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#9-74 The ENEA TRIGA RC-1 facility inside the SECURE project: production of medical isotopes by neutron activation

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The TRIGA RC-1 is a research reactor with a thermal power output of 1 MW, located at the ENEA Casaccia Research Centre in Rome (RM). This facility is extensively utilized for neutron activation analyses and various neutron-related experiments and applications, owing to its capability to produce a broad range of thermal spectral neutron fluence rates.

Neutron Activation Analysis (NAA) can be employed for radionuclide production, such as generating a new radioactive source for technical applications or supplying medical isotopes. In this process, a non-radioactive material is exposed to neutrons, resulting in the generation of radioactive nuclei.

In this context, the ENEA TRIGA RC-1 is involved in the EU-funded SECURE Project (HORIZON-EURATOM-2021-NRT-01 call, Strengthening the European Chain of sUpply for next generation medical RadionuclidEs, October 2022-September 2025), which aims to explore the feasibility of local radionuclide production for medical applications in Europe, including traditional and innovative ways. Specifically, the ENEA team is investigating the potential to produce terbium-161 (^{161}Tb), an isotope that shows promise for targeted radionuclide therapy and may offer advantages over lutetium-177 (^{177}Lu), which is currently used in cancer treatment. ^{161}Tb production exploits the reaction channel ^{160}Gd(n,γ)^{161}Gd(β$^-$)^{161}Tb, involving the neutron activation of a gadolinium (Gd) target that is highly enriched in gadolinium-160 (~98%). After the appropriate chemical processes, both ^{161}Tb (the raw radionuclide precursor for radiopharmaceuticals used in cancer therapy) and ^{160}Gd oxide (which can be reused for future irradiation cycles) are extracted and purified.

To assess the production capabilities of the TRIGA RC-1, simulations were conducted using the MCNP and FISPACT-II codes alongside experimental irradiation trials for validation of simulated data. These irradiation trials took place at the reactor's Central Thimble, which is the location with the highest available neutron fluence rate (~5E+13 cm^{-2} s^{-1}) and inside the rotatory rack where the neutron fluence rate is about 3E+12 cm^{-2} s^{-1} (named "Lazy Susan"). The initial calculations, based on 1 g of Gd_2O_3 (with 98.2% enrichment in ^{160}Gd), were performed using FISPACT-II, sometimes combined with MCNP to determine appropriate neutron self-shielding correction factors. The operational constraints of the reactor management allow for sample irradiation for 6 hours a day, 5 days a week. According to the hypothesis of a 12-day irradiation (72 hours of irradiation actually), the expected final yield for ^{161}Tb is ~7 GBq (activity concentration of ~8 MBq$_{Tb-161}$/g$_{Gd-160}$).
The experimental trials conducted at the Lazy Susan involved the irradiation of 190 mg and 1.34 mg of Gd_2O_3 with a natural isotopic abundance at the reactor thermal power of 10 kW and 1000 kW, respectively, for 2 hours each. These trials showed an activity concentration at the end of irradiation (EOI) of approximately 310 kBq$_{Tb-161}$/g$_{Gd-160}$ for the 190 mg sample and approximately 69 MBq$_{Tb-161}$/g$_{Gd-160}$ for 1.34 mg sample.
The experimental trial conducted at the Central Thimble involved the irradiation of 8.7 mg of 98.2% ^{160}Gd-enriched Gd_2O_3 at the reactor thermal power of 1000 kW, for 12-day irradiation (~77 hours of irradiation actually). This trial showed an activity concentration at the end of irradiation (EOI) of approximately 15 GBq$_{Tb-161}$/g$_{Gd-160}$. It should be noted that this trial is not directly comparable to the simulation data before due to the actual timing of the irradiation/shutdown of the reactor. The effective comparison will be done by performing the realized irradiation cycle in FISPACT simulation and comparing homogeneous data. The analysis of data is still ongoing. The final output will be the maximum activity concentration, i.e. GBq of

^{161}Tb per gram of ^{160}Gd, that the ENEA TRIGA RC-1 reactor can produce.
After the reactor irradiation, the irradiated sample needs to be extracted and treated with chemical dissolution and separation to recover both ^{161}Tb and ^{160}Gd oxide. The effective separation and purification of those streams is crucial: i) to achieve a usable batch of precursor ^{161}Tb to be sent to radiopharmaceutical preparation, ii) to recover ^{160}Gd oxide raw material to new irradiation batches, as to keep the economic feasibility of the production cycle.
The paper herein describes the work carried out in the SECURE Project and major results achieved, giving experimental evidence that, even with a lower efficiency and underutilization of the 98.2% ^{160}Gd-enriched Gd_2O_3, also research reactors and low-magnitude neutron-flux facilities may contribute to the radiopharmaceutical production supply panorama.

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