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Evaluation of Gaseous and Volatile Rare Isotopes from UCx Actinide Target 1mA of RAON ISOL System

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1. Introduction

RAON, which is a heavy-ion accelerator complex that will be built in 2021, plans to produce the rare isotope (RI) beams of high purity and high intensity using the ISOL (Isotope Separation On-Line) RI production methods. For the ISOL facility, a 70 MeV proton cyclotron is used as the driver. In order to break through the technological barriers of high-power (70 kW) ISOL target, a low-power (10 kW) target will be established first. The beam intensity will be gradually ramped up to 1mA. When UCx actinide target is used for the RI beam production through the fission reaction, many unwanted gaseous and volatile radioactive isotopes will be produced simultaneously. In this study, we have studied the gaseous and volatile nuclides of RAON ISOL facility and compared with the ones of ISAC-TRIUMF.

2. Methods and Results

TRIUMF have performed a couple of irradiation tests (2μA and 10μA) on the UCx actinide target in the process of getting the operating license for its ISOL facility [1] [2]. We have reproduced ISAC-TRIUMF actinide target 10μA irradiation by using PHITS 2.76 code, which is not used for TRIUMF. We have investigated the gaseous and volatile radioactive nuclides from ISOL-RAON 70 MeV actinide target.

2.1 Benchmark of ISAC-TRIUMF

The ISAC-TRIUMF uses a 500 MeV cyclotron to produce RI beam from UCx target. In order to estimate the amount of rare isotope production from the target, they have employed FLUKA and MCNPX codes. In addition, they have measured the dose-rate of gaseous and volatile radioactive nuclides from several beam-line sample sites during irradiation and cooling time. In order to minimize a radiological impact of harmful radioactive nuclides, those are supposed to be closely monitored in order not to be evacuated into environment through stack.

In order to study gaseous and volatile rare isotope from 70 MeV ISOL-RAON target, we have established the calculation procedure through reproduction of the rare isotope production at 10μA ISAC-TRIUMF actinide target irradiation using PHITS 2.76 code system. Basically, it is expected that the rare isotope production is quite different between TRIUMF and RAON due to big difference of a proton beam energy. Figure 1 shows the reproduced rare isotope production chart between 500 MeV ISAC-TRIUMF (top) and 70 MeV ISOL-RAON actinide target (bottom) simulated by PHITS. As it is expected, the rare isotope production is quite different according to impinged proton beam energies.

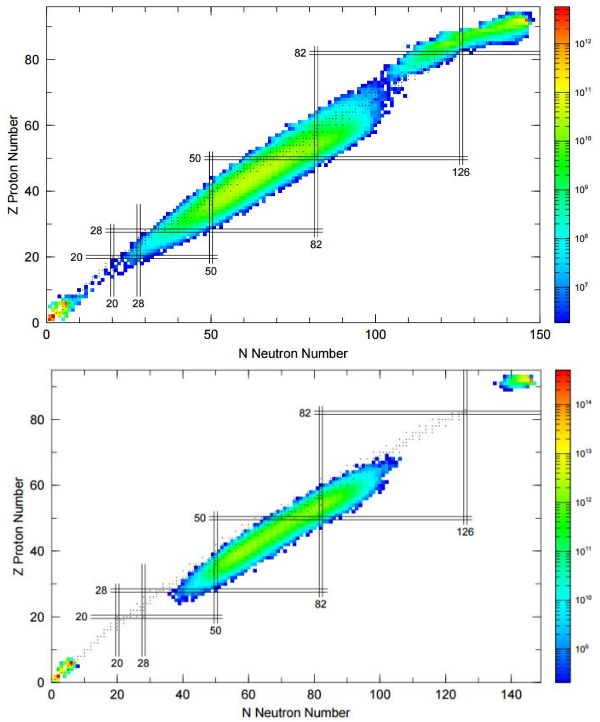

Fig. 1. Nuclide chart produced from 500 MeV ISAC-TRIUMF (top) and 70 MeV ISOL-RAON (bottom) UCx actinide target.

In their previous report, TRIUMF have calculated the production yield on several extracted RI from their actinide target. In order to verify the calculation procedure by PHITS code, we have reproduced the same RI (Sr and Rb) production rate from 500 MeV actinide target as shown in Figure 2. The production rate estimated from PHITS (red dots) agree well with the ones (blue and green dots) from other FLUKA and MCNPX calculated by TRIUMF. In the same way, we have modeled the ISOL-RAON actinide target and bombarded 70 MeV proton on it. Then, the same Sr and Rb production rate have been calculated (yellow dots). In this calculation, proton beam intensity of ISOL-RAON is 100 times bigger than one of ISAC-TRIUMF. Therefore, the production rate of RAON is also about

100 times bigger than TRIUMF. From the result, mass distribution by 70 MeV proton beam is much more narrow than 500 MeV one.

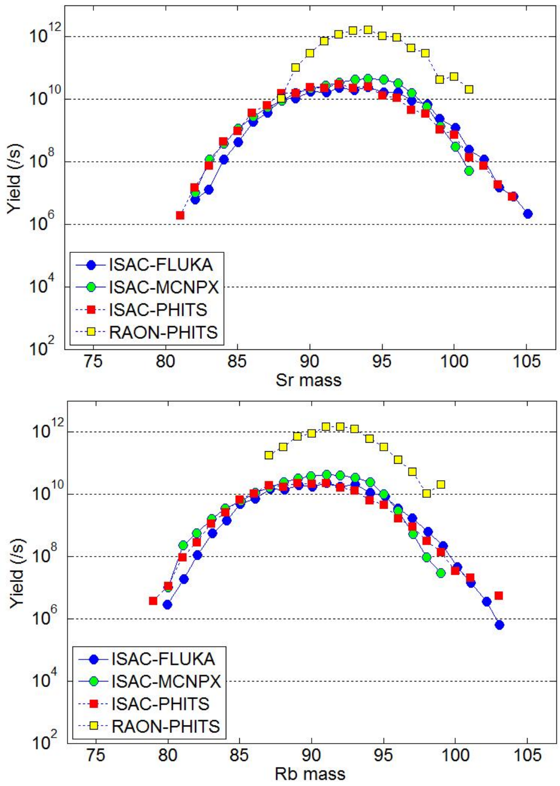

Fig. 2. Reproduction of Sr and Rb production rate from 500 MeV and 70 MeV UCx actinide target estimated by PHITS. These results are compared with ones of TRIUMF estimated by FLUKA and MCNPX

2.2 Comparison of Volatile Rare Isotopes

TRIUMF have observed the dose-rate of gaseous and volatile radioactive nuclides from either ventilation exhaust stack or dedicated actinide sampling station during irradiation (18 days) and cooling time (130 days). Table 1 shows the 10 major radioactive nuclides observed from the sampling station of TRIUMF. Their dose-rate and half-life have been calculated by PHITS code. In addition, the dose-rate and half-life of ISOL-RAON have been compared with the ones of TRIUMF.

From the result, major gaseous and volatile nuclides will be different depending on the proton beam energies. For ISAC-TRIUMF using 500 MeV proton beam, Bi-206 and Bi-205 are the most important volatile nuclides. However, Sb-136 and I-131 are the most important nuclides in the ISOL-RAON using 70 MeV proton beam. Figure 3 compare the amount of major nuclides depending on the proton beam energies. The gaseous and volatile rare isotopes of TRIUMF using higher proton energy are more various and has wider mass distribution than RAON. Especially, the amount of alpha-emitting rare isotope Po-206 is much smaller when the low energy proton beam is used for fission reaction while it was found as one of the major volatile nuclides of TRIUMF facility.

Table I: Observed 10 major radioactive nuclides from ISAC-TRIUMF and ISOL-RAON UCx Actinide target

Nuclide	ISAC-TRIUMF 500MeV, 10μA		Nuclide	ISOL-RAON 70MeV, 1mA	
	Dose Rate (μSv/ hr·m^2)	Half-life (sec)		Dose Rate (μSv/ hr·m^2)	Half-life (sec)
Bi-206	1.29E+4	5.39E+5	Sb-126	1.43E+5	1.08E+6
Bi-205	3.42E+3	1.32E+6	I-131	7.17E+4	6.93E+5
Sb-126	3.31E+3	1.08E+6	Xe-133	3.47E+3	4.53E+5
Po-206	1.93E+3	7.60E+5	I-126	9.24E+2	1.13E+6
I-131	9.71E+2	6.93E+5	Xe-131m	3.30E+2	1.02E+6
I-126	5.58E+2	1.13E+6	Rb-86	2.63E+2	1.61E+6
Rb-84	4.03E+2	2.83E+6	Xe-129m	4.71E+1	7.67E+5
Te-121	3.28E+2	1.45E+6	I-125	3.18E+1	5.13E+6
Rb-86	1.55E+2	1.61E+6	Rb-84	2.50E+1	2.83E+6
Xe-127	1.47E+2	3.15E+6	Xe-127	1.85E+1	3.15E+6

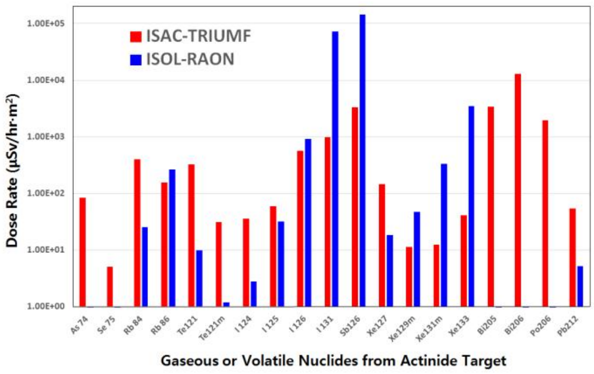

Fig. 3. Comparison of gaseous and volatile rare isotope nuclides between ISAC-TRIUMF and ISOL-RAON.

3. Conclusions

The gaseous and volatile radioactive nuclides generated from ISOL system are very important in terms of both radiation safety for personnel and radiological impact into environment. The amount and types of major nuclides will be varied according to the proton beam energies and beam current incident on UCx actinide target. RAON plans to equip the entire set of managing and monitoring these nuclides. Especially, α-emitting and relatively long-lived nuclides from ISOL facility will be carefully monitored.

REFERENCES

[1] M. Kinakin and J. Mildenberger, Actinide Target 10μA Irradiation Report, TRIUMF Document-58142, 2012.
[2] J. Mildenberger and A. Trudel, Actinide Target 2μA Irradiation Report, TRIUMF Document-35296, 2011.