Michigan State University (MSU)
View of RIA R&D Priorities

1. Introduction

Until now, RIA R&D funding has largely been distributed based upon the initial analysis provided by the NSAC ISOL Task Force (1999). In the intervening years significant experience and insight have been gained, and it is appropriate to review the R&D priorities for future funding. Michigan State University (MSU) has been intimately involved in the analysis of the RIA design (having proposed the original paradigm upon which RIA is based). The MSU view on RIA R&D priorities is delineated below.

Two guiding principles were used to develop the R&D priorities.

1. Highest priority is given to those technical issues that if unresolved pose a significant risk to project success as measured by performance, schedule, or cost (with decreasing weight).
2. Priority should be given to complete R&D efforts already begun assuming that appropriate progress has been made and that continued R&D will increase the probability of project success.

A major driving issue in terms of technical risk is the high beam power. This is reflected in the need to develop appropriate linac charge stripping and fragmentation targets, ISOL targets and related systems, beam dumps, fragment separator designs, characterization of secondary radiation fields, and radiation resistant magnets.

Schedule is an important factor. Progress on some elements must be made as quickly as possible to support early definition of the balance of plant (civil) so that it does not become a critical path element. The civil construction must take place early in the project to accommodate efficient installation and commissioning. Early detailed information derived from R&D programs on the Superconducting Radio Frequency (SRF) accelerating structures is necessary to support the civil design and accommodate long-lead time SRF systems construction. Similarly the details of the ISOL and projectile fragmentation systems must be sufficiently understood early enough to support the definition and design of the required infrastructure.

Following this logic, the RIA R&D issues and priorities are discussed below. We provide the information at a summary level to expedite the discussion. Primarily the issues are presented rather than the detailed plans to resolve them though this information has also been developed.

2. R&D Priorities

The RIA facility can be categorized as:

- Driver linac and beam distribution (beam switch yard) system
- Radioactive ion beam target area including the ISOL stations and projectile fragmentation targets

- Low-energy beam transport and reacceleration
- High-energy rare isotope production including the fragment separators, helium gas stopping systems
- Experimental equipment

R&D areas identified by MSU are listed in the table below and explained in subsequent sections. Priority ratings have been assigned with 1 being the highest and 3 the lowest. No attempt was made to further prioritize items with the same rating.

R&D Area	Priority	Section
Linac stripping targets	1	2.1.1
SRF structures	1	2.1.2
ISOL beam production	1	2.2.1
Fragmentation targets	1	2.2.4
Characterization of secondary radiation	1	2.2.5
Radiation resistant magnets	1	2.2.6
Fragment separator designs	1	2.4.1
Helium gas stopping systems	1	2.4.2
High power beam dumps	2	2.2.3
High resolution mass separation & cooling	2	2.3.1
Charge state boosting	2	2.3.2
Beam dynamics	3	2.1.3
ECR development	3	2.1.4
Ion sources for ISOL beam production	3	2.2.2
Experimental equipment	3	2.5

A possible funding model is that of the available funds 70% would support priority 1 items, 20% would support priority 2 items, and 10% would support priority 3 items.

2.1. Driver linac and beam distribution system

2.1.1. Stripping targets – Priority 1

High priority issues are those associated with high beam power and for this reason the two proposed linac stripping elements required for beams heavier than xenon are an R&D topic. Estimating the power handling requirements is difficult since the equilibrium or optimum stripping thickness is not definitively known, but reasonable estimates can be made. For a final beam power of 400 kW, the beam power at the first stripper target will be ~10 kW, with ~0.15 kW power loss in the target at a power density of ~3 kW/mm^3. Similarly, the beam power at the second stripper target will be ~90 kW, with ~5 kW power loss in the target at a power density of ~2 kW/mm^3. An appropriate solution must be developed to support the specified 100 kW uranium beam requirements and the 400 kW long-term goal.

2.1.2. Superconducting accelerating structures – Priority 1

R&D is being supported to prototype and verify performance parameters. This work must continue. The data derived from these activities will be necessary to complete the detailed system engineering necessary to determine a realistic base design and cost. This information will be required soon. First, a very early project element will be the design of the civil construction for which detailed linac tunnel and rf gallery information can only be specified after finalization of the linac accelerating lattice, i.e., rf penetrations and tunnel size. Second, the SRF cryomodule production is a long-lead item that can easily become a critical path element. Having early information to finalize the SRF designs will provide the opportunity to reduce this risk.

2.1.3. Beam dynamics – Priority 3

Beam dynamics R&D has just begun. The high beam power requires the minimization of beam losses sufficient for hands-on equipment maintenance. Progress should be made in this arena, but the timing is not yet critical, as these results will not likely drive performance, cost, or schedule elements.

2.1.4. ECR development - Priority 3

ECR design and prototyping have been funded through RIA R&D funds. Since this effort has developed the initial prototype hardware it should be continued to obtain the experimental data. Progress should be made but the timing of the result is not critical.

2.2. Radioactive Ion Beam Target Area

2.2.1. ISOL beam production – Priority 1

The realization of RIA's scientific potential depends on the utilization of high driver-linac beam power. ISOL stations capable of handling 400 kW beam power are necessary. This represents a beam power capability roughly an order of magnitude greater than existing systems. A significant R&D focus must be the development of high power ISOL targets.

Material and structural tests for targets and target containers need to be performed under conditions as realistic as possible. Data on beam and secondary radiation induced material damage are crucial input for any advanced target design and for achieving acceptable target lifetimes. Codes for the modeling of energy deposition and cooling, thermal mechanical stress, radiation damage, production and transport (diffusion, effusion) of the rare isotopes should be developed further, but critical input parameters must be measured when extrapolations are too uncertain. Dedicated target test stands with mass separators should be set up for target physics studies and for testing target design concepts. Installation of such a system at a fragmentation facility for example, would allow carrying out very specific studies of release times as a function of target material and target design. Prototypes of high-power target systems should be built and exposed to beam at facilities with beam power and energies similar to RIA. Efficient target cooling schemes need to be studied.

The detailed layout of the target area with front-ends and remote target handling will be influenced by the outcome of some of the studies listed above. Nevertheless an early evaluation of the various options will allow an optimized but still flexible facility layout.

The ISOL R&D program will likely span a significant number of years with the results driving both the early infrastructure (civil) decisions and later the facility performance. As a consequence, this activity should receive a high priority.

2.2.2. Ion sources for ISOL beam production – Priority 3

Only modest ion source development for ISOL beam production is needed at the present stage with the exception of ion sources that will suffer from the high radiation level like ECR sources. ECRs are considered the best choice for noble gases and other gaseous elements emanating from the ISOL target, but the minimization of losses typically implies that the source is exposed to high radiation fields. Since the lifetime of the magnetic materials will be short compared to the expected life of the target, the ECRs need to be cheap and disposable and should not contribute to long-term storage problems. Additionally, the residence time of the rare isotopes in the source should be short to prevent loss of short-lived nuclides. As (somewhat expensive) solutions exist, this activity does not need a high priority.

2.2.3. High power beam dumps and catchers – Priority 2

The heavier beams, such as uranium and xenon, deliver very high power densities to transmission targets, beam catchers, and other components that intercept any primary beam or prolific secondary beams. In particular, the material surfaces will experience significant damage. (Note that a uranium beam's maximum range is about 12 mm in carbon.) Once a material reaches a certain damage level, it will fail by one of several mechanisms. Developing materials capable of withstanding irradiation by high-power density beams and understanding lifetime limitations are important for building safe and reliable beam catchers.

Most of the beam power of the proton or light-ion beams used for the ISOL radioactive ion production will be deposited in the beam dumps behind the targets. The large range of the beam and the relatively large beam spots at the beam dump position reduce the problem. Hence, the ISOL beam dumps are a design rather than an R&D issue. For heavy ion beams significant R&D issues remain. For a 400 kW beam, about 150 kW will be deposited in the fragmentation target. The remaining 250 kW must be caught in a beam dump following the first dipole. In addition, depending on the case, there may be several kW of other fragments that must be collected. Locations of dumps and catchers in general cannot be fixed for all experiments but will change depending on beam, target combinations, and fragment separator tunes. Dump and catcher designs and their proximities to radiation sensitive equipment are strongly coupled to fragment separator design and will need a significant R&D effort.

2.2.4. Fragmentation Targets – Priority 1

The design of a fragmentation target capable of 400 kW beam power is a significant challenge representing a beam power capability roughly two orders of magnitude greater than that of existing systems. This program will likely span a significant number of years with the results driving both the early infrastructure decisions and later the facility performance. As a consequence, this activity should receive a high priority.

2.2.5. Characterization of secondary radiation from high-power targets and dumps – Priority 1

The magnitude of the prompt radiation, attendant activation, and radioactive material inventory generated at the target stations must be understood as these will be significant elements of the overall facility hazard category rating, and determine much of the bulk shielding and civil engineering design requirements. Second, the radioactive material inventory generated at and around target stations, beam dumps, strippers and catchers must be understood, as it will be a significant element of the overall hazard analysis and classification of the facility. The facility classification, in turn, will drive the scope and magnitude of ensuing design efforts. Total radiation doses and their spatial distributions from interactions in materials by both primary and secondary ion beams must be characterized by using data, where these exist, and newly available transport codes. An R&D effort will be necessary to obtain any currently unavailable critical data and to benchmark newly developed heavy ion production and transport codes. This information is also critical to support other R&D efforts in the target area.

2.2.6. Radiation resistant magnets – Priority 1

All magnet elements in the ISOL target areas as well as the initial stages of the fragment separator systems will be in a very high radiation environment where they must work reliability and with high performance. While some magnet designs with high radiation resistance have been developed, they are all based on normal conducting technology and have significantly reduced peak field capabilities. The resulting limited magnet performance will have a significant deleterious impact on the performance (acceptance) of the fragment separator system. The development of radiation resistant magnet designs will drive early infrastructure decisions and significantly influence RIA performance. As a consequence, this should be a high priority activity.

2.3. Low energy beam transport and post-acceleration

2.3.1. High resolution mass separation and beam cooling – Priority 2

The high beam intensities and the demand for clean rare isotope beams require high-resolution mass separators. Preliminary design studies for such systems have already been done. While these mass separators appear feasible their design is challenging, their operation can be difficult, and they are expensive. The design of these devices involves only engineering issues that can be addressed at a later stage. The same holds for the beam transport to the separators and to the experimental areas. Isobar separation could be more easily accomplished and less costly if the emittance of the beams from the ISOL stations could be improved. Low-energy radiofrequency ion guides filled with a light buffer gas at low pressure have shown to fulfill the task of beam cooling at low intensities. R&D is required to study space charge effects and to design a prototype system for high intensity ion operation. Since beam cooling has an impact on the RIA layout, performance, and cost, R&D on this issue should be given priority.

2.3.2. Charge state boosting for post-acceleration– Priority 2

An alternative to brute-force post-acceleration starting with singly charged ions and subsequent stripping is the implementation of charge-state boosting as a first step of the post-acceleration. This alternative is cost-effective and needs therefore to be considered in view of the likely financial constraints for building RIA. Even if the 1+ post-acceleration scheme is realized, the availability of a charge state booster will have the positive aspect of being able to bypass the first accelerator section and to use this section for the post-acceleration of another beam up to energies relevant for nuclear astrophysical studies.

One of the systems most strongly promoted for the charge state boosting are ECR ion sources. A promising alternative is the Electron Beam Ion Traps (EBIT) or similar devices, which may have the potential of being more efficient and faster and of delivering a better beam quality. R&D is required to design a dedicated EBIT for charge state boosting and for comparing its performance to ECRs.

2.4. High Energy Rare Isotope Production

2.4.1. Fragment separator designs – Priority 1

While significant experience in fragment separator design and operation exists at the NSCL, the RIA fragment separator requirements move the design into a nearly unexplored regime. To maximize RIA radioactive ion beam (RIB) intensities the acceptance of the fragment separator must be as large as possible for the full 6D phase space. However, the separator design must also provide high resolution and deal with the high beam powers and concomitant radiation and thermal issues of both the primary as well as secondary beams. This is a complex problem requiring suitable RIB production models including accurate determination of the tails of the particle distributions. The development of fragment separator designs will drive early infrastructure decisions and determine RIA performance. As a consequence, this should be a high priority activity.

2.4.2. Helium gas stopping systems – Priority 1

This activity has already received R&D support for several years. Two outstanding issues must still be quantified. First what is the efficiency of such a system and second what is the limitation in RIB intensity. This information will determine the design requirements of the fragment separator preceding the helium gas stopping system. It is also needed to quantify the performance of the approach. Since this will drive early infrastructure decisions and determine RIA performance, it should be a high priority activity.

2.5. Experimental equipment – Priority 3

The experimental areas should be laid out with appropriate flexibility to allow incorporation of experimental equipment already identified by the nuclear science community at workshops in LBL (1997) and ORNL (2002) as well as additional yet unspecified equipment that may be needed in the future. Expandability of the experimental areas is important in order to be able to house new projects proposed in the future. For the high-energy experimental program it appears necessary to have a minimum of four devices; a time projection chamber for studies of compressed neutron matter, an implantation station for half live and decay studies, a gamma-ray detection station for Coulomb excitation and inelastic scattering studies, and a high resolution momentum spectrometer with the capability to detect coincident neutrons at zero degrees. The ISOL beams and those from the gas stopping station will serve two experimental areas. The ‘stopped beam’ area accommodates experiments that directly use the ISOL beams, for example ion and atom trapping experiments, laser spectroscopy, β-NMR, or decay studies. The experimental area for the post-accelerated beams is likely to be equipped with a recoil separator and various target detector systems for reactions studies. R&D on experimental equipment will be useful for the physics program but at the present stage of RIA should be given low priority.