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# RADIOISOTOPE PRODUCTION AT SNS (RIPS)*

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*Abstract*

A unique opportunity exists to investigate alternative radionuclide production technologies using the high-energy proton beams available at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL). The Second Target Station (STS) is being built to address emerging science challenges in energy, security, and transportation. STS will complement the capabilities of the First Target Station and High Flux Isotope Reactor by providing capabilities for materials research that requires the combined use of intense, long-wavelength (cold) neutrons, and instruments that are optimized for exploration of complex materials. The construction of the STS beamline to the target also presents an opportunity to capitalize on additional applications, such as producing high-demand radioisotopes for medical applications.

Work began in 2024 to investigate the possibility of Radioisotope Production at SNS (RIPS) through four main goals: (1) identification of isotopes of interest through modeling and simulation of prospective irradiation parameters and target compositions, (2) development of a target design concept that can receive high-energy beam pulses from the SNS accelerator, (3) identification of enhanced isotope separation methods for SNS-produced radionuclides, and (4) development of a design concept for an experimental/demonstration test stand. An overview of the project and progress toward achieving these goals is presented herein.

## INTRODUCTION

The original design of the SNS facility was a 1 GeV, 1.4 MW proton accelerator used for neutron production primarily for materials science applications. Recently, the SNS accelerator successfully completed the Proton Power Upgrade project to double the beam power capability to 2.8 MW and beam energy to 1.3 GeV. The accelerator is expected to ramp up to a full beam power of 2.8–3 MW within a few years. Because the First Target Station has a power limit of 2 MW, an additional 0.8–1 MW of beam power will be available until the Second Target Station (STS) becomes operational in the mid- to late 2030s. After STS completion, 100–300 kW will remain accessible, depending on the final power capability of the accelerator, which is expected to be approximately 3 MW. This beam power can be leveraged for alternative applications such as radioisotope production without compromising the DOE Basic Energy Sciences neutron production mission. This ability presents a unique cost leveraging opportunity for producing isotopes without the construction cost of an accelerator. The potential location for a radioisotope production station is shown in Fig. 1.

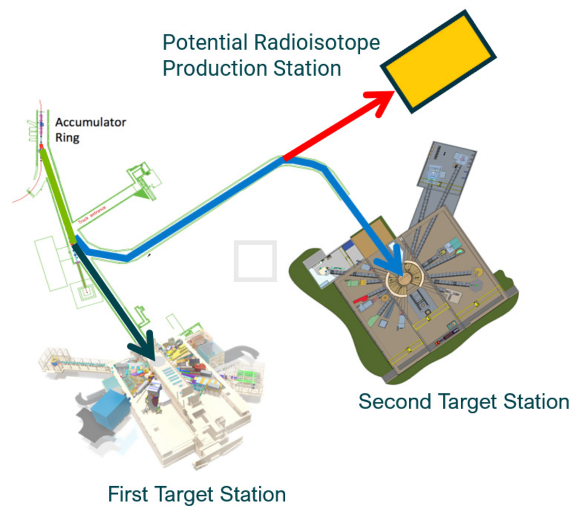


Figure 1: Location of potential RIPS facility at SNS.

Radioisotope production at this high energy range has been performed on a small scale at the European Organization Nuclear Research's (CERN's) MEDICIS facility which uses high-energy proton beams (1.4 GeV), albeit at orders of magnitude lower average beam current in comparison to SNS [1]. Higher beam current irradiations to produce radionuclides have been performed at TRIUMF Laboratories in British Columbia, Canada. TRIUMF operates a 500 MeV proton beam to produce various radioisotopes, including the highly sought-after targeted alpha therapy (TAT) medical radionuclide $^{225}$Ac [2]. Radioisotope production with high-energy (>1 GeV) protons at SNS would be the first of its kind in the US DOE laboratory complex.

## MODELING AND SIMULATION

The viability of large-scale production of radioisotopes at SNS may be realized by initially identifying radionuclides of interest through modeling and simulation. Four Monte Carlo (MC) particle transport codes—Monte Carlo N-Particle (MCNP) [3], GEometry ANd Tracking (GEANT4) [4], Fluctuierende KAskade (FLUKA) [5], and

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Particle Heavy Ion Transport System (PHITS) [6] were employed to calculate residual nuclide production cross sections for proton energies ranging from 0.1 to 1.6 GeV incident upon a thick (7.5 cm) thorium target (~620 g).

Critical radionuclides of interest were identified and analyzed, with thorium selected as the primary target material of focus for this study because of its optimized production for in-demand medical radionuclides such as $^{225}$Ac. This study revealed a diverse inventory of radioisotopes that may be produced in significant quantities through high-energy proton irradiation of thorium metal targets. Figure 2 shows this wide array of radionuclides that can be produced.

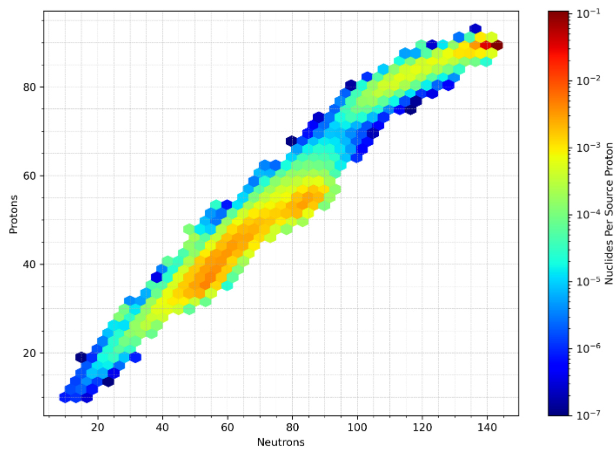


Figure 2: Time-independent nuclide distributions from 1.3 GeV proton reaction upon thorium.

Within the MC codes, various nuclear models were employed. Figure 3 shows the wide variation in results generated by these models for 225Ac yields after a 14-day irradiation. This variation in yield calculations reiterates the need for an experimental irradiation test stand to validate model results. A concept for a test stand at SNS is described in an upcoming section.

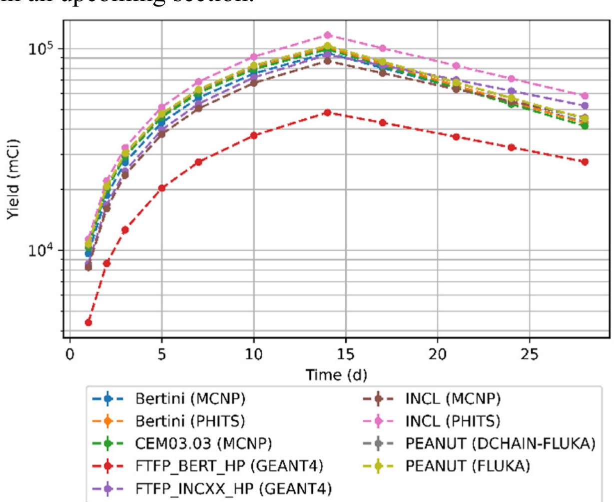


Figure 3: Various nuclear models were employed to calculate $^{225}$Ac yields for 14-day irradiation of a 7.5 cm thick natural thorium target (~620 g).

Radioisotope yields were calculated assuming 1.3 GeV protons at a nominal beam power of 250 kW. Time-independent residual nuclide yields were output from the codes and input into DCHAIN-PHITS [7] to simulate the time-dependent activation, transmutation, and decay processes for a variety of prospective irradiation/decay time steps. A selection of results from these yield calculations are shown in Table 1 with activity values at end of bombardment (EOB). Notably, the significant variation in yields depends on the choice of nuclear model.

Table 1: Yields for 14-day Irradiation of Thorium Target

| Isotope | Half-life (days) | Activity (Ci) | Application |
|---|---|---|---|
| $^{155}$Tb | 5.32 | 0.5–34 | SPECT |
| $^{161}$Tb | 6.89 | 0.1–2.0 | β therapy |
| $^{225}$Ac | 9.92 | 48–117 | α therapy |
| $^{225}$Ra | 14.9 | 8.8–39 | α therapy |

## PRODUCTION TARGET CONCEPT

Development of a target concept that could receive 250 kW of the reserve beam power capacity was another important aim of this effort. The production target concept is an assembly engineered to endure extreme energy deposition without succumbing to structural failure or causing radiological hazards. The SNS accelerator beam imposes distinct challenges on target design because of its high intensity, pulsed, 1.3 GeV proton beam and the highly dynamic thermal conditions generated by proton energy deposition.

The target concept consists of five thin thorium discs (0.5 mm each) encapsulated in 316 L austenitic stainless steel capsules with layers of flexible graphite positioned between the discs to absorb shock waves, thereby reducing material degradation. The capsules are assembled into two cassette holders (20 capsules per holder) that allow for independent retrieval of the cassettes as needed. To maintain efficient heat removal, a cooling system employs 2.25 mm channels with optimized water flow rates, which prevent boiling and mitigate thermal damage through high-throughput cooling. An early concept drawing is shown in Figure 4.

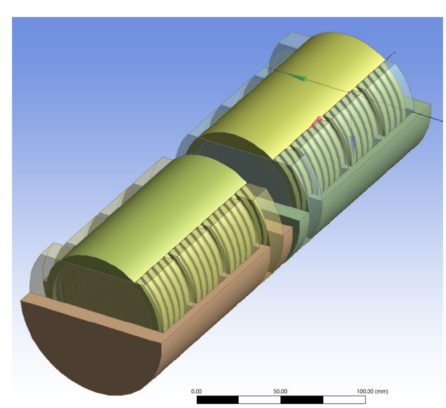

Figure 4: Production target with two cassettes.

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Stress and fatigue analyses were conducted using finite element simulations (via ANSYS) [8], which modeled the interactions of heat transfer, stress waves, and vibrations experienced by the irradiated targets. Under prolonged exposure to SNS beam conditions, these simulations revealed several critical findings. Encapsulated thorium demonstrated excellent suitability for the ultradynamic environment, showing minimal long-term fatigue damage. Additionally, stress amplitudes resulting from the 700 ns proton pulses remained well within tolerable limits, registering at less than 80 MPa for the 0.5 mm thorium disc geometry [9]. Future work will be dedicated to designing a target station with shielding, radioactive material cells, and remote handling equipment.

## ISOTOPE SEPARATION METHODS

As shown in Figure 2, a wide assortment of radionuclides will be generated through 1.3 GeV proton irradiation of thorium radioisotope production targets. After irradiation, these targets need to be chemically processed to isolate the desired elements from coproduced byproducts. Although this separation could possibly be performed at the greenfield facility that would be constructed alongside STS, leveraging unique facilities that are already established at ORNL such as the Radiochemical Engineering Development Center or the future Radioisotope Processing Facility, would be preferable.

Flow sheets outlining potential chemical separation techniques have been developed using the outputs of the modeling and simulation results. In support of other efforts, such as the DOE Tri-Lab Project to produce $^{225}$Ac, methods have been developed to efficiently separate thorium from co-produced fission products and other actinides. However, several radioisotopes of the same element will still be produced (e.g., $^{225}$Ac and $^{227}$Ac) that cannot be separated by normal chemical methods. In addition to chemical separation of various elements, electromagnetic separation would be extremely useful in isolating radioisotopes, especially those deployed in medical applications that require high specific activity. Implementation of an offline radioactive electromagnetic isotope separator would significantly increase the number of radioisotopes that could be viably produced and purified at RIPS.

## EXPERIMENTAL TEST STAND

As discussed previously, an experimental test stand to validate theoretical production yields is a critical path to success for RIPS. The test stand could also generate small quantities of radioisotopes that can be used for further development of chemical and electromagnetic isotope separation techniques. A design concept for a test target station at the SNS linac dump area has been developed to support this effort, as shown in Figure 5.

The target station will demonstrate the feasibility of applying a 1.3 GeV proton beam for efficient radioisotope production. Irradiation of a thorium target with a 1 kW beam for 48 h was simulated. Thermal and structural analyses showed that the target assembly can withstand the beam power without requiring active cooling. Additional particle transport and shielding analyses revealed that the target can be extracted and transported for post irradiation examinations without requiring remote handling. Figure 6 shows a detailed dose map of the surrounding area at EOB and after 24 h of decay.

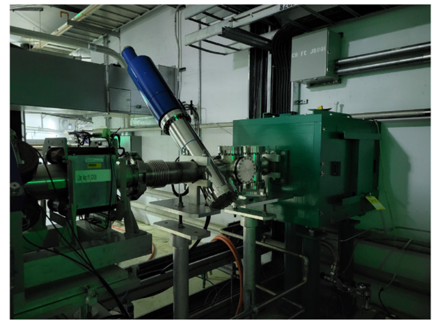

Figure 5: Possible location of experimental facility at linac beam dump area.

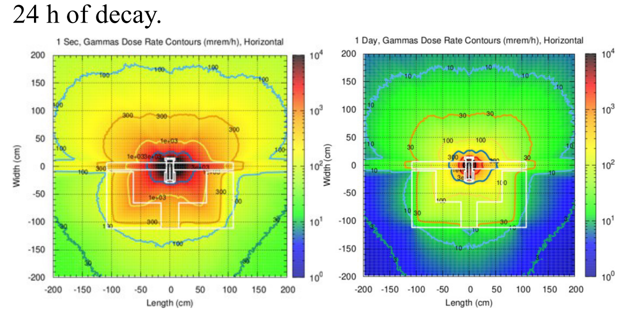


Figure 6: Top view of the decay dose (left) at EOB and (right) after 24 h of decay time.

Upon successful execution of proof-of-concept experiments at the SNS linac dump station, an opportunity will be available for a dedicated >100 kW class radioisotope production target station at SNS [10].

## CONCLUSION

The Radioisotope Production at SNS (RIPS) initiative represents a transformative opportunity to leverage existing infrastructure and excess beam power at SNS for large-scale production of radioisotopes. Initial modeling and simulation efforts have shown that significant (Curie level) quantities of medically relevant radionuclides can be produced with 1.3 GeV protons incident upon a thick thorium target. Progress has also been made in the development of a robust target design, isotope separation methods, and a conceptual experimental validation test stand. Integrating radioisotope production into SNS allows RIPS to support DOE missions and help mitigate global shortages of crucial radionuclides for targeted therapies and medical diagnostics.

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