Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, Oct 25-26, 2012

Monte Carlo Simulation for Radioisotope Production Yields Calculation and Radiation Shielding for Rh, RbCl, ZnO, and Ga Target

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1. Introduction

The 100 MeV linear accelerator at the proton engineering frontier project (PEFP) will be operated with average current of 300 μA for 100 MeV beam line and 600 μA for 20 MeV beam line. With this high current proton beam, all proton beam irradiated targets may be highly radio-activated, so we will install hot cell for radiation work. In this paper, we simulated production yield of radioisotopes such as ^{109}Pd, ^{82}Sr, ^{67}Cu, and ^{68}Ge, so we used natural Rh, RbCl, ZnO, and Ga prototype target of 2-mm thickness. Proton beam irradiation condition is 1-μA current and 1-hour irradiation at all target cases. Also we simulated radiation shielding calculation for 10 cm thickness lead plate. The Monte Carlo codes, MCNPX and PHITS, and the analyzing decay & build-up code, DCHAIN-SP were used to these calculations.

2. Simulation study

2.1. Cross-section

We investigated nuclear reaction cross-section of each radioisotope (Fig. 1.) to find maximum production cross-section range of ^{109}Pd, ^{82}Sr, ^{67}Cu, and ^{68}Ge, then we set incident proton beam energy of each target as listed table 1.

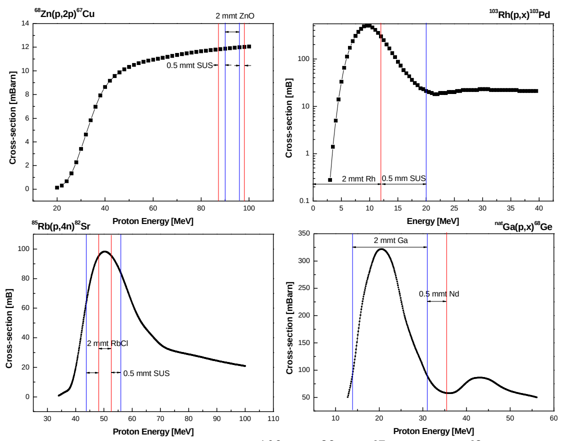

Fig. 1. Cross-section data of ^{109}Pd, ^{82}Sr, ^{67}Cu, and ^{68}Ge.

All targets were surrounded by 0.5-mmt SUS cladding except Ga target, because of chemical reaction between the Ga target and SUS. The Ga target was surrounded by 0.5-mmt niobium cladding.

Table I : Characteristics of Rh, RbCl, ZnO, and Ga target.

Target	Density [g/cm^3]	Energy range [MeV]	Sample Geometry
Rh	12.45	12.0 ~ 0	Φ5 mm × 2 mmt
RbCl	2.76	52.5 ~ 48.0	
ZnO	5.60	96.0 ~ 89.9	
Ga	5.90	31.0 ~ 13.8	

2.2. Monte Carlo Code Simulation

First, we calculated secondary neutron spectra, which was produced by primary proton beam, using MCNPX v. 2.5 code [1], then production rates of radioisotopes for each target were calculated with PHITS v. 2.15 code [2]. With the results of MCNPX and PHITS code simulations, we calculated activities of residual radioisotopes and their time-dependant decay characteristics of each target using DCHAIN-SP code [3]. Finally we evaluated gamma dose rates with calculated gamma-ray energy intensities from DCHAIN-SP code [4]. The schematic diagrams of the models applied to the Monte Carlo code simulation are shown in Figure 2.

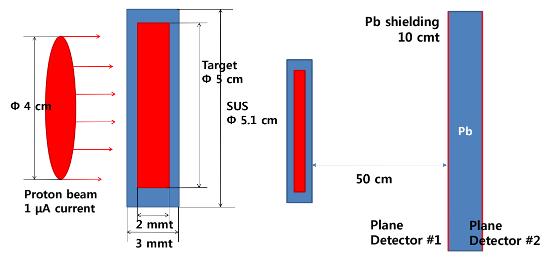

Fig. 2. The schematic diagram. (left) residual radioisotopes calculation, (right) shielding calculation.

3. Results

3.1. Production Yield

Production yields of each target at EOB (end of bombardment) are listed in table 2, and decay properties are at figure 3 and 4. Production yield of ^{103}Pd is the largest, when we use 2-mmt target. The Rh target have the least radioactive waste. Because there is small number of nuclear reactions between 20 MeV proton beam and the Rh target and low nuclear reaction cross-section. The figure 4 shows decay properties of the targets. Activities of all targets are rapidly decreased.

Table II : Calculated yield of Rh, ZnO, RbCl, Ga target.

Target (RI)	$T_{1/2}$ [d]	Activity at EOB	Activity at maximum beam current
Rh	-	6.0 mCi	(600 μA)
SUS	-	21.6 mCi	
^{103}Pd	17.0	179.3 μCi	107.6 mCi
ZnO	-	294.3 mCi	(300 μA)
SUS	-	53.5 mCi	
^{67}Cu	2.6	137.4 μCi	41.2 mCi
RbCl	-	99.5 mCi	(300 μA)
SUS	-	46.2 mCi	
^{82}Sr	25.5	35.3 μCi	10.6 mCi
Ga	-	397.4 mCi	(300 μA)
Nb	-	68.2 mCi	
^{68}Ge	270.8	34.5 μCi	10.4 mCi

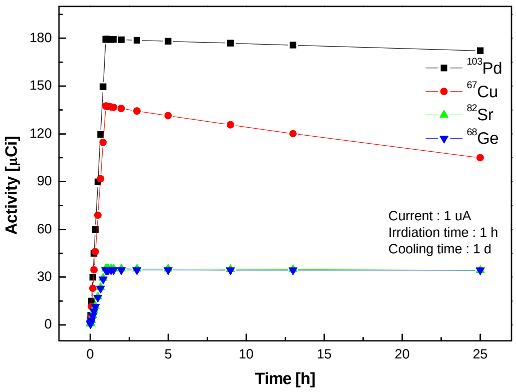

Fig. 3. Calculated yield of ^{109}Pd, ^{82}Sr, ^{67}Cu, and ^{68}Ge isotopes.

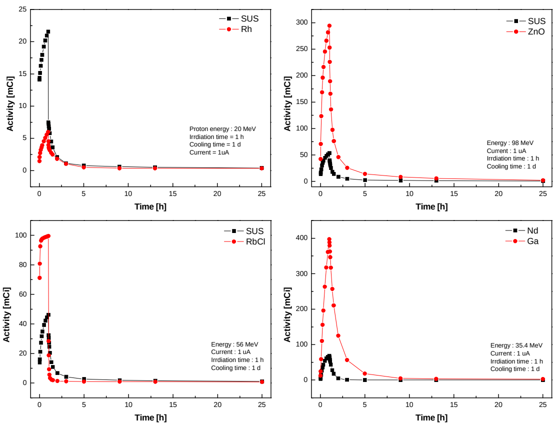

Fig. 4: Total calculated radio-activities of cladding and target.

3.2. Shielding Calculation

When we will extract ^{109}Pd, ^{82}Sr, ^{67}Cu, and ^{68}Ge radioisotopes from the targets, we have to handle the highly radio-activated targets in the hot cell. So we performed shielding calculation for 10-cmt lead shielding. The right image in Figure 2 shows schematic diagram for shielding calculation, and we evaluated dose rates at inside and outside lead shielding wall.

Table III : Calculated dose rate at lead shielding wall.

Time [min]	Rh [nSv/h] Plane #1	Rh [nSv/h] Plane #2	ZnO [μSv/h] Plane #1	ZnO [μSv/h] Plane #2
0 (EOB)	69.93	0.025	671.74	0.422
1	34.09	0.016	565.52	0.282
4	9.79	0.007	408.23	0.160
10	3.50	0.003	288.20	0.104
30	0.34	0.001	157.60	0.059
60	0.17	0.000	89.27	0.034
120	0.12	0.000	44.64	0.018
Time [min]	**RbCl [μSv/h] Plane #1**	**RbCl [μSv/h] Plane #2**	**Ga [μSv/h] Plane #1**	**Ga [μSv/h] Plane #2**
0 (EOB)	220.57	0.045	349.73	0.065
1	60.71	0.015	344.99	0.064
4	17.30	0.007	334.35	0.062
10	4.19	0.005	313.09	0.057
30	2.08	0.002	252.84	0.046
60	1.61	0.001	186.67	0.034
120	1.37	0.001	103.10	0.020

The dose rates of outside lead shielding wall do not exceed permissible dose rate for radiation worker, 12.5 μSv/h. If we irradiate proton beam with maximum current, we are not able to handle some targets like the ZnO, and Ga in the hot cell of 10-cmt lead. Then, we decide to install 15-cm lead shielding wall.

4. Conclusion

We confirmed radiation safety for worker by calculating total radio-activities and radiation shielding for the targets. But the conditions of the targets in this study are for procedure of separation targets from claddings and comparing experimental and calculated yields. Real targets for 109Pd, 82Sr, 67Cu, and 68Ge radioisotopes may be thicker than this study and needed more proton beam current. So it is required to pay more attention to radiation safety.

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