated Target for radiopharmaceuticals production is a gas target device. Because Gas is invisible and has been influenced by pressure among other devices is the highest level above everything else. Gas target 3D modeling is configured as Figure 1 and composed of 7 parts in total [5].



(a) (b)

Figure 2. Collimator 3D Modeling (a=General view, b=Section view)

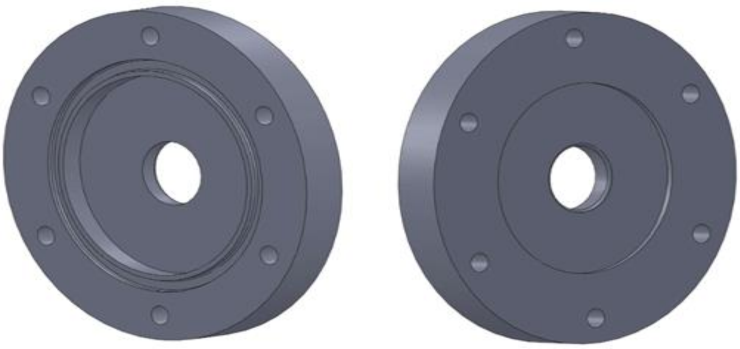
When the beam is irradiated from cyclotron, collimator performs that beam cannot be irradiated to external equipment by limiting the size of the beam up to 10Ø from the central point and is a part coupling with beam line. Also, a beam can be irradiated even though beam size is more than 10Ø as shown in 'b' of -Figure 2, cooling water line has been designed.



(a) (b)

Figure 3. Insulating plate 3D Modeling (a=Front, b=Back)

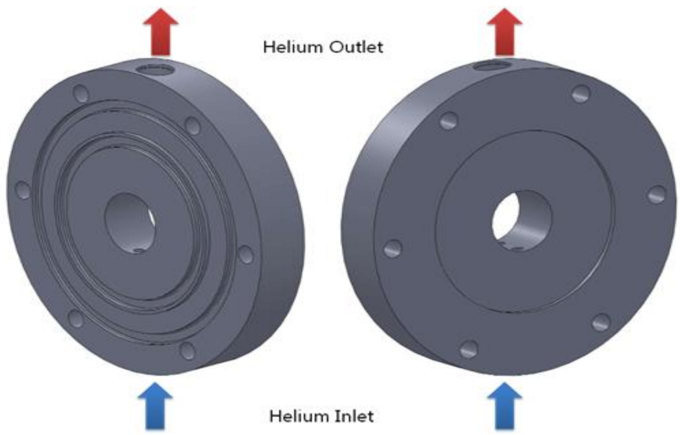
Insulating plate has been designed as Figure 3 and manufactured with material of vespel. Operator of cyclotron should check and inspect how many beam current is irradiated to gas target device when irradiating proton beam. In order to read beam current value of target device correctly, insulating plate between collimator and gas cooled window to prevent leakage of current. Therefore, vespel was used because it is strong material in heat and radiation hardening in spite of high price.



(a) (b)

Figure 4. Insulating Ring 3D Modeling (a=Front, b=Back)

Insulating ring performs as fixing plate to fix insulating plate and Havar foil. Insulating ring has been designed that O-ring can be enterel as ‘a’ in Figure 4 in order to remove leakage.



(a) (b)

Figure 5. Gas Cooled Window 3D Modeling (a=Front, b=Back)

Gas cooled window separates ^{124}Xe inside of target chamber and a vacuum of beam line. Beam line should maintain high-level vacuum status more than 5.0x10^{-6} mbar so that beam output can be irradiated to the target chamber exactly without motion. In addition, Havar foil has been designed to put one on each side of a gas cooled window to separate high-level vacuum of beam line because ^{124}Xe is in the target chamber. Indium and rubber O-ring has been inserted to prevent vacuum and ^{124}Xe leakage. There are two circular grooves in ‘a’ of Figure 5 and processed groove adjacent to the center is a space where indium spread and flowed. When the beam current with high energy go through two Havar foils and enters into target chamber, a lot of heat is generated from Havar foil. Therefore, we designed cooling line capable of cooling using helium.

Figure 6. Target Chamber 3D Modeling (a=Front, b=Back)

This is equipped with target chamber ^{124}Xe and generates nuclear reaction of (p, 2n) and (p, n) by irradiating with beam output (30MeV, 200uA). Therefore, high temperature heat is generated and a lot of radiations are also generated. As shown in Figure 7, inside of target chamber is plated with nickel and this made smooth surface like glass. This intends to be excellent corrosion resistance and strong on curing, flexibility, and corrosion-proof. ^{123}I is absorbed to the surface of inside after nuclear reaction of ^{124}Xe during irradiation of beam, so this was designed to take off the absorption ^{123}I with absorbent solution. Also, target chamber generating a lot of heat has been designed to equip cooling system using cooling water. In order to increase cooling efficiency, cooling method is designed in spiral and remove vortex so that surface of cooling water was able to expand. End section also designed to be cooling by making as outlet of cooling water up to the end of target chamber. Target chamber cover shown in Figure 1 has been configured as one of the parts by connecting with target chamber and welding.

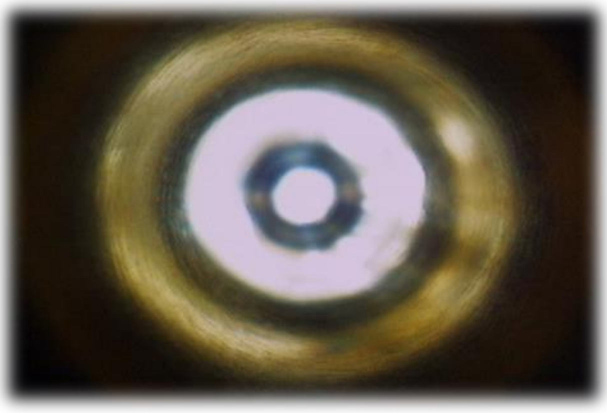


Figure 7. Picture of Inside of Target Chamber Plated with Nickel

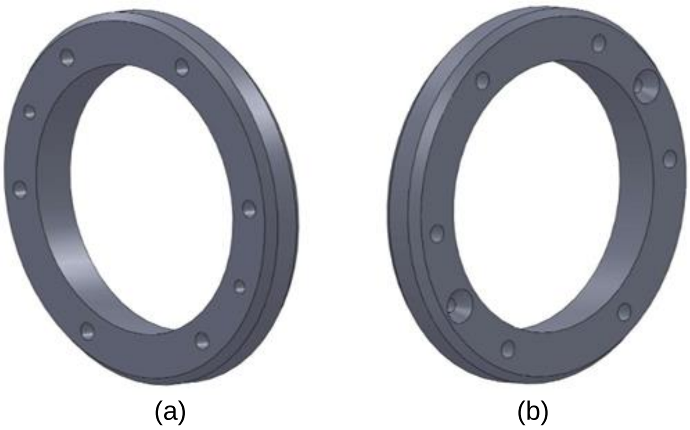


Figure 8. Flange Ring 3D Modeling (a=Front, b=Back)

As presented in Figure 8, flange ring is fixed with six 30mm screws as a role for binding all the parts, and flange ring is fixed to target chamber using two places where countersunk head screw enters in ‘b’ of Figure 8.

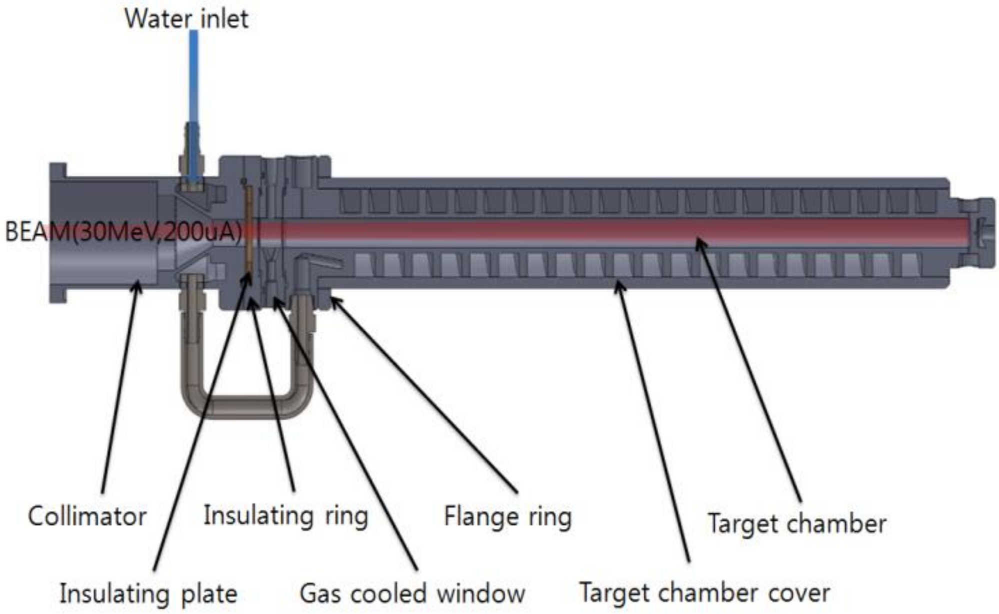


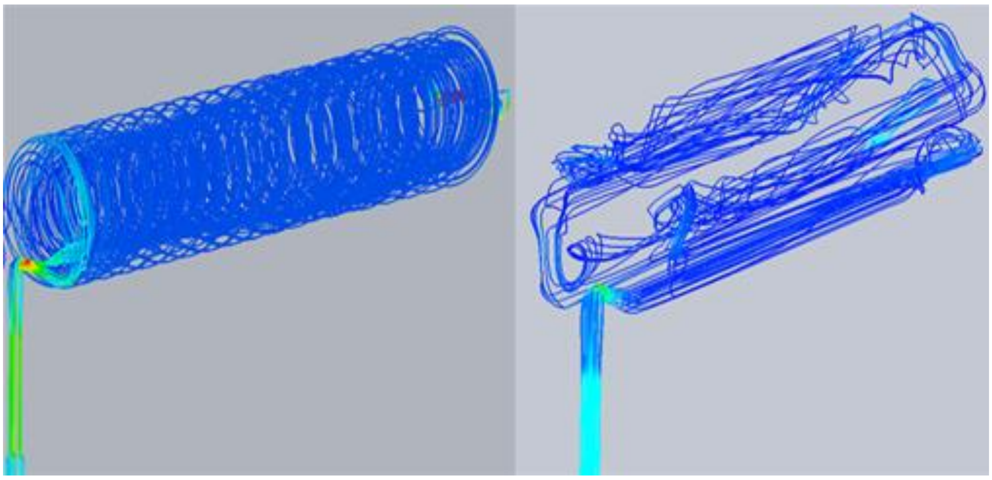
Figure 9. Cross-sectional View of Gas Target 3D Modeling

Figure 9 presents the figure that proton beam is coming from the state where all parts are assembled. Currently, domestic gas target which imported was designed to 30MeV, 100uA and used. But newly designed gas target can obtain more ^{123}I by generating more nuclear reaction in the same time by irradiation with beam output of 30MeV, 200uA. Hose type NPT 1/4 was used to connect collimator and water line for cooling target chamber, and manufactured prototype as shown in Figure 10.

Figure 20. Prototype Picture of Gas Target

3. Experiment, Simulation and Analysis

In order to increase beam current, this should be newly designed to enhance cooling efficiency of cooling system. In this paper, cooling line inside of target chamber has been designed in spiral and expands the surface of cooling water and attenuates vortex since incoming speed of cooling water is constant. As you see in Figure 11, gas target of other companies generates more vortex when analyzing cooling water method (a= System designed in spiral type, b= MDS Nordion of an existing product from another company) with particle transfer simulation of cooling water particle. Therefore, we applied the same as Figure 12 by spiral design. Cooling water flows to the first end of collimator and go through the target chamber in spirals. Cooling is fully practicable with cooling water regardless of vortex as beam isn't reached to collimator.



(a) (b)

Figure 31. Comparison of Transfer Simulation of Cooling Water Particle (a= Transfer of Designed Cooling Water Particle, b= Transfer of Cooling Water Particle from other Company's Product)

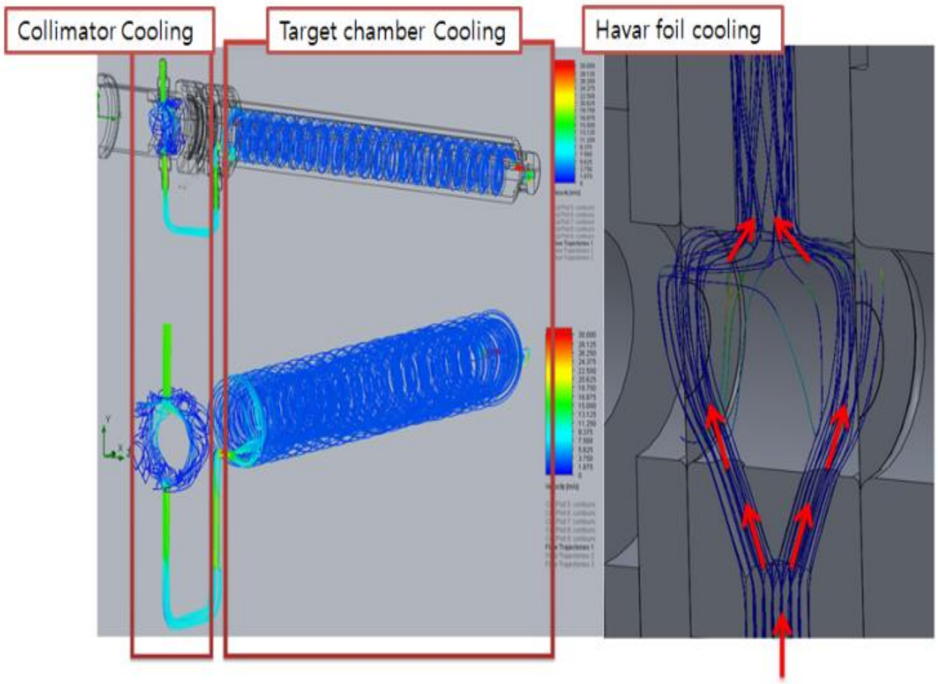


Figure 42. Transfer Simulation of Cooling Water and Helium Particle

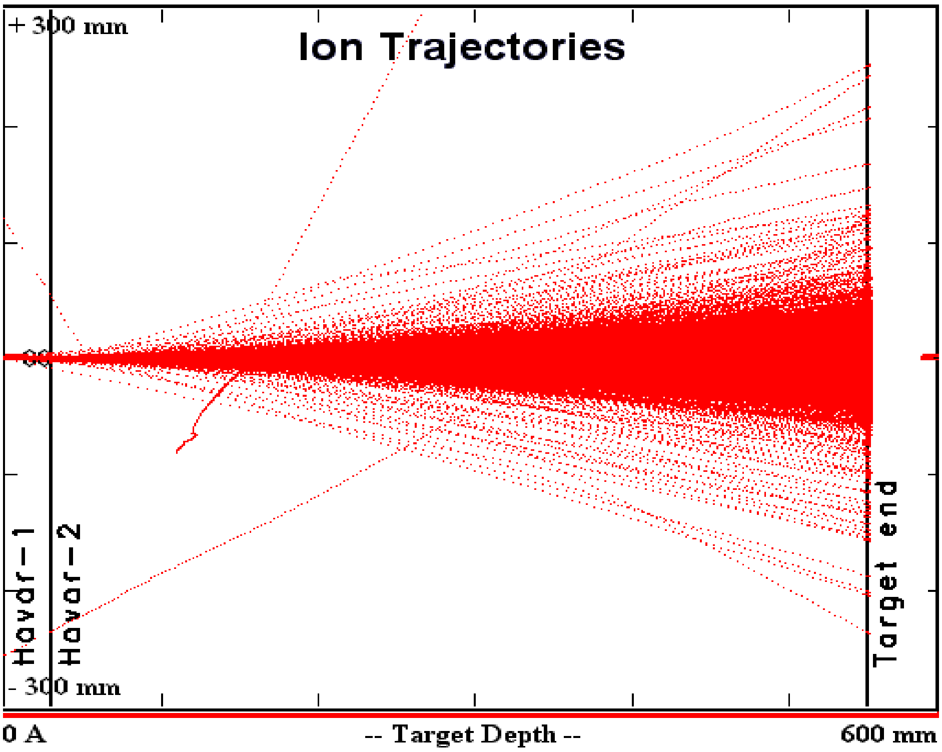


Figure 53. Beam Trajectory Entering into Gas Target

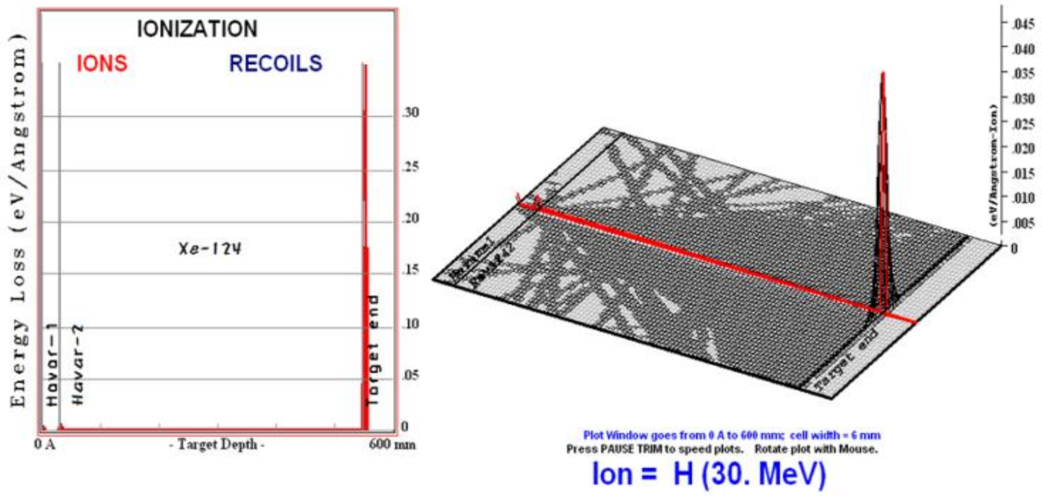


Figure 64. Energy-Loss when entered into Gas Target

Table 1. Value of Energy Loss on each Section

	Thickness(mm)	Energy Loss(eV)
Havar-1	2.5E-02	2.74E+05
Helium	5.0E+01	1.39E+04
Havar-2	2.5E-02	2.74E+05
Xe-124	5.149E+02	8.46E+06
Target chamber	3.0E+01	2.09E+07

Trajectory of beam fits a lot with the end of an inside target chamber such as Figure 13 when proton beam (30MeV, 200uA) has entered into a gas target using the program of SRIM. Energy loss occurs due to thin Havar foil such as Figure 14, and shows that energy loss occurs less at the end of a target chamber as shown in Table 1.

Table 2. Thermal Properties of Al 6061 and Havar

	Current	Al 6061 (Target chamber)	Havar-1	Havar-2
Heat source (Watt)	100uA	2090	27.4	27.4
	200uA	4180	54.8	54.8
Thermal conductivity (W/m•K)		166	14.7	14.7
Melting Point(˚C)		650	1480	1480
Density(g/cm^3)		2.70	8.3	8.3

We changed average energy loss of beam from each section into a volumetric heat source generated from a target by calculating energy loss degree of proton beam. As shown in Table 2, heat source transferred to Havar foil-1, Havar foil-2, and Target chamber by proton beam is distributed into 54.8W, 54.8W, and 4180W for irradiation with current of 200uA. Output of proton beam which is irradiated onto target is 6000W that is a beam energy (30MeV) multiplied by itself current (200uA). In addition, 1710.4W is generated from ^{124}Xe, Helium and another outer wall, and this doesn't take into account because it doesn't contribute significantly.

$$\delta_{ts}\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot (-\underline{k}\nabla T) = Q - \rho C_p \mathbf{u} \cdot \nabla T$$

Equation 1. Conjugate Heat Transfer Governing Equation

Analysis on heat transfer of heat source and cooling water can be solved with simple governing Equation, .-1 by current and conduction. Heat transfer by radiation didn't analyze because direct heat transfer to the surface target with beam output takes up the majority. δts for time-scaling coefficient, ρ for density, Cρ for heat capacity, k for thermal sensor, Q for heat source, and u is vector per speed of cooling water [2, 4, 6].

Figure 75. Target Chamber Temperature Distribution (Max Temperature =30.18°C) during Irradiation of Beam Output(30MeV, 100uA)

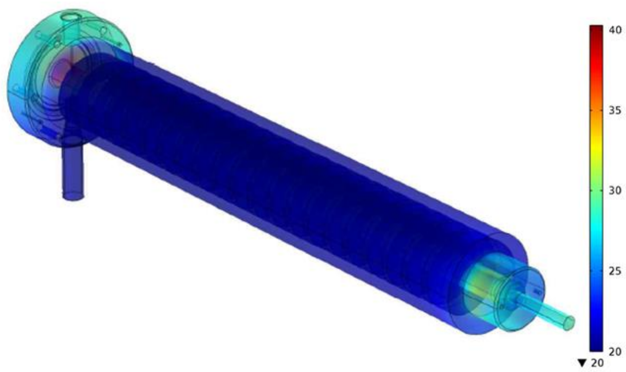
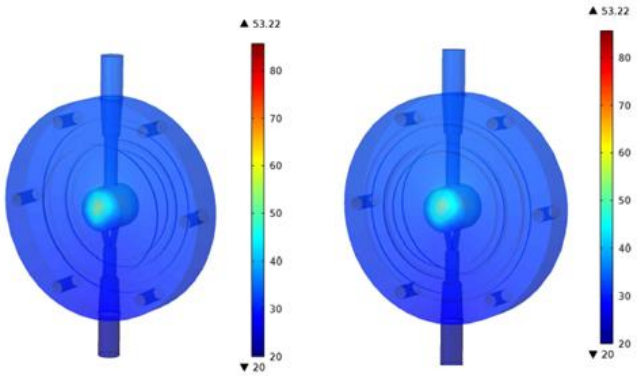


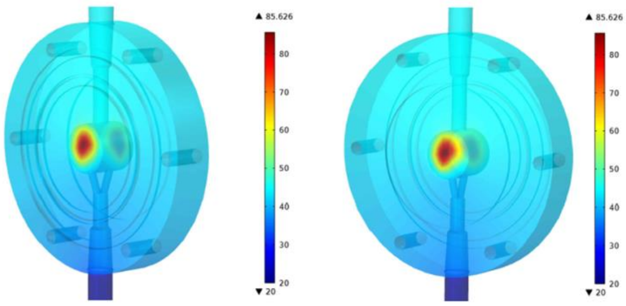
Figure 86. Target Chamber Temperature Distribution (Max Temperature=40°C) during Irradiation of Beam Output(30MeV, 200uA)

As a result of simulation with application of 30MeV-100uA and 30MeV-200uA of beam output to the target chamber was designed with spiral cooling system, maximum temperature was 30.18℃ on 100uA and 40℃ on 200uA, respectively, as shown in Figure 15 and Figure 16. For cooling water of target device, vortex has been reduced and surface has been expanded, and gas target was not melt with the higher beam output by cooling the end of the target chamber (Melting point of AI 6061 = 650˚C) [3, 7].



(a) (b)

Figure 97. Havar Foil Temperature Distribution (a=Havar foil-1, b=Havar foil-2) during Irradiation of Beam Output (30MeV, 100uA)



(a) (b)

Figure 108. Havar Foil Temperature Distribution (a=Havar foil-1, b=Havar foil-2) during Irradiation of Beam Output (30MeV, 200uA)

As more heat is generated in Havar foil in accordance with increasing of beam output, result of temperature distribution were obtained such as Figure 17 and Figure 18 as a result of simulation showing whether it can withstand beam energy of 30MeV-200uA. Melting Point of Havar is 1480˚C. Maximum temperature of Havar foil was 53.22˚C on 100uA and 85.62˚C on 200uA. Simulation result shows that Havar foil isn't melted with the higher beam output [3, 7].

4. Conclusions

New gas target has been designed to produce a greater amount of ^{123}I using high beam output (30MeV, 200uA) in the same time. Vortex has been improved by applying spiral cooling system and enhanced cooling efficiency by expanding cooling surface. Compared to gas targets with other products, vortex has radically been reduced. When cooling the end of a target chamber, the result of a simulation that maximum temperature of 40℃ for target chamber was obtained. With the result of analysis for simulation that Havar foil is reached to the maximum temperature of 85.62℃ as well as a target chamber, we expect that production of ^{123}I can be possible at the higher beam energy and have completed manufacturing prototype.

Acknowledgements

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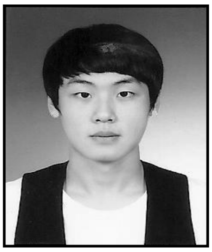

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