98-111R2 -- CONCEPT DEVELOPMENT AND OPTIMIZATION FOR THE ISOL EXOTIC BEAM FACILITY PROPOSAL

Associate Lab Director Area: Physical, Biological and Chemical Sciences

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FY 2001	-0-
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Purpose: Since the early 1990's in the field of low energy nuclear science, there has been worldwide interest in an advanced facility capable of producing energetic, high-quality beams of radionuclides. The scientific case for such a facility led to its recommendation in the 1996 Nuclear Science Long Range Plan as the highest priority for new construction following the completion of the Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Laboratory. An evaluation of various possible technical approaches to the implementation of such a facility was carried out during 1999 by a subcommittee of Nuclear Science Advisory Committee (NSAC) called the "ISOL Task Force." (ISOL stands for "Isotope Separator On Line.") A report was presented to NSAC on November 22, 1999. A facility based on the ANL concept of a multi-beam (heavy ion) driver was recommended. The purpose of this LDRD project is to develop design concepts for the major components of this larger facility, now known as the Rare Isotope Accelerator (RIA), to provide the foundation for a more solid cost estimate. The preliminary design concepts developed under this project will be the basis for DOE to proceed with authorizing and funding a Conceptual Design Report. A variety of technical concepts are involved as described below.

The specific technical goals for this year were to develop engineering concepts to demonstrate the feasibility of a 400-kW beam power multi-beam (including uranium beams) driver for RIA and to study and develop new methods for fast, efficient, and chemically independent methods for the generation of secondary beams of short-lived rare isotopes. These elements of RIA are critical to demonstrating the feasibility of the overall concept and supporting the upcoming preliminary cost study.

Approach: The NSAC ISOL Task Force recommended a driver with beams as heavy as uranium at energies up to 400 MeV/u and beam power of 400 kW. The overall cost

of the RIA facility is expected to be over $500M, but several feasibility studies of critical components are necessary before a credible cost estimate can be made.

The technical developments this year were in the areas of high-power-density production targets for both heavy ion fragmentation and spallation mechanisms, development of the new classes of superconducting resonators required for the driver linac concept, preliminary design simulations of new ideas for increasing the power output of the driver linac through the use of multiple charge state acceleration, simulations of the radionuclide production rates via a variety of nuclear physics mechanisms, development and demonstration of the performance of the fast gas catcher concept, and development of Monte-Carlo simulation methods to enable optimization of high power ISOL-type production targets.

With the help of Ahmed Hassanein in ET, we investigated the use of liquid lithium for high power density heavy ion fragmentation targets via thermal simulations. This work involved software development for the 3-D geometries being considered for these targets. Preliminary mechanical designs for a prototypical liquid lithium target system (1 kW) using beryllium windows and another windowless system (30 kW) have been developed with the help of Claude Reed in TD. We simulated new classes of drift-tube superconducting resonators with the MAFIA eigenmode software with the help of T. Tretyakova, a scientist from ITEP in Moscow. Testing of prototype niobium spoke-type resonators continued using the new 350 MHz, 5-kW RF power supply that was constructed this year. M. Kelly, a Physics Division post-doc, assisted with this work. We constructed beam dynamics studies for the use of multiple-charge-states in the driver with the help of A. Kolomiets, a scientist from ITEP in Moscow. S. Aseev, a scientist from INS, Troitsk, also worked with us on beam transport calculations for multiple-charge-state-beams in the ion source region as well as the stripper sections of the driver. I. Gomes from TD worked with us on simulations of yields from spallation and fission reactions. B. Mustapha, a Physics Division post-doc, worked on the simulations of diffusion and effusion delays in ISOL-type ion sources. G. Sprouse, on sabbatical from Stony Brook, and J. Schwarz, a Physics Division post-doc, assisted with the fast gas catcher development. M. Portillo, a PhD student in the Physics Division, assisted with the experiments at Gatchina, Russia, and with the isobar separator optical design.

Technical Progress and Results:

1. We developed engineering concepts for three types of high-power production targets. Two of these incorporate liquid lithium cooling technology and were developed building on technology previously developed in the TD and ET divisions of ANL. We performed detailed calculations for a target for production of fission products using a lithium-cooled porous tungsten converter to produce secondary neutrons irradiating an uranium carbide target by means of extensive Monte-Carlo simulations, and we measured the pressure drop through the porous tungsten to confirm the preliminary design. The third target type involves large-area, thin targets for direct heavy-ion irradiation. These concepts alleviated fears that beam power of 100 kW heavy ion beams could not be fully utilized. A preliminary design for a 1 kW flowing liquid lithium production target for fragmentation has been prepared in

collaboration with Michigan State University (MSU) and will be used in production runs at MSU.

2. The original ANL proposal was based on a multi-beam superconducting heavy-ion linac with a maximum beam energy of 100 MeV/u for beams with masses up to krypton. Beams up to uranium would have been available at reduced intensities and energies. The Task Force recommended an expanded scope to include high power uranium beams of up to 400 MeV/u. This scope involved pushing the superconducting RF cavity technology from the velocity regime developed at Argonne's ATLAS accelerator to a much higher one, bridging the gap to cavities for ions approaching the velocity of light. The intermediate-velocity section of this accelerator, in particular, utilizes accelerating structures for a velocity regime not covered by previously existing superconducting cavities. Spoke type cavities were developed for this purpose, and testing of the first two such superconducting resonators was completed. Both resonators (two different velocity parameters) were tested successfully at gradients of 4-5 MV/m, the initial design goal. We purchased and installed a new high-power, 350-MHz RF amplifier to condition the spoke (β~0.4) cavities during summer 2000. With this 5-kW amplifier the gradients were increased to 5-6 MV/m in this single-cell test. MAFIA 3-D calculations of all six classes of drift-tube resonators were completed. Aluminum warm models of two of these six types — the 2-cell spoke-type and the lollipop-type — were constructed and their testing was initiated,

3. We performed computer simulations to demonstrate that multiple charge states of a given heavy ion can be accelerated simultaneously. The new driver accelerator incorporating this feature will now be capable of reaching over 100-kW uranium beam power with existing electron cyclotron resonance (ECR) ion source technology. The accelerator lattice was optimized and yields continuous beams with variable output energies up to 400 MeV/u for uranium and higher energies for lighter ions (up to 900 MeV for protons). We also developed concepts for cryostats, including RF couplers. The multiple-charge-state design requires achromatic and isochronous matching sections at the stripping stages. Proof-of-principle ion optical designs of those was been completed.

4. Systematic calculations of radionuclide production rates were carried out for the primary beams available from the new driver accelerator. Those were validated by comparison with existing data wherever possible. The influence of the maximum energy of the driver accelerator was also determined and has played a major role in the selection of the optimum energy for this accelerator. We conducted an experiment to validate the two-step target yield simulations at the ISOL facility at PNPI, Gatchina, Russia, in collaboration with that institution's mass separator group. The ratio of yields of Cs and Rb isotopes produced via direct and indirect irradiations were measured, and they agreed well with the Monte-Carlo simulations done with LAHET and MCNP.

5. The concept of a magnetic fragment separator followed by a gas catcher/ion guide is a critical component of the facility. The gas catcher concept was developed at Argonne, and a second generation system was built and tested this year. Extraction

times below 10 ms were obtained for radioactive isotopes, and the efficiency of this new version of the gas cell more than doubled that attained with the original. This new cell was developed based on ion optics simulations developed and performed in the Physics Division, combined with gas flow calculations performed in the MCS division. The same simulation techniques are now being used to develop a full-scale version of the gas cell that will be tested at the full RIA energy. Further development of this concept is expected to lead to a highly productive method that combines the best features of the fragmentation production mechanism with the excellent beam quality of the traditional ISOL method.

6. We developed a Monte-Carlo simulation procedure based on the GEANT4 code to model delay times for diffusion and effusion out of ISOL targets. The model will be used to refine the concepts for high-power ISOL targets, should future funding for that effort be obtained.

Specific Accomplishments: There have been many publications, seminars, invited papers, and contributions to international conferences and workshops based on the work done under this LDRD project. Items 1-13 below are based on the work begun in 1998 and 1999. Items 14-31 are based on work done primarily in 2000. Publications 2 and 25 are in refereed journals.

1. Superconducting Driver Linac for a Rare Isotope Facility, K.W. Shepard, J.R. Delayen, C. M. Lyneis, J. Nolen, P. Ostroumov, J. W. Staples, J. Brawley, C. Hovater, M. Kedzie, M. P. Kelly, J. Mammosser, C. Piller, M. Portillo, Proceedings of the 9th Workshop on RF Superconductivity, Santa Fe, New Mexico, November 1-5, 1999.
2. Multi-charge Beam Dynamics in an Ion Linac, P. N. Ostroumov and K. W. Shepard, Phys Rev. Special Topics Accel. Beams, Vol. 3, p. 1-10, (2000) (refereed).
3. Performance of the Argonne Electric Field Ion Guide and RF Gas Cooler System, G. Savard, invited talk given at the International Workshop on Ion Chemical Aspects in Ion Guide Systems, Mainz, Germany, September 30-October 2, 1999.
4. The Argonne Rare Isotope Accelerator Project, G. Savard, Colloquium given at TUNL, Duke University, NC, November 1999.
5. Production Mechanisms and Predicted Yields of Exotic Beams at the Proposed Rare Isotope Accelerator, J. Nolen, B. Back, C.-L. Jiang, K.-E. Rehm, G. Savard, A. Heinz, and I. Gomes, paper presented at the Fall meeting of the Division of Nuclear Physics, American Physical Society, Asilomar, CA, October, 1999, Bull. Am. Phys. Soc. 44, 57 (1999).
6. ISOL Beams from Fragmentation, the Best of Both Worlds, G. Savard, paper presented at the Fall meeting of the Division of Nuclear Physics, American Physical Society, Asilomar, CA, October, 1999 Bull. Am. Phys. Soc. 44, 57 (1999).
7. Technological Basis and Performance Goals of RIA, J.A. Nolen, seminar at IUCF, Indiana University, March 3, 2000.
8. Liquid lithium cooling for 100 kW ISOL and fragmentation targets, J.A. Nolen, invited talk presented at the Fifth International Conference on Radioactive Nuclear Beams, Divonne, France, April 3-8, 2000.
9. The Rare Isotope Accelerator, D.F. Geesaman, seminar at Rutgers University, April 12, 2000 .

10. Heavy-ion Driver Accelerator for a Rare Isotope Facility, K. W. Shepard, invited talk presented at the Fifth International Conference on Radioactive Nuclear Beams, Geneva, Switzerland, April 3-8, 2000.
11. The Science Case for RIA, K.-E. Rehm, talk at the Nuclear Physics Discussion Group, University of Illinois, Urbana-Champaign, May 19, 2000.
12. Plans for High Power ISOL and Fragmentation Production Targets for RIA, J.A. Nolen, invited talk at the TWIST-II Workshop, GANIL, Caen, France, June 14-16, 2000.
13. Perspectives and physics with high intensity beam, J. A. Nolen, invited talk presented at the Seventh International Conference on Nucleus-Nucleus Collisions, Strasbourg, France, July 3-7, 2000.
14. Heavy-ion Beam Acceleration of Two-charge States from an ECR Ion Source, P.N. Ostroumov, K. W. Shepard, V. N. Aseev, A. A. Kolomiets, 20th Intl. Linac Conference, LINAC2000, Monterey, CA, Aug. 20-25, 2000.
15. Multiple-Charge Beam Dynamics in an Ion Linac, P. N. Ostroumov, J. A. Nolen, and K. W. Shepard, 20th Intl. Linac Conference, LINAC2000, Monterey, CA, Aug. 20-25, 2000.
16. Multiple-Charge State Beam Acceleration at ATLAS, P. N. Ostroumov, R. C. Pardo, G. P. Zinkann, K. W. Shepard, J. A. Nolen, 20th Intl. Linac Conference, LINAC2000, Monterey, CA, Aug. 20-25, 2000.
17. Superconducting Accelerating Structures for a Multi-Beam Driver Linac for RIA, K.W. Shepard and T. E. Tretyakova, 20th Intl. Linac Conference, LINAC2000, Monterey, CA, Aug. 20-25, 2000.
18. Prospects for an Ultra-cold Neutron Source at RIA, invited talk at the Workshop on Ultra-Cold Neutrons, Los Alamos, September 6-8, 2000.
19. Status of Accelerator R & D for RIA, J. A. Nolen, Fall APS-DNP Meeting, Williamsburg, VA, Oct. 4-7, 2000.
20. Overview of RIA - How it works, what it can provide, G. Savard, Fall APS-DNP Meeting, Williamsburg, VA, Oct. 4-7, 2000.
21. Overview of RIA and New Mechanisms for the Production of High Energy Neutron Beams and Isotopes for Industrial Applications with High Power Heavy Ion Beams, invited talk at the Workshop of Applications of RIA, Los Alamos, October 30-31, 2000.
22. A Superconducting Ion Linac as a Driver for RIA, Kenneth W. Shepard, invited talk presented at 16th Intl. Conf. on the Application of Accelerators in Research and Industry (CAARI2000), Denton, TX, November 1-4, 2000.
23. Prospects for Exotic Beam Facilities in North America, J. A. Nolen, invited talk presented at International Symposium on Perspectives in Physics with Radioactive Isotope Beams 2000 (RIB00), Hayama, Kanagawa, Japan, Nov. 13-16, 2000.
24. The Rare Isotope Accelerator, D.F. Geesaman, Colloquium at the Physics Division, BNL, December 12, 2000.
25. Simultaneous Acceleration of Multiply-Charged Ions Through a Superconducting Linac, P. N. Ostroumov, R. C. Pardo, G. P. Zinkann, K. W. Shepard and J. A. Nolen, accepted for Phys. Rev. Letters, January, 2001 (refereed).
26. Design Layout of an Isobar Separator Based on 5th Order Calculations, T. A. Barlow, J. A. Nolen, M. Portillo, 2001 Particle Accelerator Conference, Chicago, IL, June 18-22, 2001.
27. New Concept for Acceleration of Slow, Low-Charge-State Heavy Ion Beams,

P.N. Ostroumov, A. A. Kolomiets, 2001 Particle Accelerator Conference, Chicago, IL, June 18-22, 2001.
28. Design of a Post-Accelerator for Rare Isotope Accelerator Facility, P. N. Ostroumov, K. W. Shepard, A. A. Kolomiets, J. A. Nolen, R. C. Pardo, 2001 Particle Accelerator Conference, Chicago, IL, June 18-22, 2001.
29. Cold Tests of a Spoke Cavity Prototype for RIA, M. P. Kelly, K. W. Shepard, M. Kedzie, 2001 Particle Accelerator Conference, Chicago, IL, June 18-22, 2001.
30. Singly-charged Heavy-Ion Beam Studies on 12 MHz RFQ, M. P. Kelly, P.N. Ostroumov, K. W. Shepard, M. Kedzie, B. E. Clifft, 2001 Particle Accelerator Conference, Chicago, IL, June 18-22, 2001.
31. Design of a Magnetic Optical System for Transport and Matching of Multiple-Charge-State Heavy-Ion Beams, T. V. N. Aseev, J. A. Nolen, P. N. Ostroumov, M. Portillo, 2001 Particle Accelerator Conference, Chicago, IL, June 18-22, 2001.

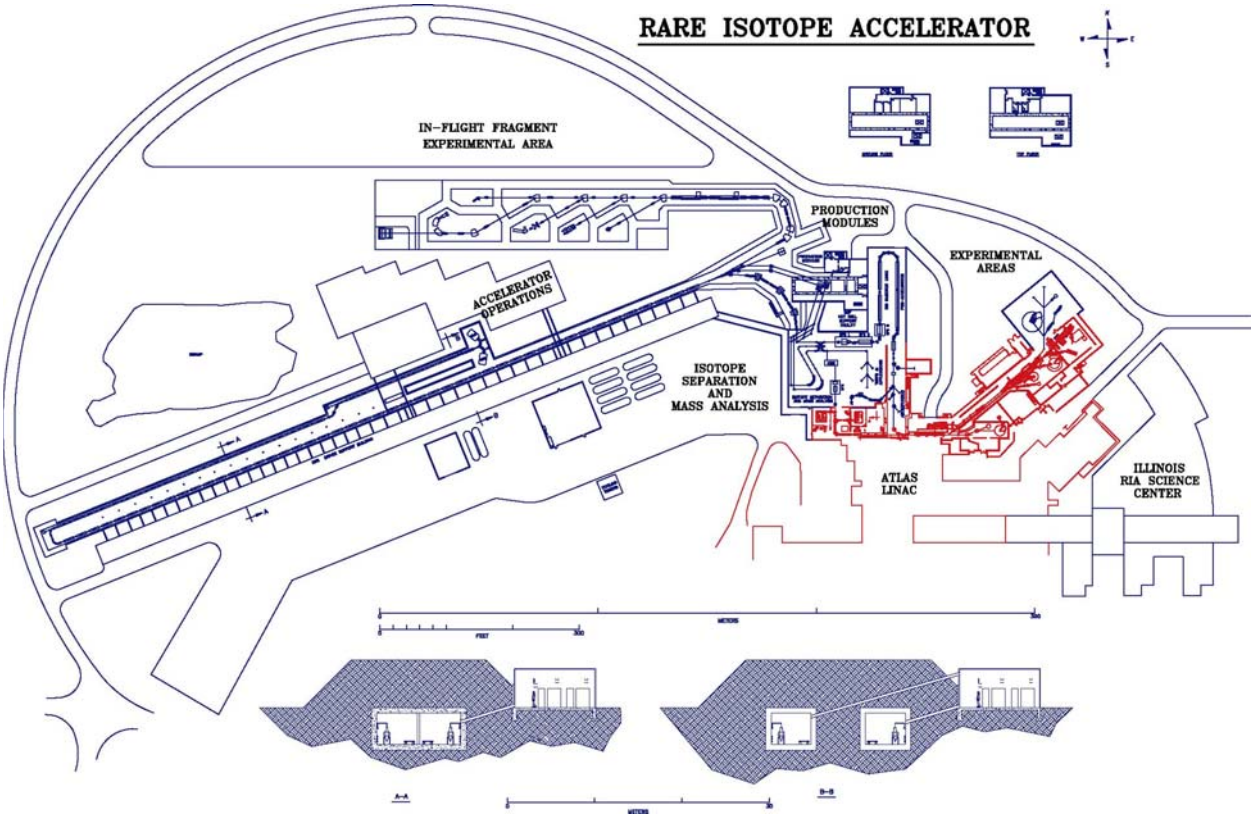

Figure showing an overview of the concept for the RIA facility at Argonne. The proposed new components are shown in blue and the existing building 203 and ATLAS components are shown in red.