RADIATION SIMULATIONS AND DEVELOPMENT OF CONCEPTS FOR HIGH POWER BEAM DUMPS, CATCHERS AND PRE-SEPARATOR AREA LAYOUTS FOR THE FRAGMENT SEPARATORS FOR RIA*

Reginald Ronningen, Georg Bollen, Valentin Blideanu, Don Lawton, David Morrissey, Bradley Sherrill, Al Zeller, NSCL, East Lansing, MI 48824, U.S.A.
Itacil Chiari Gomes#, Anthony Levand, Yoichi Momozaki, Jerry Nolen, Claude Reed, ANL, Argonne, IL 60439, U.S.A.
Hans Geissel, Hiroshi Iwase, GSI, Darmstadt, Germany
Lawrence Heilbronn, LBNL, Berkeley, CA 94720, U.S.A.
Larry Ahle, Jason Boles, Susana Reyes, Werner Stein, Mark Stoyer, LLNL, Livermore, CA 94550, U.S.A.
James R. Beene, Thomas Burgess, Ken Carter, David Conner, Tony Gabriel, Louis Mansur, Igor Remec, Mark Rennich, Dan Stracener, Mark Wendel, ORNL, Oak Ridge, TN 37830, U.S.A.

Abstract

The development of high-power beam dumps and catchers, and pre-separator layouts for proposed fragment separators of the Rare-Isotope Accelerator (RIA) Facility are important in realizing how to handle the 400 kW in the primary beam. Examples of pre-conceptual designs of the pre-separator area and components, along with examples of ongoing radiation simulations with results characterizing the secondary radiation are given. These initial studies will yield insight into the impact of the high-power dissipation on fragment separator design, remote handling concepts, nuclear safety and potential facility hazard classification, shielding design, civil construction design, component design, and material choices. Furthermore, they will provide guidance on detailed radiation analyses as designs mature.

INTRODUCTION

The Rare Isotope Accelerator (RIA) is planned as the next-generation U.S. national user facility for basic and applied research with radioactive (rare isotopes) beams [1]. Fast beams and in-flight separation will be available from fragment separation devices in addition to low-energy beams from conventional ISOL sources.

RIA is being designed to deliver primary heavy ion beams through uranium having beam powers up to 400 kW [2] to the fragmentation pre-separator targets. Approximately 30% of the primary beam power will be deposited in the target. The remaining fraction will be transported through the pre-separator. Fragments of interest will be spatially separated from the primary beam, which will be stopped in a beam dump located after the dipole. Many kilowatts of other fragments will be dumped within the pre-separator. The relative rigidity of the beam and fragments will be different for nearly all desired fragments and the location of the beam dump may change for each experiment.

RIA's wide-ranging and unique attributes will need characterization of prompt radiation levels that will drive bulk shielding requirements, radiological inventories, radiological environmental impacts, doses to materials, activation levels of materials surrounding regions of beam loss, estimation of worker doses and remote maintenance requirements to guide more detailed engineering and safety studies. This paper presents examples of on-going radiation simulations supporting this goal.

SIMULATION AND CHARACTERIZATION OF RADIATION

We are using the transport code PHITS [3] to simulate particle fluxes, isotope yield, prompt nuclear heating and material damage for the components of interest. PHITS meets the requirements to transport both light and heavy ions, and to have magnetic field capabilities. Comparisons to data performed to date with PHITS are promising [4].

PHITS isotope production and neutron flux tallies are coupled to the code DCHAINSP2001 [5] to calculate radioactivity inventories, radiation decay heating, photon spectra *etc*.

PRE-SEPARATOR LAYOUT

Two fragmentation/fission fragment separators (see Fig. 1) are planned for RIA, one having high-resolution capabilities to deliver fast in-flight separated rare isotopes to high-energy experimental areas, and the other having high-acceptance to deliver rare isotopes to a gas-stopping region, from which ions will be reaccelerated to low energies for astrophysics and nuclear structure studies.

In order to ensure continuous operation, beam dump and catcher lifetimes of several weeks minimum are required with 1-2 months or more desired. Also, target change and commission times of less than 2 weeks are needed. These requirements will be used as a basis for developing remote concepts.

Possible layouts of the pre-separators are being considered including studying civil engineering and facility safety impact.

*Work supported by U.S.D.O.E. grant number DE-FG02-04ER41313
#Consultant

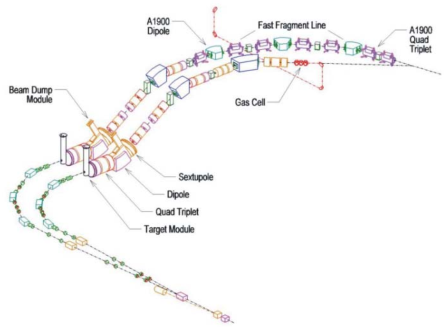

Figure 1: Possible layout of RIA's fragment separators. Magnets downstream of the pre-separator may be like those in the NSCL's A1900 FRS. Horizontal layouts are also being considered.

TARGET CONCEPTS

Power densities in the target are extremely high, up to ~5 MW/cm^3 (assuming 30% of a 400 kW primary beam having diameter ~ 1mm). Prototype work done at ANL [6] established that a windowless liquid-lithium target could handle power densities well above a 200-kW RIA uranium beam. The liquid lithium target planned for use with the uranium beam may be too thick for lighter beams, introducing image aberrations. Hybrid lithium-beryllium or rotating targets are possible. The issues are remote handling and survivability of rotating components. Target modules are desirable and concepts must integrate issues such as liquid metal safety, heat rejection system design, remote handling, and component sizing. Fig. 2 shows an example of a liquid-Li target module concept.

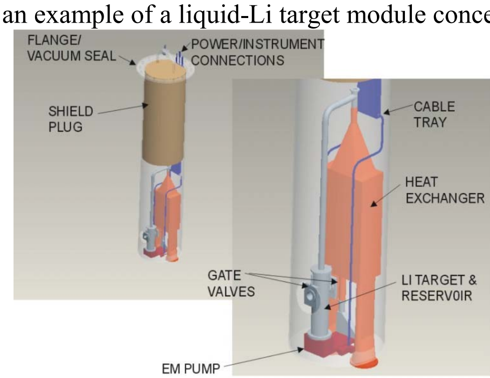

Figure 2: Conceptual design of a target module for an electromagnetically-pumped liquid-lithium target.

SIMULATIONS FOR THE PRE-SEPARATOR

1st Quadrupole Simulations

The first quadrupoles in the pre-separators will be subject to intense prompt radiation. A realistic model was developed for simulations using PHITS, based on a high-temperature superconductor (HTS)-magnet design by Brookhaven National Laboratory. The materials used include mixtures to simulate BSCCO 2212 tape for the conductors, and Mylar and alumina for insulation. Detailed results including prompt radiation heating, effects of off-center and misaligned beams, and thermal-finite-element-analysis to determine temperature rise and cooling requirements, are discussed by Zeller *et al.* [7]. An example of a heat deposition study is shown in Fig. 3.

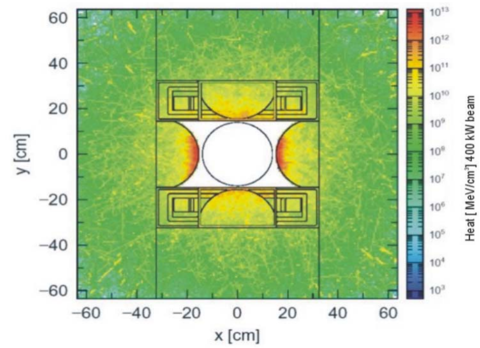

Figure 3: Simulation of heat deposition in the first quadrupole of the pre-sesparator, for a 500 MeV/u ^{48}Ca primary beam.

The peak dose in the coil is about 0.01 W/cm^3, or a dose rate of 1 mW/g (1 Gy/s) for a density of 10 g/cm^3. At 10^7 s of operation per year, we have 10 MGy per year. If the radiation resistance of HTS material is as good as NbTi (500 MGy), then the coils will last 50 years.

Pre-separator Simulations

The pre-separator, magnetic devices and coils were entered as concentric cylinders having realistic materials, to reduce computation times. Fig. 4 shows a simulation of the proton flux in the first quadrupole for a ^{48}Ca beam at 500 MeV/u incident on a Li target and magnetically transported. A truncated-cone of tungsten helps protect the magnet from direct radiation.

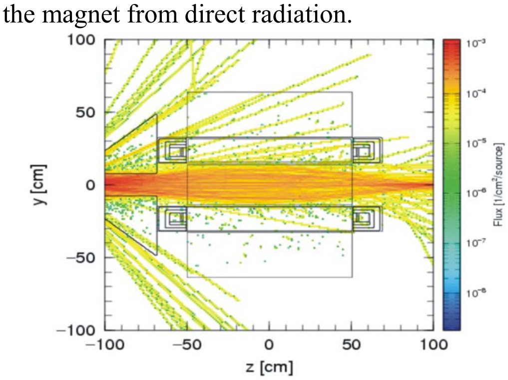

Figure 4: Simulation of the pre-separator first quadrupole using PHITS. Levels of proton flux are shown, for a ^{48}Ca beam at 500 MeV/u. The magnetic field option was used.

The quadrupole magnetic field helps protect the downstream regions of the magnet from proton heating and damage. Simulations for the entire pre-separator show that the resistive sextupole and shielding downstream of the beam dump will become highly radioactive. For a 400 kW 341 MeV/u ^{136}Xe beam stopping in the dump for 28 days and after 1 day from end-of-bombardment, the dose rate at 30 cm on-axis from the sextupole is estimated at 0.5 Sv/hr.

0-7803-8859-3/05/$20.00 ©2005 IEEE

BEAM DUMP CONCEPTS, SIMULATIONS

Fragment catcher and beam dump systems must intercept unwanted fragments and the non-reacting primary beam, for beam diameters of several centimeters, yet they should not cut into the phase space of the desired fragments. Dumps must cover a wide area or be moveable (to allow for the differing locations where beams may hit) and required to absorb up to 400 kW (as in case of target malfunction) at sometimes extremely high power density. Simulations of heat deposition, beam sputtering, radiation damage, and gas production and buildup are being done to address issues of radiation damage and dump lifetime.

A static water-cooled wedge-shaped beam dump concept that can meet the above requirements for beam rigidities not too similar to those of desired fragments is shown in Fig. 5.

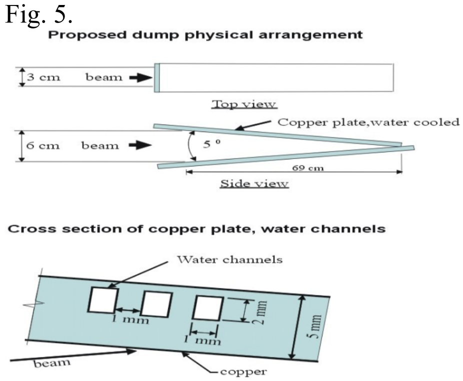

Figure 5: Water-cooled copper stationary beam dump concept.

Preliminary radiation damage simulations show very large damage, ~ 20 displacements per atom (DPA) per day near the end of the uranium ion range. The significance of this large and the very localized damage will be investigated.

Liquids could form the basis of beam dump designs that would survive heat and radiation damage by RIA's uranium beam. If the liquid is metal, *e.g.* lithium, the selection of the containment material is an issue. Non-static dump concepts are also being developed. These ensure longer lifetimes however necessitate the need for more complicated remote handling, seals, bearings and motors. Fig. 6 shows a concept of a rotating wheel of water contained by aluminum. Here, the motor-drive elements are placed outside of shielding. The simulations show that the components will become highly radioactive and that hands-on maintenance will not be possible. The wheel dump system specific activity is predicted to be about 5×10^{9} Bq/cm^3 at the end of a 28-day bombardment by a 341 MeV/u ^{136}Xe beam at 3.74×10^{13} ions/sec. This decreases to about 2×10^{8} Bq/cm^3 thirty days after end-of-bombardment.

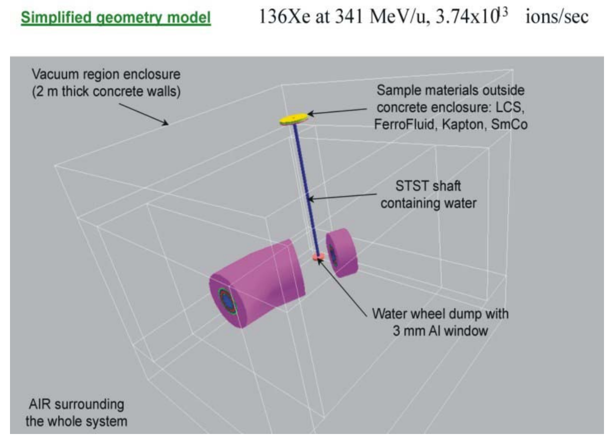

Figure 6: Geometry for a rotating water-cooled aluminum wheel dump concept used in simulations.

DISCUSSION

Initial radiation simulation calculations have been performed for RIA fragmentation pre-separators, to estimate radiation fields, component heating and activation, and material damage. Many similar studies are planned. These initial simulations have shown the necessity for radiation resistant magnets in the pre-separator, a resistive first sextupole, and remote handling of components such as targets and beam dumps that may need frequent change out.

REFERENCES

[1] Web links to key publications documenting RIA's evolution and potential missions may be found at the RIA Users web site: http://www.orau.org/ria/.
[2] H. Grunder (chair), "ISOL Task Force Report to NSAC", November 22, 1999 (unpublished).
[3] 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.
[4] Hiroshi Iwase, Ph.D. thesis, Tohoku University, 2002, unpublished.
[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), February 2001.
[6] J.A. Nolen, Jr., C.B. Reed, V.J. Novick, J.R. Specht, J.M. Bogaty, P.T Plotkin, and Y. Momozaki, "Behavior of liquid lithium jet irradiated by 1 MeV electron beams up to 20 kW", Rev. Sci. Inst. 76, July 2005.
[7] A.F. Zeller, V. Blideanu, R.M. Ronningen, B.M. Sherrill, and R. Gupta, Particle Accelerator Conference PAC05, May 16-20 2005, Knoxville TN, contribution MPPT031.