DETERMINATION OF COMPONENT ACTIVATION AND RADIATION ENVIRONMENT IN THE SECOND STRIPPING REGION OF A HIGH-POWER HEAVY-ION LINEAR ACCELERATOR*

I. Baek#, R.M. Ronningen, X. Wu, and A. F. Zeller, NSCL, East Lansing, MI 48824, U.S.A
I. Remec, ORNL, Oak Ridge, TN 37831, U.S.A.Abstract

Abstract

In supporting pre-conceptual research and development of the Rare-Isotope Accelerator (RIA) facility or similar next-generation exotic beam facilities, one critical focus area is to estimate the level of activation and radiation in the linear accelerator second stripping region and to determine if remote handling is necessary in this area.

A basic geometric layout of the second stripping region having beamline magnets, beam pipes and boxes, a stripper foil, beam slits, and surrounding concrete shielding was constructed for Monte Carlo simulations. Beam characteristics were provided within the stripping region based on this layout. Radiation fields, radioactive inventories, levels of activation, heat loads on surrounding components, and prompt and delayed radiation dose rates were simulated using Monte-Carlo radiation transport code PHITS[1]. Results from simulations using a simplified geometry show that remote handling of foils and slits will be necessary. Simulations using a more realistic geometry were performed and the results agree well with the estimation by the simple model.

OVERVIEW

To meet the 400 kW beam power requirement [2], the superconducting linac (SCL) driver for RIA is being designed to allow the acceleration of two-charge-state beams from the ion source for ions heavier than xenon. The SCL driver will have two charge-stripping regions that will accept up to 100 kW beams of heavy ions. One charge-stripping station will be used for light ions. The second stripping region is the focus of this report and is located just after the SCL's "Segment II". . Segment II will be used to accelerate ions from ~12 MeV/u to about 90 MeV/u (Uranium) or higher energies (up to 250 MeV/u for protons). A schematic drawing of the second stripping region between Segment II and Segment III is shown in Fig. 1.

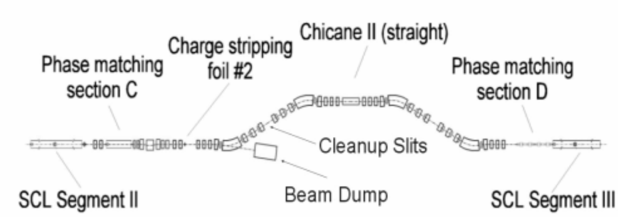

Figure 1: Conceptual layout of the second stripping region of the RIA driver linac. The locations for the stripper foil, cleanup slits, and beam dump are shown.

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#baek@nscl.msu.edu

Results of analyses, using the GLOBAL charge state distribution code [3] indicate that losses of the stripped beam at the cleanup slits may be as large as 20%. In our simulations described below, we assume a 20% loss.

The technical challenge is to ensure that significant beam losses in this region are fully considered in conceptual layouts in terms of local shielding and component design for radiation resistance and maintenance. The critical focus area is to estimate the level of activation and radiation in the second stripper area, to determine if remote handling is necessary in this area

CALCULATION OF INITIAL RADIATION FIELD OVERVIEW OF THE SECOND STRIPPER REGION USING A SIMPLIFIED GEOMETRY

Radiation transport simulations and activation studies were first carried out using a simplified geometrical model of the second stripper area. The purpose of simulations using a simplified geometry was to give estimates of radiation environment in the second stripper area for planning purposes while a more realistic model was being developed.

The simple geometry is shown in Fig. 2. Generic devices "Q1, DP, Q2, Q3", replaced the magnets in the beamline. These were made from nested cylinders. Each device contains an inner annular cylinder of low-carbon steel representing magnet steel, an annular region of high-temperature superconducting coil material, and an outer annulus of magnet steel. The primary beam was "killed" in the simulation after "quadrupole" Q3.

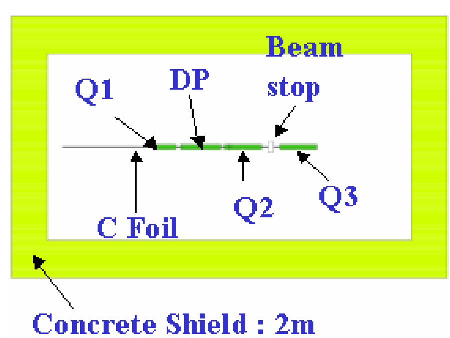

Figure 2: Simplified geometry of the second stripping region for the purpose of radiation transport simulations using PHITS.

The beamline is contained in a cylindrical concrete enclosure having an overall length of 24 meters, a diameter of 14 meters and a wall thick of 2 meters. The PHITS code system at present does not allow for ion charge states other than "fully stripped". Therefore, a tungsten plate having an aperture approximated the clean-up slit system. The hole was sized to allow 80% of the beam to pass through it, simulating the 20% losses expected at the cleanup slits.

It was found from the simulations using a simplified geometry that 1) the clean-up slits and the stripper foil will be the most radioactive of those elements; and 2) the quadrupole elements located after the clean-up slits (Q3) and the quadrupole elements located after the stripper foil will be the most radioactive of those magnetic elements.

DESCRIPTION OF A "REALISTIC" SECOND STRIPPING REGION GEOMETRY DEVELOPED FOR MONTE CARLO SIMULATIONS

A more realistic geometry was developed and used in the Monte Carlo simulations. Fig. 3 shows this layout of beam line components and concrete shielding in the second stripping region.

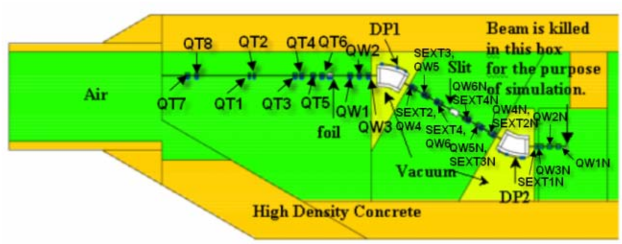

Figure 3: The geometry of the second stripping region as developed for the simulations using PHITS is shown.

CALCULATIONS BY PHITS OF PRIMARY BEAM TRACK THROUGH THE SECOND STRIPPING REGION USING THE "REALISTIC" GEOMETRY

Simulations were performed with the geometry shown Fig. 3 Magnetic fields were "turned on" only for the two dipoles. It was important to check the reliability of the simulations by making sure that the primary beam is transported correctly through the system.

Fig. 4 shows the simulation results for transporting the primary beam. The energy of ^{238}U beam ions was assumed to be 88.235 MeV per nucleon before the carbon foil and 85.122 MeV per nucleon after the carbon foil. The figure shows that the primary beam is transported correctly through the system, agreeing with standard charged particle optics calculations.

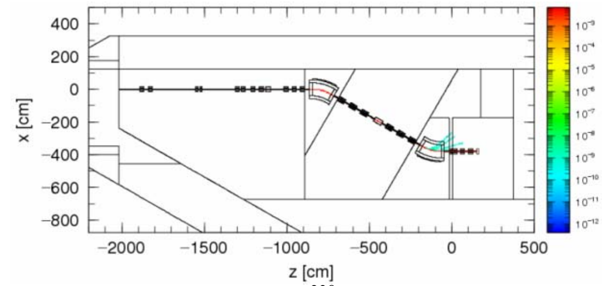

Figure 4: The primary beam, ^{238}U having 88.235 MeV per nucleon before foil, was tracked in the second stripper region using PHITS.

The neutron fluence is shown in Fig 5. The particle fluence is observed to be highest around the carbon foil and around the tungsten slit. The proton and photon fluence distributions are similar to neutron fluence distribution.

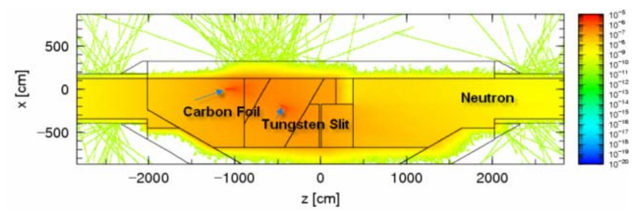

Figure 5: The neutron fluence distribution.

ACTIVATION OF THE OPTICAL COMPONENTS IN THE SECOND STRIPPER REGION

The activation of the optical components was calculated using the PHITS and DCHAIN-SP2001 code systems [4]. The purpose was to determine levels of activation in the second stripping region, to predict dose rates in the area and compare dose rates to the dose rate criterion that will allow hands-on maintenance: less than 100 mrem in an hour at 30 cm. If higher, the recommendation is made for some type of remote handling.

Activation of Magnet Coils, Carbon Foil, and Tungsten Slit

Fig. 6 shows the concentrations of total radioactivity in QW1, QW2, and QW3 as a function of time since the end of a 30 day bombardment in the regions of low carbon steel of quadrupoles and sextupoles that are radially outside of the coils. The activity concentration of the quadrupole magnet QW1, located immediately after the carbon foil, is the highest. The induced activity (Fig. 7) in tungsten slit is similar to that in QW2. The induced activity in carbon foil (Fig. 8) is highest among all components.

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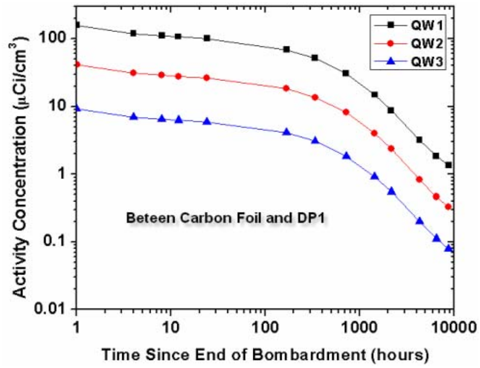

Figure 6: Concentration of total radioactivity in the coils of the quadrupoles.

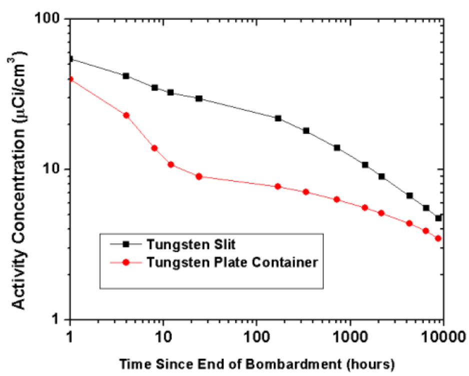

Figure 7: Concentration of total radioactivity in the tungsten slit and its vacuum container.

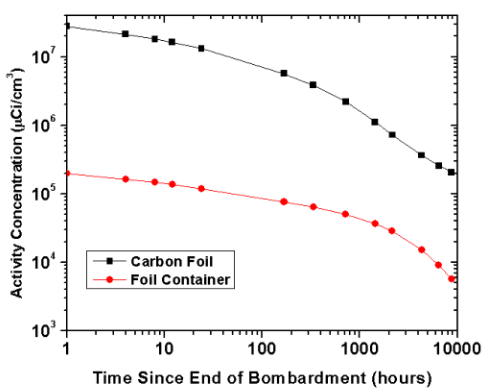

Figure 8: Concentration of total radioactivity in the carbon foil and its vacuum container.

CALCULATIONS OF RESIDUAL DOSE RATES FROM THE CARBON FOIL AND THE TUNGSTEN SLIT USING THE REALISTIC GEOMETRY AND THE PHITS AND MCNPX CODE SYSTEMS

The residual dose equivalent rates for carbon foil and the stainless steel vacuum enclosure box surrounding carbon foil are shown Fig. 9 as a function of time since the end of bombardment.

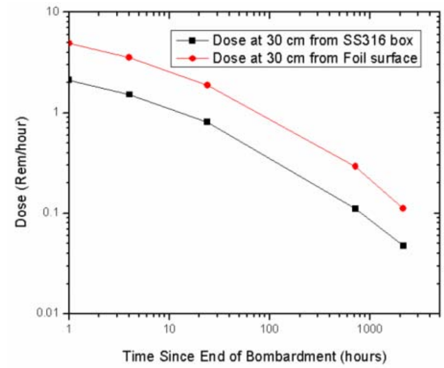

Figure 9: Residual doses at 30 cm from the carbon foil and from the SS-316 box surrounding carbon foil were calculated.

The residual dose equivalent rates for tungsten slit is shown Fig. 10 as a function of time since the end of bombardment.

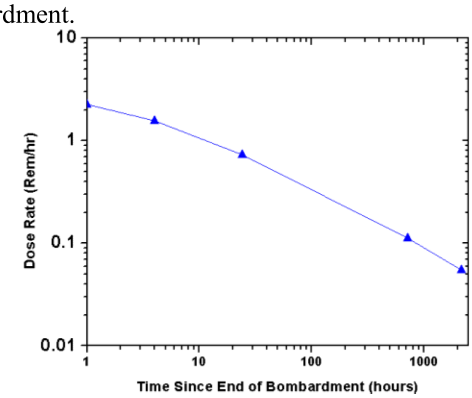

Figure 10: Residual dose equivalent rates at 30 cm from the tungsten slit were calculated.

It is expected that, for hands-on maintainance of these components, about 90 days of cooling is required for the dose equivalent to drop below 100 mrem per hour at 30 cm. If maintenance of these components is required sooner than 90 days, remote handling will likely be necessary.

CONCLUSION

It is concluded that remote handling is likely necessary in the areas of the carbon foil and the tungsten slit in the second stripping region.

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