BEAM DUMP DEVELOPMENT FOR A KOREAN PROTON ACCELERATOR*

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Abstract

A beam dump for a 20 MeV, 4.8 mA proton beam had been manufactured in Korea. The beam dump was made of graphite for low radioactivity, and was brazed to copper for cooling. The IG 430 graphite and Oxygen Free High Conductivity (OFHC) copper were brazed using a TiCuSil filler metal, which is a compound of 4.5% titanium, 27% copper, and 68.8% silver [1]. The beam dump was designed by placing two graphite plates 30 cm × 60 cm in size at an angle of 15 degrees in order to reduce the peak heat flux in the beam dump [2,3,4]. Also, a 100 MeV proton beam dump was designed with copper of high heat conductivity.

INTRODUCTION

A proton accelerator is under construction in Korea. In 2012, the energy of the proton beam will be raised up to 100 MeV, and the average current will be 1.6 mA. A 20 MeV proton beam is currently being tested. Dumps for the 20, 100 MeV proton beams have been designed for the Korean proton accelerator. A beam dump for the 20 MeV, 4.8 mA proton beam was manufactured to minimize radioactivity using graphite. The detailed specifications of the 20, 100 MeV beam dumps including activation analyses will be presented in this paper.

20 MeV BEAM DUMP

The conceptual design of the beam dump for the 20 MeV, 4.8 mA proton beam is shown in Fig. 1. The angle between two beam dump plates is 15 degrees and the peak heat flux in the beam dump plates is 200 W/cm^2. The beam profile in the beam dump is presented in Fig. 2.

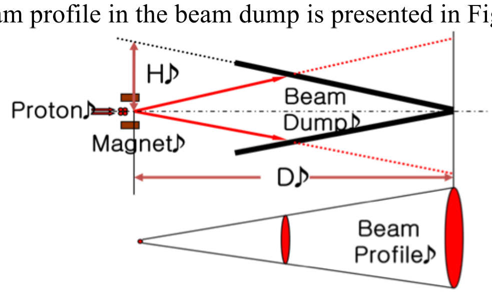

Figure 1: Conceptual design of the beam dump.

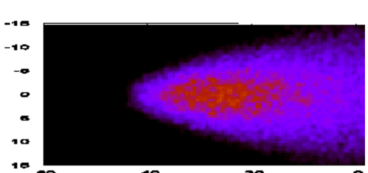

Figure 2: The beam profile in the beam dump.

Specifications

The beam dump for a 20 MeV proton beam was designed using the following specifications.

- Beam dump materials: Graphite (IG 430), Copper (OFHC), SUS 304.
- Brazing filler metal: TiCuSil (Titanium: 4.5 %, Copper: 27.7 %, Silver: 68.8 %).
- Two plates (30 cm × 60 cm, angle 15°)
- Average power: 96 kW (20 MeV, 4.8 mA)
- Peak heat flux in the beam dump: 200 W/ cm^2.
- Ma ximum temperature: Graphite 223 °C, Copper 146 °C, Cooling water 85 °C.

Figure 3 shows four graphite beam dump blocks and the beam dump arrangement.

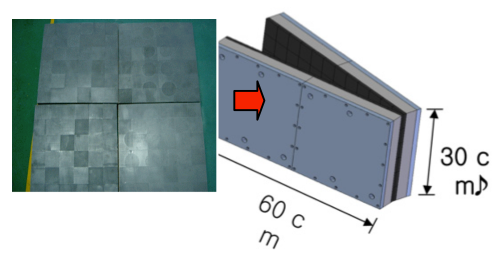

Figure 3: Manufactured graphite beam dump blocks and the beam dump arrangement.

Brazing

The beam dump was designed to minimize radioactivity at the surrounding materials of the beam dump as well as the beam dump itself. Graphite was selected as the proton beam facing material for low radioactivity. However, graphite is not a good material for water cooling due to its low heat conductivity and high hygroscopicity. To resolve these problems, the brazing of graphite and copper was considered. The brazing of graphite and copper is not easy due to their different thermal expansion rates at high brazing temperatures. The stresses of graphite and copper with their thicknesses at the brazing progress were analyzed with ANSYS code [5]. Figure 4 shows the different stresses during the brazing process based on thickness. The tensile stress of graphite during the copper brazing is the lowest at around 1 cm of graphite. The graphite stresses due to the brazing copper are not sensitive to the copper thicknesses. The graphite

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tiles (5 cm × 5 cm x 1 cm) were successfully brazed to the OFHC copper using a TiCuSil filler metal. Fortunately, as the stopping range of a 20 MeV proton in the graphite is about 2.3 mm, the protons only interact with the graphite tile of 1 cm thickness [6,7]. The heating curve for the graphite tiles and copper brazing is presented in Fig. 5.

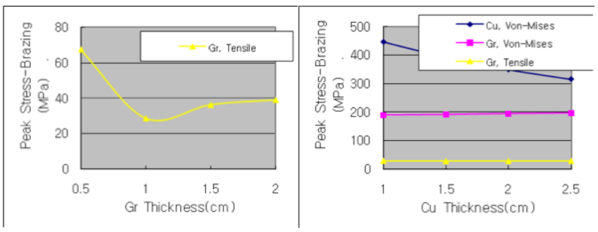

Figure 4: Graphite tensile stress analyses to find the optimum graphite thickness during brazing.

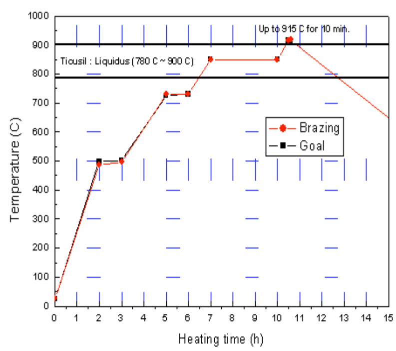

Figure 5: Heating curve for graphite and copper brazing.

Manufactured Beam Dump

Figure 6 shows a manufactured beam dump for a 20 MeV, 1.6 mA proton beam in Korea.

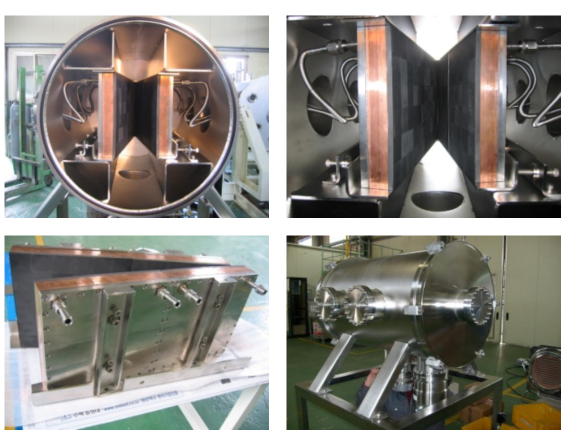

Figure 6: Photographs of the manufactured 20 MeV beam dump.

The vacuum chamber was made of SUS 304 and was manufactured to maintain a 10^{-7} torr vacuum. The cooling system was designed for a flow rate of 1.8 - 3.0 liter/sec.

Activation Analysis

Figure 7 shows an MCNP [8] calculation model for the activation analyses of the beam dump.

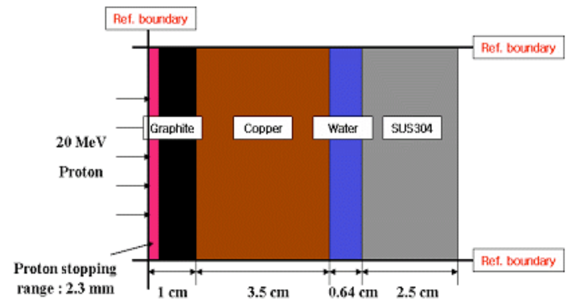

Figure 7: MCNP calculation model for activation analyses of the beam dump.

The protons only interact with graphite and produce radioisotopes $^{11}C(T_{1/2} = 20.39$ min.) through $^{12}C(p,np)^{11}C$ reactions, and radioisotopes $^{13}N(T_{1/2} = 9.97$ min.) through $^{12}C(p,gamma)^{13}N$ reactions. The radioisotopes in copper and SUS 304 are produced by the secondary neutrons that are produced in graphite by the protons. The radioactivity in copper is mainly caused by $^{64}Cu(T_{1/2} = 12.7$ h) through $^{63}Cu(n,gamma)^{64}Cu$ and $^{65}Cu(n,2n)^{64}Cu$ reactions. The radioisotopes $^{56}Mn(T_{1/2} = 2.58$ h) and $^{51}Cr(T_{1/2} = 27.7$ d) are produced in SUS 304 through $^{56}Fe(n,p)^{56}Mn$, $^{57}Fe(n,np)^{56}Mn$, $^{55}Mn(n,gamma)^{56}Mn$ and $^{50}Cr(n,gamma)^{51}Cr$, $^{52}Cr(n,2n)^{51}Cr$, $^{54}Fe(n,alpha)^{51}Cr$ reactions, respectively. Figure 8 shows the residual radioactivities in the beam dump after a 3-hour-operation with a 20 MeV, 4.8 mA proton beam. The short-lived radioisotopes are produced in the graphite and the relatively long-lived radioisotopes are produced in the SUS 304.

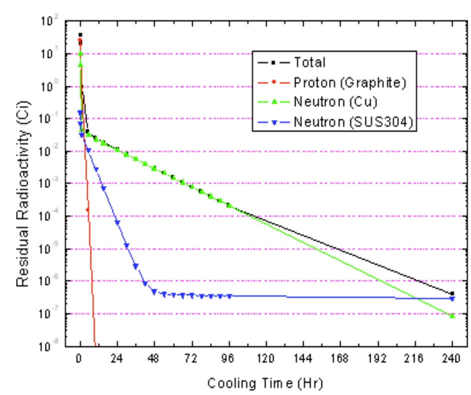

Figure 8: Residual activity in the beam dump.

Table 1 compares the residual radioactivities occurring in the graphite and copper beam dump after a 3-hour-operation with the 20 MeV, 4.8 mA proton beam. Residual radioactivity can be dramatically reduced with the graphite beam dump compared with the copper beam dump.

Table 1: Comparison of the Residual Radioactivity in the Graphite and Copper Beam Dump

Beam Dump	Particle	Radioactivity (Ci)			
		Graph-ite	Copper	SUS	Total Activity (Ci)
Graphite + Copper	Proton	25.6	-		35.7
	Neutron	-	9.9	0.2	
Copper	Proton	-	9751		10276.9
	Neutron		521	4.9	

100 MeV BEAM DUMP

The brazing of graphite and copper is not easy because of the different thermal expansion rates of graphite and copper at high temperature. Graphite should overcome a large amount of stress during the brazing process. The tensile stress of graphite during the brazing with copper is the smallest at around graphite thickness of 1 cm. The brazing of graphite and copper failed at other graphite thicknesses. Unfortunately, the stopping range of a 100 MeV proton beam in graphite is about 39 mm. There is no big advantage to braze graphite and copper for a 100 MeV proton beam in view of the radioactivity of the beam dump itself. The beam dump of the 100 MeV proton beam has been designed using copper. Figure 9 shows the designed 100 MeV beam dump model and beam profile in the beam dump.

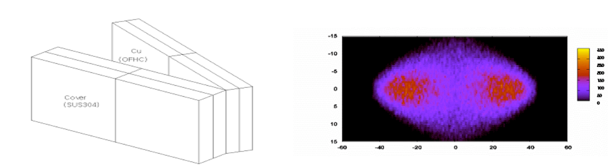

Figure 9: 100 Mev beam dump model and beam profile in the beam dump.

The 100 Mev beam dump is designed for the angle between the two beam dump plates to be 15 degrees, and for the peak heat flux to be 333W/cm^2. Table 2 summarizes the design specifications of the 100 MeV beam dump.

Table 2: Design Specifications of 100 MeV Beam Dump

Type	Plate-type
Beam facing material	Copper(OFHC)
Cover	SUS 304
Block size	30 cm × 30 cm (4 blocks)
Angle between plates	15°±2°
Coolant: velocity	2 - 3 m/sec
Coolant: flow rate	1.8 - 3.0 liter/sec
Coolant: inlet temp.	30°C
Coolant: outlet temp.	80°C
Degree of vacuum	10^{-7} torr
Sensors	Flow meters, thermocouples, pressure gauges

Activation Analysis

Figure 10 shows an MCNP calculation model for the activation analyses of the 100 MeV beam dump.

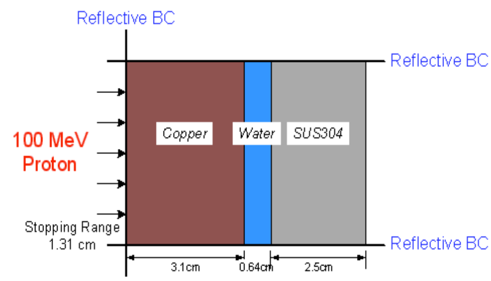

Figure 10: MCNPX model for residual radioactivity analyses in the designed 100 MeV beam dump.

Many radioisotopes are produced in copper by proton and secondary neutrons. The short-lived radioisotopes ^{62}Cu($T_{1/2}$ = 9.74 min.), ^{64}Cu($T_{1/2}$ = 12.7 h), $^{56-58}$Co, and ^{65}Zn are produced by the proton beam. The radioisotopes in copper and SUS 304 are produced by the secondary neutrons produced in copper by the proton beam. The radioisotopes such as ^{64}Cu($T_{1/2}$ = 12.7 h) in copper and ^{56}Mn($T_{1/2}$ = 2.58 h) and ^{51}Cr($T_{1/2}$ = 27.7 d) in SUS 304 are also produced by the secondary neutrons. Figure 11 shows the residual radioactivities in the beam dump after 3-hour-operation with a 100 MeV, 1.6 mA proton beam. The short-lived radioisotopes are produced in copper by the proton beam, and relatively long-lived radioisotopes are produced in copper and SUS 304 by the secondary neutrons.

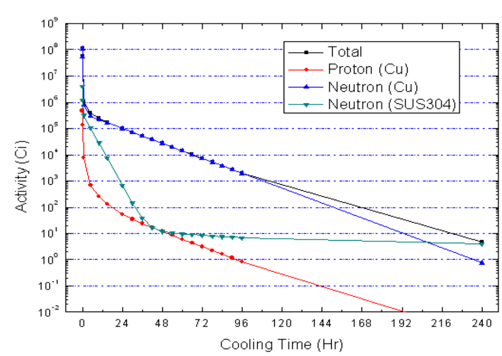

Figure 11: Residual activity in a 100 MeV beam dump.

Table 3 shows the residual radioactivity in the designed 100 MeV beam dump after a 3-hour-operation with a 100 MeV, 1.6 mA proton beam. The residual radioactivity becomes 4.74 Ci at 10 days after the proton accelerator shutdown.

Table 3: Residual Radioactivity in the Designed 100 MeV Beam Dump

	Particle	Radioactivity (Ci)		
		Copper	SUS 304	Total
After operation	proton	4.71×10^5	-	1.15×10^8
	neutron	1.11×10^8	3.90×10^6	
After 1 days	proton	52.8	-	1.00×10^5
	neutron	9.94×10^4	672.8	
After 4 days	proton	0.83	-	1959.4
	neutron	1951.8	6.86	
After 10 days	proton	1.21×10^{-3}	-	4.74
	neutron	0.75	3.99	

CONCLUSION

The beam dump for a 20 MeV, 4.8 mA proton beam was manufactured with graphite to reduce radioactivity. The tensile stress of graphite during the brazing process with copper is the smallest when the graphite is around 1 cm thick. Activation assessments were carried out in the beam dump. The radioactivity is dramatically reduced in the graphite beam dump compared with a copper beam dump.

In the future activation analyses should be performed based on the data from the operation scenario/ maintenance plan.

A beam dump for a 100 MeV, 1.6 mA proton beam has been designed using copper. Too many neutrons can be produced in the beam dump during accelerator operation, and secondary neutrons can activate the materials around the beam dump as well as beam dump itself. The manufacturing of a 100 MeV beam dump has not yet been decided due to the shielding and/or activation problems.

REFERENCES

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