RADIATION SIMULATIONS FOR THE PROPOSED ISOL STATIONS FOR RIA*

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Abstract

The Department of Energy's Office of Nuclear Physics, within the Office of Science (SC), has given high priority to consider and analyze design concepts for the target areas for the production of rare isotopes via the ISOL technique at the Rare-Isotope Accelerator (RIA) Facility. Key criteria are the maximum primary beam power of 400 kW, minimizing target change-out time, good radiological protection, flexibility with respect to implementing new target concepts, and the analysis and minimization of hazards associated with the operation of the facility. We will present examples of on-going work on simulations of radiation heating of targets, surrounding components and shielding, component activation, and levels of radiation dose, using the simulation codes MARS, MCNPX, and PHITS. These results are important to make decisions that may have a major impact on the layout, operational efficiency and cost of the facility, hazard analysis, shielding design, civil construction, component design, and material selection overall layout, and remote handling concepts.

INTRODUCTION

The Rare Isotope Accelerator (RIA) combines the three most powerful production techniques for rare isotopes in one single facility: in flight separation, isotope separation on-line (ISOL), and stopping-in-gas with reacceleration.

In the ISOL technique, a high-intensity light-ion beam, primarily protons or helium, bombards a thick production target. When a beam particle hits a heavy target nucleus, the target nucleus breaks up into smaller nuclei that are stopped in the thick target material. Some of these target fragments are the desired rare isotopes. These fragments are further extracted from the target, ionized and separated in a high-resolution isotope separator and then reaccelerated.

An obvious starting point for the development of a layout of the ISOL target stations is to adopt a system similar to the one existing at ISAC [1]. This facility is operated at about 50 kW of beam power, *c.f.* 400 kW envisaged for RIA. The ion beam species and energies currently planned for RIA's ISOL stations include protons, deuterons and ^{3}He ions with energies of about 1 GeV, 600 MeV/u and 750 MeV/u respectively. For the primary production target, the studies related in this work used a simple design consisting of a 15 cm long, 1.27 cm radius pure tungsten cylinder. For all beam-target configurations, it is important to model accurately primary and secondary interactions in the target and surrounding materials for a precise determination of radiation fields, components heating and residual radioactivity. These issues are considered as key topics in the R&D effort for RIA. Their magnitude will be a significant element of the overall safety hazard analysis.

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RADIATION TRANSPORT CALCULATIONS

Several Monte Carlo based computational tools are available to the scientific community for application-specific simulations. However, not all of them are able to give an accurate description of nuclear interactions taking place in the system, mainly because of inappropriate reaction models used. Therefore, a selection based on different benchmark studies against available experimental data was performed in order to decide on the best option to be used to satisfy specific requirements.

Calculations presented in this work were performed using PHITS transport code [2]. PHITS uses an intra-nuclear cascade model to simulate nucleon-induced reactions and a model based on QMD theory for reactions induced by both nucleons and heavy ions. Statistical decay of compound nucleus is calculated using GEM [3], an extension by Furihata of the evaporation model implemented in the old LAHET code system [4]. These models showed satisfactory agreement with experimental data, making PHITS the only code available to the community able to simulate both nucleon and heavy ion induced reactions. In addition, it is providing useful, timesaving tools to the user, as the possibility to import directly any MCNPX-type geometry definition and the direct access to application related information: particle angle and energy spectra, heating, DPA, residual inventory, prompt dose, etc. For activation analysis purposes, PHITS was coupled with DCHAIN-SP2001 code [5]. This code uses specific output from PHITS to calculate residual activity, decay heat and photon spectra via FENDL/D-1 and ENSDF decay data libraries for all isotopes.

Occasionally, MARS15 code [6] was used in the calculations. This code is under development for heavy ion transport, the version available at present to the users allows simulating only nucleon-induced reactions.

Geometry Definition

Calculations were performed using a detailed geometry defined for one ISOL module using MORITZ geometry package [7]. A three-dimensional layout of the geometry is given in Fig. 1.

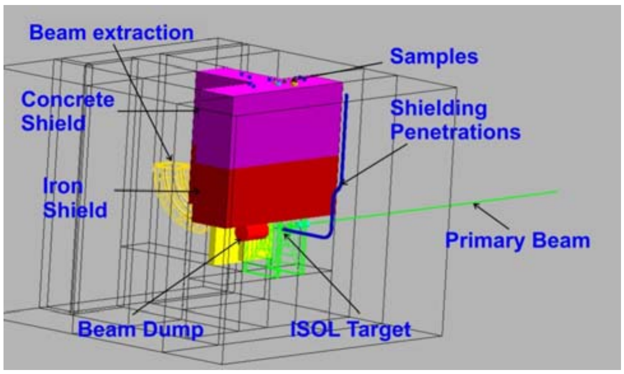

Figure 1: ISOL module geometry used in simulations. The steel shielding is shown as wire-frame.

A thick steel shield surrounds the module, while the whole system is placed in air, allowing air activation analysis outside of module to be performed. The same kind of analysis was done for some samples of representative materials placed outside the shielding, at 90^0 with respect to the direction of the primary beam.

In the geometry definition, special attention was paid to important details, such as the pipe penetrations through the shielding and accurate material compositions, to add realism to the configuration.

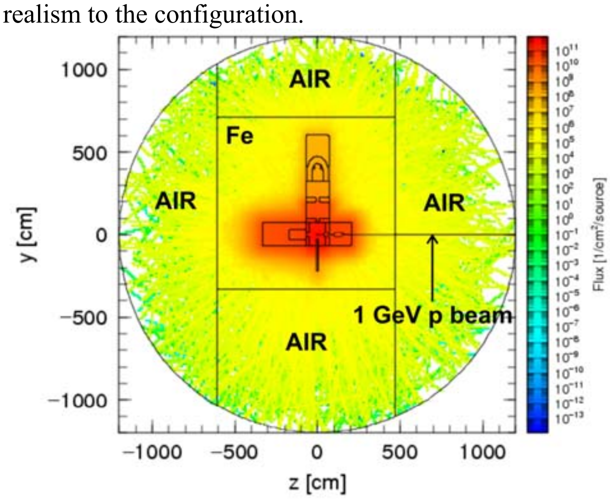

Figure 2: Top view of the ISOL module in PHITS and calculated neutron flux in the system.

PHITS Calculations

Fig. 2 presents a graphical geometry output from PHITS showing a top view of the module surrounded by the air environment and the neutron flux in the system in the case of 1 GeV proton beam incident on the tungsten target. The neutron flux is normalized to the 400 kW beam power.

A first study is dedicated to the influence of the thickness of the concrete shield above the target on the prompt dose in the air region at the top of the shielding, and to the activation of air and material samples in that region. Therefore, two extreme cases were studied, in one the concrete block was completely removed from the geometry, while in the second case a 2.4 m concrete layer was used in addition to the iron shielding. Fig. 3 shows the results obtained for both cases for the prompt dose due to neutrons. Results were obtained directly from the neutron flux with the fluence-to-dose conversion given by the parameterization from [8] used in PHITS. The results obtained using this parameterization were compared to the ones from a well-documented reference [9] and an excellent agreement was found.

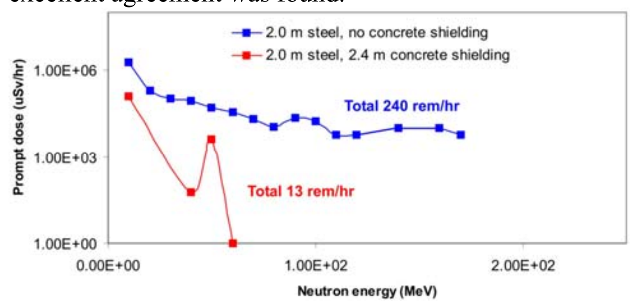

Figure 3: Prompt dose due to neutrons in the air region above the ISOL module.

As it can be seen in the figure, the concrete layer reduces the neutron flux and consequently the prompt dose by a factor of 18, significantly below the expected dose reduction (about a factor of 10 with each meter of concrete). The reason for this difference is related to the duct-streaming effect through the pipes penetrating the shielding and to the neutrons going out through the beam extraction region, which is not shielded.

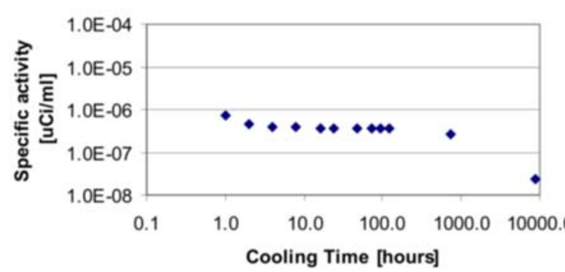

Figure 4: Residual activity in air region above the module as a function of cooling time.

The mass distribution of residual nuclei produced in the air region above the ISOL module was calculated with PHITS. Only production rates corresponding to neutron energies above 20 MeV were considered, while yields for E_n<20 MeV and total residual activity in air as a function of cooling time were further calculated using DCHAIN-SP2001 code. Results obtained in the worst case with no concrete shielding above the target are shown in Fig. 4. The major contributors to the residual activity are the isotopes ^{7}Be, ^{11}C and ^{13}N, with specific activities at t_{cool}=

1 hour of 3.5E-07, 2.1E-07 and 8.1E-08 μCi/ml respectively.

Very low or no activation was found for material samples. For a copper sample placed on the top of the module the total residual activity after 1 day of cooling is 28 nCi/g in the conservative study with no concrete shielding above the target. No activation was found for other materials considered in simulation such as Kapton, rubber, epoxy, Al_2O_3 and Teflon.

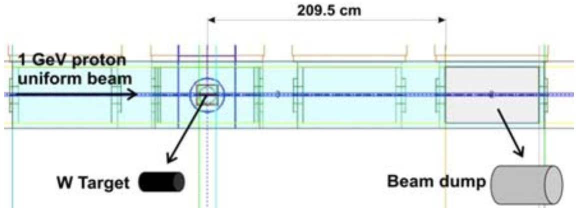

Figure 5: Configuration used in MARS15 for ISOL beam dump calculations.

MARS15 Calculations for ISOL Beam Dump

Additional calculations were related to the beam dump activation and heating. Several options for the ISOL beam dump material have been studied. Calculations were performed using MARS15 code for the configuration shown in Fig. 5.

Fig. 6 shows a comparison of residual doses at contact for each material versus cooling time, after 100 days of

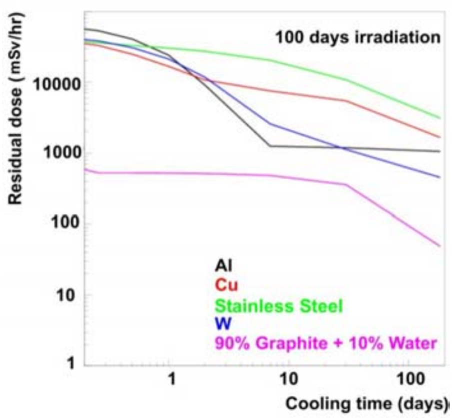

Figure 6: Residual dose at contact for different beam dump materials.

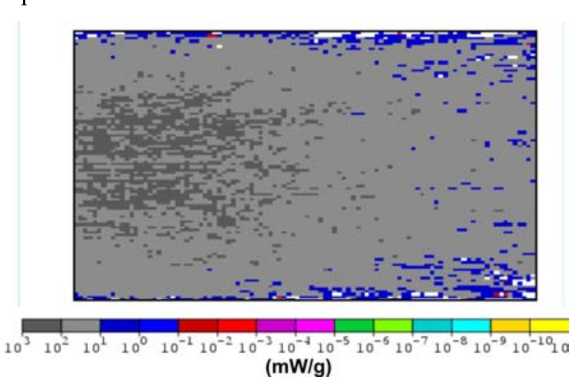

Figure 7: Heat deposition in the ISOL beam dump. The beam dump material is a mixture of 90% graphite and 10% water.

operation at 400 kW. It is obvious that a graphite beam dump is the best candidate in terms of low activation. On the other hand, cooling requirements may apply for the beam dump when using graphite, due to a relatively high and uniform heat deposition as can be seen in Fig. 7.

DISCUSSION

Initial, detailed radiation transport calculations have been performed for one module of RIA's ISOL stations. Special attention was paid to geometry and material definition, allowing the study of different aspects in a realistic way. Calculations were dedicated to the determination of radiation fields, components heating and residual radioactivity. In particular, two extreme cases for concrete shield have been studied, giving an indication on the shielding requirements for the ISOL stations. Many similar studies are underway.

REFERENCES

[1] P.G. Bricault, M. Dombsky, P.W. Schmor, G. Stanford, "Radioactive ion beams facility at TRIUMF", Nucl. Instr. Meth. B126 (1997) 213.

[2] Hiroshi Iwase, Tadahiro Kurosawa, Takashi Nakamura, Nobuaki Yoshizawa, and Jun Funabiki, "Development of heavy ion transport Monte Carlo code", Nucl. Inst. Meth. Phys. Res. B183 (2001) 374.

[3] S. Furihata *et al.,*"The GEM Code-A simulation program for the evaporation and fission process of an excited nucleus", JAERI-Data/Code 2001-015, JAERI, Tokaimura, Japan (2001).

[4] R.E. Prael and H. Lichtenstein, "User guide to LCS: The LAHET Code System", LA-UR-89-3014 (1989).

[5] H. Takada and K. Kosako, "A Code System for Analyzing Decay and Build-up Characteristics of Spallation Products," JAERI-Data/Code-99-008, March 1999, T. Kai, F. Maekawa, et al., DCHAIN-SP2001: High Energy Particle Induced Radioactivity Calculation Code," JAERI-Data/Code 2001-016 (In Japanese) (2001).

[6] N.V. Mokhov, "The Mars Code System User's Guide", Fermilab-FN-628 (1995); O.E. Krivosheev, N.V. Mokhov, "MARS Code Status", Proc. Monte Carlo 2000 Conf., p. 943, Lisbon, October 23-26, 2000; Fermilab-Conf-00/181 (2000); N.V. Mokhov, "Status of MARS Code", Fermilab-Conf-03/053 (2003); N.V. Mokhov, K.K. Gudima, C.C. James et al, "Recent Enhancements to the MARS15 Code", Fermilab-Conf-04/053 (2004); http://www-ap.fnal.gov/MARS/.

[7] Kenneth A. Van Riper, MORITZ User's Guide, White Rock Science (2004).

[8] Y. Sakamoto and Y. Yamaguchi, "Dose Conversion Coefficients in the Shielding Design Calculation for High Energy Proton Accelerator Facilities" JAERI-Tech 2001-042 (2001).

[9] J. Donald Cossairt, Radiation Physics for Personnel and Environmental Protection, FERMILAB Report TM-1834 (2004).

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