Report of the 2003 RIA R&D Workshop

October 15, 2003

Satoshi Ozaki
Workshop Chair

The 2003 RIA R&D Workshop

Sponsor:	DOE Nuclear Physics Division
Date:	August 26 – 28, 2003
Place:	Four Points by Sheraton Bethesda 8400 Wisconsin Ave. Bethesda, Maryland 20814
Workshop Chair:	Satoshi Ozaki, BNL Tel: 631-344-5590 e-mail: ozaki@bnl.gov
Workshop Secretary:	Doris Rueger, BNL Tel: 631-344-5663 e-mail: Rueger@bnl.gov Mail: Bldg. 510F, Brookhaven National Laboratory PO Box 5000, Upton, NY 11973-5000
Administrative Support:	Cathy Hanlin and Brenda May, DOE/NP
Editorial Support:	Peter Yamin, BNL
IT Support	Nick Franco, Frank Naase, BNL

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U.S. Department of Energy, Office of Science, Division of Nuclear Physics

Brookhaven National Laboratory

Preamble

The 2003 RIA R&D Workshop was held on August 26 – 28, 2003 at the Four Points Sheraton Hotel in Bethesda, Maryland. This Workshop was chaired by Satoshi Ozaki of BNL and sponsored by the Nuclear Physics Division of DOE, with the help of Oak Ridge Institute for Science and Education (ORISE).

The purpose of this workshop was to understand the present status of R&D efforts for RIA, to evaluate the needs for further R&D, and to identify opportunities for international collaborations. The workshop examined and documented the current pre-conceptual design for RIA, identifying areas where decisions on technical options remain. The status of the current RIA R&D program was documented, recognizing areas where efforts were needed in light of what had been learned. The ongoing and planned R&D activities for operating and planned rare-isotope facilities were presented, enabling the workshop to be a venue to develop coordinated R&D efforts of mutual benefit to U.S. and international efforts.

The scientific program for the first day (August 26, 2003) consisted mostly of invited talks presented by major research groups involved in RIA and other RI beam facilities. The talks included those covering:

- Science of RIA and the RIA Facility Performance Requirements
- The Reference RIA Facility Pre-CDR design that was used for the NSAC cost exercise (M. Harrison Sub-Panel) in January 2001
- New or latest perspectives on the RIA design at ANL & MSU
- RI Beam facility plans and overview of the R&D activities at overseas laboratories

The second day (August 27, 2003) was devoted to contributed talks on continuing R&D, including that which had been supported by DOE RIA R&D funds.

The third day (August 28, 2003) began with open panel discussions in the morning, including further input from participants. The panel members discussed the present status of the RIA planning and R&D needs in a closed session for the rest of the day, and then worked on report planning and writing.

This Workshop enjoyed participation by over 100 scientists, including those who represented international rare ion beam facilities. The workshop also had the good fortune of having an outstanding panel of experts covering subsystems of RIA in depth. The Workshop Chairman wishes to take this opportunity to thank all of the participants for making this workshop a success, and the panel members for their willingness to help the cause of the workshop and their valuable expert advice. The Charge Letter, List of Panel Members and Consultants, List of Participants, the Agenda of the Scientific Program, and invited and contributed papers presented at the Workshop are appended to this report. For the CD version of this report, the List of Participants, Presentations at the workshop, and Invited and Contributed papers can be accessed through the link on the title page.

1. Executive Summary

We believe that several credible reference designs exist for the RIA facility. The R&D effort should now use considerations based on beam dynamics, activation, cost and reliability to compare the designs. Panel members who were on the 1998 NSAC ISOL Task Force believe that significant progress in R&D activities occurred since and most of the potential risks that were identified at that time have now been removed.

Further directed R&D will enable RIA to refine its design and will permit an ideal choice to be made between alternative technologies, leading to a full Conceptual Design.

For example, some questions remain as to the type of superconducting cavities to be used for the linac drivers. Although the choice of one or the other technology does not seem to present a risk to the performance of RIA, the choice for the CDR should be made within a year based on the beam dynamics considerations. Fabrication technology of superconducting cavities has been advancing rapidly in recent years and it is likely that significant cost reductions may be achieved.

The RIA designs for the 50 kW target stations and rare isotope systems are similar to those presently in operation at other RI beam facilities and can most likely be extended to 100 kW. However, significant R&D will be necessary to extend the capability to achieve the 400 kW design goal on a single target.

The functionality of RIA includes bombardment of strippers and targets with high average power beams for RI beam production, and appropriate beam dumping stations. The experience with radiation safety at the SNS and other high power RIB facilities should provide a valuable guide to the issues that will arise at RIA. It is now appropriate to evaluate the radiation safety issues and develop mitigating strategies.

Realistic reliability requirements must be carefully considered as the Conceptual Design is developed. The availability of the facility to the experimental program is an important issue with RIA, and it should be optimized by innovative layout and engineering approaches that emphasize proven technologies. It is also essential to include realistic schemes for accommodating multiple simultaneous users.

Consideration should be given to ensure that the facility addresses the needs of all the potential users, whether they are from the nuclear physics community or not.

Detailed reports by panel members, which cover their evaluation if a credible pre-CDR design exists, their assessment as to the RIA performance level that can be supported by this design, and current status of R&D and future R&D opportunities on the individual subsystem of RIA are given in sections 2 to 10 below.

2. Particle Dynamics and End-to-End Simulation Modeling for RIA: (Tom Wangler)

RIA pre-CDR design issues

The limitation to single charge-state operation in conventional heavy-ion accelerators results in low beam intensities. This limitation is overcome in the RIA driver-linac design concept by the innovative approach of simultaneous acceleration of multiple charge states of a given ion species. This results in high-power beams for RIA of several hundred kilowatts for all beams ranging from protons to uranium. Initial beam-dynamics studies, supported by experimental confirmation at the Argonne ATLAS facility [1], have demonstrated the feasibility of this new approach.

However, the high beam power, combined with the need for high availability of the RIA facility, introduces a more challenging requirement to control beam losses that would cause radio-activation of the driver linac. Radio-activation of the linac-beamline components would hinder routine maintenance and result in reduced availability of the facility. To avoid problems from beam-induced radio-activation and to allow hands-on maintenance in the driver linac, beam losses must be limited to low values, typically in the range of 1 W/m at the high-energy end. Therefore, it will be important to produce a robust beam-dynamics design of the driver linac that minimizes the threat of beam losses. This is the most important beam-dynamics issue for the driver-linac design. As an important consequence of this design requirement, it will also be necessary to develop computer-simulation tools with the capability of accurately modeling the driver-linac beam dynamics and computing the beam losses throughout the linac, especially at high energies where beam loss translates into greater radio-activation.

The low beam-loss requirement means that the emittance growth must be limited in the driver linac, and for any proposed design it will be necessary to compute the high-energy beam losses to ensure that the loss requirement is satisfied. Such a computation will require the use of simulation codes that accurately track the beam particles through the whole accelerator using a physics model that includes all effects that can lead to emittance growth and beam-halo formation that can lead to beam losses. These effects must include the unavoidable imperfections that exist in a real accelerator, including misalignments with re-steering corrections, field errors in focusing lenses and RF cavities, and various fault conditions that could interrupt the beam and cause undesirable transient conditions. The simulation studies must be repeated with multiple sets of errors, and with enough particles to provide sufficient resolution to observe beam losses as low as 1 W/m. Parallel processing computation will be required to provide an acceptable turn-around time per run.

R&D carried out to date and what has been learned

Recent papers have been published that have described the most important aspects of the beam dynamics for the RIA driver linac [2,3,4]. Additional papers presented at the RIA R&D Workshop summarize the present status of the beam dynamics effort [5,6]. These references include the study of sources of emittance growth and halo formation that would increase the risk of beam losses.

Credibility of the pre-CDR design concepts

From the point of view of the beam dynamics, credible pre-CDR designs have been developed that satisfy the energy, intensity and rms emittance requirements. With respect to beam losses, although the beam-loss specifications have not been precisely defined, there is not yet enough evidence that the pre-CDR designs will meet the low beam-loss specifications that will be needed to satisfy facility availability requirements that are at least comparable to the requirements for Spallation Neutron Source (SNS). Perhaps, an R&D effort should be mounted to develop beam loss criteria for the accelerator and for sputtering loss from the strippers, both for heavy ions and for proton beams.

Availability of design options

Options do exist in areas of the beam-dynamics design, and in particular for dealing with the important beam-loss issue. These options include the choice of accelerating structure in the high energy section, where the lower-frequency spoke structure can be expected to provide a larger longitudinal acceptance for the multi-charge beams, but a focusing lattice with a smaller transverse acceptance, by comparison with the higher frequency elliptical structure. Collimation after the strippers can remove beam halo that is formed as the beam traverses the stripper. Suitable collimation systems will have to be designed, and computer simulation of the beam dynamics will be important for comparing the different collimation systems. An important input will be an improved and experimentally based beam-dynamics model of the scattering and energy straggling in the stripper. Plans are in place for experiments that will allow for refinements to the present stripper model.

Progress in beam dynamics R&D

Most of the driver-linac beam-dynamics simulations have been carried out using the code LANA [7,8] at MSU, and the code TRACK [9] at ANL. The importance of the beam-loss issue justifies the development of more than one simulation code to provide the necessary cross checks on the simulations.

Work has begun to develop end-to-end parallel computing tools for accurate computation of beam losses. Two recent initiatives include the work at ANL using TRACK [10], and the joint effort including four laboratories, LANL, LBNL, ANL, and MSU [11,12]. The four-laboratory project is based on the use of two well-established beam-dynamics codes, which are different from the ANL and MSU codes, TRACK and LANA. For these high-statistics simulations, the typical number of particles per run lies in the range of 5 million to 10 million with about 300 error sets. Initial results were reported at the RIA R&D Workshop by ANL, describing simulations with 100 different error sets with 100K particles per run using TRACK. No lost particles were observed in these runs, an encouraging result.

Areas of beam dynamics R&D to be continued or enhanced

We believe the most important R&D for the beam dynamics includes two areas: 1) continued development and application of the parallel-computing simulation tools for beam-loss calculations; and 2) experiments to measure scattering and energy loss straggling in stripper media. The parallel computing tools will allow assessment of the robustness of the different candidate driver-linac designs with respect to control of beam-losses. These tools will also be important for optimization of the designs, especially with respect to the design of beam-collimation systems that may be necessary to ensure low losses. If the beam-loss predictions using different codes are in good agreement, it will provide much needed confidence in the results. The experimental measurements of beam characteristics after the strippers will provide important data for the computer simulation models, especially since the strippers will be an important source of halo.

Assessment of need for R&D relative to CD1 date

It is important to settle the major questions about the beam-physics design, especially the beam-dynamics, early in the project schedule, since the beam-physics work generally precedes that of the engineering. This is especially true if there are open questions at the time of CD1 regarding which accelerating structures provide the optimum beam dynamics solution.

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3. Front End Including the ECR, LEBT, RFQ, and MEBT: (Jim Alessi)

A credible front-end pre-CDR design exists. There is a rough parameter list for intensity and charge states from the source for species from p to U. Emittance requirements are less well defined, but the ECR emittance is expected to be satisfactory, based on the past observation of an emittance reduction for higher charge states due to the accumulation of these ions closer to the axis of the source. Present ECR performance meets the 400 kW requirement for low mass ions, but a factor of ~6 over demonstrated performance is required for the heaviest ions (U). Present ECR performance for U will support operation at 150 kW if 2 charge states are matched and accelerated through the RFQ. Based on projected future higher frequency operation of the new VENUS source at LBNL, one may well produce sufficient U intensity to achieve 400 kW operation with acceleration of only a single charge state.

Two ECRs feeding one RFQ are shown in the design, but one should also consider a design with 2 RFQs feeding the linac, based on availability considerations (ANL plans to do this).

R&D Issues:

ECR – The ion source is a crucial element of the RIA project, and has a big impact on the accelerator design and eventual performance. It is important to demonstrate as soon as possible the required source performance, so the support for R&D on the ECR is well justified. Excellent progress was made on the ECR source development at LBNL. Operating at 18 GHz, they have achieved good initial intensities with gas injection, and have just started initial metal ion beam operation with their high temperature oven. A 10 kW, 28 GHz gyrotron has been ordered, with delivery scheduled for December, 2003.

LBNL has an appropriate plan for future R&D, which should be supported. They certainly need to demonstrate the expected enhanced performance on the source at 28 GHz (tests can begin in spring of ’04). If one can achieve desired intensity reliably, only single charge acceleration would be needed from the source/LEBT, which, as mentioned below, is desirable. It is important to get emittance measurements as soon as possible, for metal ions as well as for gases, to feed in to linac simulations. Beyond this, support for ongoing ECR development at LBNL is essential since it will take a long development for the source to reach an “operational” state, develop operation over the range of desired ions, etc. Operation is also important to provide a test bed for development of the high current LEBT.

LEBT- LBNL has done a very nice job in building a large acceptance double-focusing analyzing magnet. Initial testing has been done with good results, but it is important that they verify performance at high currents, where space charge will make extraction and transport more challenging. Initial simulations at ANL and MSU of acceleration of 2 charge states from the source look promising. However, this will make tuning/matching into the RFQ and linac more difficult, so it is preferable in a high current machine, requiring low beam loss, to avoid this if possible. Therefore, the hope should be that the source currents becomes sufficient to reach required intensities with only one charge state. Future R&D to demonstrate 2-charge-state acceleration through the RFQ would otherwise be needed, but should consider waiting at least for initial 28 GHz uranium results from VENUS.

RFQ – In a joint ANL/LANL/AES effort, very good progress has been made on the development of a 57.5 MHz RIA RFQ design. There is a good beam dynamics design, and a very good candidate has been chosen for the final resonant structure. RF, thermal, and structural analysis of the RFQ has been done. A full scale, 1-segment Al cold model has been successfully tested. Fabrication drawings are completed for a full power engineering prototype (1 segment), which is needed to verify operation over wide power range (factor of 70), when going from p to U. This is an important test for the viability of the present, single-RFQ, front end designs. Also, a CW RFQ is still far from being a "standard" device, so it is desirable to get operational experience. The use of a second RFQ dedicated to low mass beams should still be considered, since its performance could then be better optimized to these low masses.

MEBT – Beam dynamics designs for the MEBT exist, but beam-chopping requirements need to be established and included in the design. (For example, chopping has been suggested as a method of beam intensity control).

4. Linac Driver: (Jean Delayen, Vincenzo Palmieri, Tom Wangler)

RIA Pre-CDR Reference Design Issues

The RIA driver linac is intended to deliver up to 400 kW of 400 MeV/amu of uranium and be capable of delivering ~ 1 GeV of protons to a variety of targets. Several design options for the driver linac are now under consideration and they seem to be credible as far as the beam energy and current design parameters.

Although the various design options are credible there are differences between them. These include the frequency of the cavities, the number of types and total number of cavities and ancillary components, the assumed surface fields, etc. This implies that there still exists ample opportunity and necessity for optimization of the design in terms of performance and cost.

One of the critical issues for the driver, though, is that of acceptable beam loss. No design criteria have been fully specified yet, besides the canonical 1 W/m, and it cannot be asserted that the design options that have been presented will fully meet the beam loss requirement. Nevertheless, the beam loss requirement will need to be clearly specified and will be one of the main criteria that will be used in the selection process for the driver linac design. [this is the point I was making above]

The beam loss requirement will necessarily be derived from the need for hands-on maintenance. It will also be related to the availability requirement for the RIA complex in terms of average availability, mean time between failure, mean time to recovery, etc. At present no such availability requirement has been specified but it may have a major impact on the design of the driver linac.

The main parameters that have been considered in the present designs seem to be the current and energy, with some attention to beam loss. Other top-level performance parameters (such as a better defined acceptable beam loss and availability) need to be included as design parameters.

The selection process for the RIA driver linac needs to be based on top-level performance parameters and specifications. These include:

- Availability, reliability, mean-time between failure, mean-time to recovery;
- Energy and current (beam power);
- Beam loss;
- Beam emittances;
- Acceptances;
- Cost.

The equilibrium charge distribution produced by the strippers seems to be well understood, but some open questions remain in the understanding of the energy straggling and scattering. There also seems to be some uncertainty in the lifetime of the first stripper and the potential contamination of the superconducting linac by the strippers will have to be addressed.

R&D carried out to date and what has been learned

Multiple charge state acceleration is, at present, needed for achieving the required beam currents for uranium beams. The ability to capture and accelerate a loss-free multiple charge state beam has been clearly shown to be feasible in simulations and demonstrated experimentally at ANL.

Several types of new superconducting cavities for the particle velocity regime of relevance to RIA (low-β elliptical and multiple spoke) have been developed and have been shown to produce the required accelerating fields.

Extensive measurements of the dynamic properties (microphonics) of RIA cavities have been performed and are being incorporated into a model of the low-level rf control systems. Alternate means of reducing and controlling microphonics are being developed.

The development of liquid Li strippers is encouraging.

The development of parallel processing codes for front-to-end high-statistics simulations including machine errors has been initiated and will be a key tool in the assessment of various design options against the design criteria.

At present, there does not seem to be any showstopper as far as the driver linac is concerned. On the other hand, there remain many unresolved issues as well as many opportunities for cost reduction and performance improvement.

Opportunities for future R&D

The development and application of parallel processing codes for front to end high-statistics simulations including machine errors and faults (rf trips, cavities out of lock) needs to be pursued actively. Ideally the codes should include not only the static errors but also the dynamic errors introduced by the superconducting cavities. For example, a short out-of-lock situation might be acceptable as far as beam loss, but a longer one may not be. Performance parameters from actual cavities should be introduced in the simulation codes.

The demonstration of the performance of various superconducting cavities, including the multi-spoke cavity, in a realistic environment should be completed. The required gradients for RIA are fairly modest and their achievement is only a first step. Determination of real performance parameters is important for the cavity type selection process.

Microphonics control will be a design and cost driver for the RIA driver linac, and the exploration of microphonics reduction schemes as well as the development of a state-of-the-art low level rf control system need to be pursued in conjunction with cavity development.

Alternate cavity fabrication techniques (for example sputtering) may be cost-effective alternatives to the more traditional ones and their applicability to the RIA driver should be explored.

The tuning of the driver linac and measurement of the beam properties will require that high-beam-power longitudinal and transverse diagnostics be developed. In particular, beam halo detectors will be essential.

Usable and practical beam loss requirements (in particular in the area of the strippers) will have to be defined soon in order to determine the practicality of hands-on maintenance or the need for remote handling.

A better understanding of straggling and scattering in the strippers (preferably experimentally) will be needed. Stripper development needs to be pursued actively.

5. R&D on High Power Targeting*: (Tony Gabriel)

*As submitted this section included contributions now included in sections 6 and 7.

There are three areas at RIA where high power CW beams, as powerful as 400 kW, interact with targets for the production of the rare ion beams. Because of this high power-targeting situation, these areas must be considered for further R&D. These three areas include the ISOL target area, the fragmentation target area including the beam dump, and the second ion stripping area within the accelerator. All of these areas are discussed in this section and sections 6 and 7, below, starting with discussions on the nuclear safety issues. Over all, the committee was impressed with the amount of R&D currently underway.

Nuclear Safety Considerations for RIA and Its Effect on the R&D Program

ISOL Target:

Because high-powered (~100kW) beams and associated secondary beams are going to be incident on high Z targets like W, Ta, U and possibly Hg, the ISOL target area will be a nuclear facility. Preliminary calculations indicate that the facility associated with these targets will be at least Category 3, approaching Category 2. All radioactive products will contribute to the classification. As important as the nuclide levels are the methods by which the hazardous material can be dispersed. This is further discussed below and can have an effect on the R&D program.

It is recommended that an ES&H person be brought on board during the R&D phase so as to help with future direction, especially in the area of the design of the nuclear facility and other highly radioactive areas.

Because the accelerator facility falls under DOE Order 420.2A and the nuclear facility, under DOE Order 10CFR830, the case to separate the accelerator part and some of the experimental areas from the nuclear facility must be made early or this inaction could drive not only the R&D budget, but also the design, construction, and operation of the entire facility.

During the ongoing R&D program the "final" design of a two-step target (for example, a W, Li cooled center with a UC external matrix) plus its support system must be considered. *After the design begins to solidify, a prototype mock-up of such a system is highly recommended to ensure that change-out can be accomplished in a safe and timely fashion.* The SNS carried out similar research under its R&D program and it proved its worth by saving redesign effort during the final design phase of its nuclear facility.

The current use of Li, which is a very reactive material under certain circumstances, is being considered as the primary coolant for the core of the ISOL target. *It is recommended that Li as the coolant be reconsidered because of the high reactivity of this material which will be in contact with the material that drives the nuclear facility.* Hg is a possible substitute and will even enhance the neutron production in this target since it is a high-Z material. Since Hg will represent a small amount of the target volume the activation should be minimal but this has to be shown by calculations. The best case would be to use Hg as the target material (see section on ISOL targets below).

Another issue that will possibly arise more in the design phase than in the R&D phase, but should be considered now since it will impact the remote handling and the conventional facilities construction, is a loss of coolant accident (LOCA) around the core material if Ta or W is used. The core material may heat-up due to radioactive decay to a temperature that could result in a burning of the material if it comes into contact with air. The amount of residual heat has to be calculated and the heat transfer considered such that the final equilibrium temperature. This is another reason to use Hg as the target material since the LOCA concern will be removed (heating is spread over a larger volume).

The Fragmentation Target Area and the Beam Dump:

Very little information was presented at the Workshop dealing with the beam dump following the fragmentation target/magnet system. However, all recognized the difficulty associated with this system. *This will possibly require some thinking outside the box and it is recommended that some design effort be put forth to define the fragmentation area* *and a realistic beam dump setup so as to determine the type of R&D that is necessary, especially in the remote handling area.* It is currently felt that an R&D mock-up of this area, including the magnet separator, will be required to determine the best way to repair or replace components. As stated above, SNS had a R&D remote handling part and it proved its worth by saving costs in the final design. Since a "large amount" of T will be produced, a determination of the level should be done as soon as possible.

The Second Stripping Area in the Accelerator:

The importance of remote handling in the nuclear facility and fragmentation areas has already been pointed out. However, these parts of the facility are not the only areas which will potentially become highly activated and will require remote handling. The other area is the second stripper area in the accelerator. The level of activation and radiation in the second stripper area must be determined as soon as possible to see if remote handling is necessary in this area. Again as above, if remote handling is necessary then, a mock-up should be used to ensure that repair and change out is possible.

Nuclear Modeling

The determination of the nuclide inventory, energy deposition, and other data needed for the R&D and design of the facility and, in particular, the nuclear facility part, has to be determined by calculations. However, in contrast to codes like CALOR(HETC, EGS, MORSE or MCNP), LAHET, MCNPX, etc, heavy ion transport codes have not had the long history of benchmarking and debugging as well as learning the weaknesses of the codes. Many codes are being developed and will be available over the next several years but will not have been utilized to their full extent. *It is recommended that additional benchmarking be carried out with available experimental data including both thin and thick targets using what is considered to be the currently best code available.* This will at least give additional information on the accuracy of this code and what can be anticipated from the other ones. Other codes can be considered as they become available. These data should include energy deposition, high energy (>25MeV) neutron production (since this will drive the shielding requirements), and residual nuclei production. Some data must exist at the current facilities or simple experiments could be performed.

6. ISOL System and ISOL Target Development Program: (Helge Ravn)

General remarks

Radioisotopes for medicine, industry and applied sciences
The RIA facility has a better potential for production of radioisotopes for applied sciences for the following reasons:

- It can use all known nuclear reactions covering all known nuclei;
- It can introduce hitherto inaccessible nuclei;
- It can transfer knowledge from mass-separation and the ISOL target technology;
- This will allow more modern production methods with minimum waste streams;
- It will make higher isotopic purity products available.

The relevant isotopes can be derived from:

- The proton to neutron converter target;
- The beam dumps;
- The spent target materials;
- Parasitic collection of the very abundant beams of long-lived nuclei of limited scientific interest.

The nuclear physics community should promote and identify the techniques and laboratory space needed for this purpose and offer it to the potential users. The needed resources, mainly of collection devices and off-line laboratory space, should at an early stage be identified and incorporated in the layout and the cost estimate. This could be done in collaboration with ISOLDE where such a programmed exists.

The ISOL target stations

The target stations and their support laboratories will be one of the cost drivers of RIA, as well as having the highest probability of lengthy (>48h) interruptions. Progress on this subject was presented by MSU. *A baseline scenario for their number, remote handling servicing, shutdown maintenance principles and footprint should be chosen and described in detail with highest priority.* It would be best to build their heavily shielded cavities from the start and possibly equip them in a staged approach. To add them later on not only requires that real estate free from other structures and funding is available, but also the willingness of the users to accept the unavoidable disturbances to the program. The resulting inefficiencies in the use of already made investments could well be prohibitive.

Number of target stations:

Experience at ISOLDE has shown that two target stations independently accessible and capable of working simultaneously is an absolute minimum in order serve multiple users and achieve an >70% availability. In addition this requires the investment in spare plugs for the target mount and the main insulator as well as scheme for their rapid (<48h) exchange and a spare acceleration HT power supply.
One or two additional target stations is strongly recommended since it allows a less demanding >48h target change scenario, frequent access to on-line tests of target prototypes and multiple beams and users.

Sharing of the driver beam:

A scheme is recommended for proton or light-ion sharing between the ISOL target stations as well as delivering the about 10 to 100 kW average power to the directly irradiated targets in the form of bunches with a typical length of 10 to 100 ms i.e. the half-life of the short-lived nucleus to be studied spaced by a few half-lives.

Safety and remote handling:

The safety aspects of this miniaturized spallation neutron source surrounded by a fission target should be evaluated in detail at an early stage.

Participation of RIA engineers and physicists in the EURISOL/ SAFERIB network is recommended as a way to share the experience from the European RIB facilities.

Availability and break down analysis:

The availability of RIA could probably be further optimized by an analysis of the breakdown and other beam time loss causes at other facilities like ISOLDE and TRIUMF followed by development of techniques that allows their elimination. Such studies have rarely been done and could be very beneficial.

The ongoing target test and R&D program:

Experience has shown that the success of an ISOL-RIA facility depends critically on a continuously ongoing beam development program. This requires that on-site laboratories where off-line and on-line test stands be available and that frequent access to driver beam time is assured.

Ancillary and off-line Laboratories

In order to define the size and their substantial cost the shielding, layout, internal transport routes and equipment of the following items should quantified:

- Chemical and radio chemical laboratories for target material synthesis
- Workshops for target material container and ion source production and mounting including capabilities for machining radioactive parts
- Storage facilities for spent targets
- Radiochemical laboratory for recovery of useful radioisotopes and waste reduction.
- Laboratories for off-line experiments on collected long lived isotopes
- Laboratory for preparation of radioisotopes for applied sciences.

Recommendations on R&D for the ISOL Target & Ion Source

Of the approximately 50 reports presented at the workshop less than 10 were related to the ISOL target and ion sources. Very good progress was reported from Oak Ridge who now can produce and operate finely dispersed uranium carbide and other target materials equivalent to those used at ISOLDE and measure the effusion delay of gaseous products in real systems. Also, the effusion simulation code developed at Argonne is a major step in the development towards the design of targets in general and the high power two-step fission target. It was noted that no details or discussion of the design and possible testing of this target, which is being designed by W. Talbert, was given. Also no progress was reported on the so-called challenged elements not yet available at ISOL.

Priority and further effort should be put into the following subjects listed in order of priority:

Optimization of targets driven by neutrons from a proton to neutron converter

In view of the importance given to beams of fission fragments the two steps target plays a key role in RIB facilities.
The release as function of half-life and target dimensions should be simulated and optimized at least for some key elements by means of the effusion simulation code mentioned above, including the diffusion step by using parameters from present UC_x targets measured on-line. The management of the released power and production rates in the UC_x target material should be studied by means of calculations with codes like ANSYS and MCNPX-CYNDER.

Verify these results with data obtained on-line from the low-power two-step targets now routinely in operation and determine well-documented final RIA beam intensities.
The several years' old suggestion of using a molten-Li cooled W-target as the neutron source should be discussed in favor of using mercury as both target and heat transfer medium. The Hg solution has the following advantages:

- No additional pyroforic material in the neighborhood of the UC_x;
- No solid-liquid phase transition management of the coolant;
- The Hg with its radioactivity inventory can be drained to a largely self-screening storage tank during target changes;
- The recovery of useful radio nuclides and reduction to a small volume of those for disposal can conveniently be done by distillation in almost commercially available equipment;
- A flowing Hg target seems to easier to make in a windowless version.

The lifetime reduction of the ~1cm^2 entrance window to the neutron production target due to radiation damage should be evaluated in detail.

Directly irradiated targets

In order to have beams available before the fission target is approved and commissioned, work on the well-known target materials, particularly on the management of the deposited power must be undertaken. Modeling, optimization and performance prediction of such targets where the power density is reduced by sweeping or defocusing the driver beam spread over presumably larger target volumes should be as like for the fissioning target.

In beam tests and development of beams that are not available

Participation in determination of fundamental design parameters from targets operating at existing facilities is strongly recommended. This not only supports the above mentioned priorities but effectively trains and educates the personnel that will develop, build and operate RIA.

Alternatively, a program of using projectile fragments injected into prototype target and ion-source systems could serve the same purpose, while advancing the development of beams of elements not yet available at ISOL.

Resonant Ionization laser ion source and ECR and EBIS charge breeding

These two subjects are very promising techniques for ISOL-RIB facilities that are pioneered at ISOLDE. RIA participation in the development program of these subjects, described in my presentation at this workshop, could accelerate the transfer of this knowledge to similar set-ups in the US.

7. The Fragmentation Facility of RIA (Hans Geissel)

General scheme to provide rare isotope beams at RIA

The RIA facility will be unique in the world to provide rare isotopes from both ISOL and In-Flight production and separation schemes with the highest possible intensities. The driver accelerator will provide projectile beams from protons up to uranium ions. The maximum kinetic energy for protons reaches 1000 MeV and for uranium projectiles reaches 400 MeV/u. Driver beam power up to 400 kW will be delivered.

Research potential from the in-flight branch

The advantage of an in-flight separator system is that the separation time is only given by the transit time through the ion-optical system. This characteristic yields access to the most short-lived isotopes and isomers down to the sub-micro second range with secondary beams in the energy regime up to 400 MeV/u. A second fragment separator coupled to a fast gas catcher system gives access to rare isotopes with half-lives of milliseconds and longer for research in traps or with high-quality post-accelerated beams. In both cases the separation is not dependent on any chemical property but solely on the kinematics of the applied nuclear reactions. These properties give access to nuclides at the limits of nuclear existence, which gives high potential for addressing important open questions in nuclear physics. The standard ISOL system has its merits in providing the higher intensities together with small emittance for longer-lived isotopes with suitable atomic properties like rapid effusion and diffusion characteristics. In essence, this combination of production and separation schemes is complementary and cover completely the interest of nuclear structure research and its applications in other fields of science.

RIA fragment separators

The fragment separator design plans are a result of a continuous fruitful international collaboration between ANL (USA), GSI (Germany), NSCL (USA) and Riken (Japan). Partially, the new design proposals are based on the experience of the running facilities A1900(NSCL) [1], FRS (GSI) [2] Rips(Riken) [3] and also the design work which has been done for the Super-FRS project [4] at GSI and the BigRips project [5] at RIKEN.

The high primary beam intensities of the RIA driver require at least a two-stage separation scheme consisting of a pre- and a main separator each equipped with degrader systems. This effort is absolutely needed to achieve separated isotopic beams.

A new separation feature is introduced in the fragmentation facility with the possibility to stop the projectile fragments in a gas cell filled with He [6,7,8]. This gives the opportunity to also access short-lived ions at low energies and excellent emittances which can only be efficiently addressed with an in-flight facility. The slowed-down and cooled fragments extracted from the gas volume are then available either for precision research with rare isotopes at rest or for research with high-quality post-accelerated beams.

To implement these different scenarios of in-flight separation it is necessary to provide two separator branches, a high acceptance and a high resolution one. At the same time these separators must accommodate the quite different kinematics of projectile fragments and fission products. For example, an acceptance of at least 12 %, and optimally 18 %, is required to make efficient use of n-rich fission fragments from 400 MeV/u ^{238}U projectiles.

Status of the design specifications of the separators:

	High Resolution Separator	High Acceptance Separator
$B\rho_{max}$	8-10 Tm	8-10 Tm
solid angle	8 msr	10 msr
momentum acceptance	6 %	12-18%
Resolving Power for a beam spot of < 1 mm	~3000	>1000

Besides the classical optical calculations for the magnetic field configurations also the atomic and nuclear interactions in the target and degrader systems have to be included to characterize and to optimise the performance of the fragment separators. Detailed layout calculations have already been done but further R&D work is required to finalize the designs and to consider the trade-offs of the various design options. *The area of the production target up to the first wedge degrader will be in a high radiation field that has to accommodate remote handling and the special design of the beam dump. This presents a great challenge with respects to heat transfer and radioactivity.*

In the iterative optimisation process the decision can be made whether superconducting or normal magnets will be used for various components of the fragment separators. Unfortunately, the magnets that require the highest field strength and therefore are in principle predestined to superconductivity have to be positioned in the highest radiation fields near the production target and beam dump areas. *As a consequence, the radiation resistance of the magnets is a critical issue that has to be solved and thus represents a significant R&D task.*

Strippers and projectile fragmentation targets

The presented plans for the use of liquid lithium for the driver beam strippers and the projectile fragmentation targets seems to be viable. High priority should be given to use the planned prototype devices to determine the stability of the heat transfer coefficient between the beryllium and the Li at high power as well as the thickness stability of the thin beam strippers.

Gas-cell stopping of rare isotopes for traps and post-acceleration

The gas catcher system is a key component of the RIA facility. In principle all elements produced by the fragment separators can be efficiently stopped in the gas cell volume after momentum compression with mono-energetic degraders placed at dispersive focal planes of the separator stages in front. The quality of range bunching depends on the ion-optical resolving power of the magnet system and the precision of the mechanical shape of the piece of matter matched to the dispersion and imaging condition of the separator stage in front. The overall efficiency of the range bunching also depends of the fraction of ions lost to nuclear reactions, as well as the degree of energy straggling in the absorbers and the ion optical resolution of the dispersive optical system. The gas catcher stops fast fragments in high purity helium and uses electric fields together with gas flow to obtain high efficiency and short delay times in the extraction of the cooled radioactive ions. Several prototypes of RIA gas catcher system have been developed at ANL and the NSCL. For the ¼ scale prototype of a RIA cell at ANL, the extraction efficiency is up to 40-45 % both for fission fragments from a ^{252}Cf source and fusion products from Coulomb-barrier nuclear fusion reactions. A large gas cell has been constructed and commissioned at ANL and will be moved to the FRS facility at GSI for operation and evaluation at the full RIA energy. Preliminary measurements with this cell have demonstrated that about 95% of the fragments are extracted as singly charged or sometimes doubly charged ions. The extraction efficiency ranged from 10-40% in initial tests both with fission fragments from a spontaneous fission source and secondary radioactive beams produced in-flight at ATLAS. Investigations of space charge effects on the efficiency did not reveal any effect within the range of ionization density produced by 10^6 particles per second entering the gas catcher. *Further studies have to be carried out to determine the intensity limits that are relevant for RIA.*

In addition, an alternative approach to constructing gas cells with higher gas stopping power is under development at NSCL. The NSCL has up to 200 MeV/nucleon heavy ion and rare isotope beams and can explore most aspects of the momentum compression, stopping and extraction processes. To date, the NSCL cell has been used to study the range compression and stopping process. Values of the ranges are in excellent agreement (an error of <0.5%) with the most recent range-energy calculations using the ATIMA code. Measurements are underway to determine the efficiency of the cell and its intensity limitations.

Detectors for beam diagnostics and particle identification

The basic experimental equipment to study the separated fragments is already applied in the presently operating facilities. However, the much higher rates envisaged with RIA demands new developments both for detector performance and data acquisition. Tracking detectors to verify the ion-optical performance are essential to make the best use of the separators with respect to resolution and separation quality. R&D work has to be performed in this field to meet the conditions created by the next-generation exotic nuclear beam facilities.

Needs for further R&D

- Fragment separators:
  - Optics:
    - Exploration of the options for the baseline separator designs for RIA
  - Fragment separator simulation codes:
    - Continue development of simulation codes for the collection, separation, and stopping process that can accurately and quickly allow various design alternatives to be investigated.
    - Continue the process to verify existing codes and fragment production cross-sections and phase space.
  - Beam dumps:
    - Complete simulations of the locations of beam dumps for a range of production reaction scenarios and failure modes
    - Determine beam power and power densities for various production scenarios
    - Determine power requirements of collimator slits and magnet liners to determine if further R&D is necessary
    - Develop design concepts for the high power beam dumps
  - High-power fragmentation targets:
    - confirm stability of windowless liquid lithium at power densities required for minimum powers of 100-kW, 1-mm diameter uranium beams at 400 MeV/u
    - Develop target scenarios for lower Z beams
  - Radiation fields:
    - Carryout simulations to characterize radiation doses to magnets and other components near the production targets and beam dumps
    - Continue to develop and verify heavy ion beam tracking codes necessary for these simulations
    - Characterize activation levels and appropriate containment of activated coolants such as liquid lithium and cooling water
  - Radiation hard magnets:
    - Develop magnet design concepts that are consistent with the radiation fields calculated and the magnet field and aperture requirements set by the optics calculations
    - Develop concepts for remote handling/maintenance that may be required for radiation damaged and activated magnets and other components.
  - Multiple simultaneous secondary beams:
    - Consider options for delivery of more than one secondary beam from a given separator
  - Long-lived isotope harvesting:
    - Develop design/layout concepts that will permit collection of long lived isotopes with high isotopic purity for both radioactive target preparation and industrial or medical applications
  - High-quality degraders:
    - Determine degrader uniformity requirements for various production scenarios and concepts for their fabrication and adjustment
- Gas cell:
  - Range bunching:

    - Determine the limitations of the range bunching technique via detailed simulations of the optical limitations due to aberrations and finite acceptances and straggling effects in the absorbers
    - Determine the optimum energies for range bunching and overall production yields with consideration of charge states, reaction losses, and irreducible straggling losses at higher energies
  - Matching of the separator, gas cell and post acceleration stages:
    - Simulate the refocusing of the very large emittance dispersed image from the range bunching section into the aperture of the gas cell
    - Characterize the beam extracted from the gas cell system and match it to the following beam transport system
    - Determine the needs for mass separation of molecular ions from the rare isotopes of interest
    - Develop the concept for matching the output of the gas cell system to the downstream RFQ's, etc.
  - Intensity limitations:
    - Determine the gas cell efficiency as a function of the overall rates of ions passing through or stopping in the gas.
    - Attempt to model and understand the limitations of cell configurations.
    - Explore options to increase the efficiency and/or reduce space charge effects in the cell.
  - Efficiency:
    - Determine the overall system efficiency and the important parameters for the optimisation of this efficiency, such as the optimal energy for the initial reactions and absorber thickness and materials required for the various masses of rare isotopes.
  - Explore alternatives:
    - Explore alternative gas cell geometries that have promise to increase the overall efficiency of the system.
    - Investigate possible alternative catchers for very high intensities or specific ions

The required R&D work can be done most efficiently by international collaborations using resources at ANL, GSI, NSCL and Riken where a lot of experience and possibilities for the next-generation in-flight facilities exist.

Options for multiple users

With both production and separation schemes planned for RIA, it would be very advantageous to make use of both branches in a beam sharing mode in short time intervals. Experience with this option has been gained in several laboratories worldwide. At GSI it has been demonstrated that this option has large advantages.

The two in-flight branches can certainly provide additional degrees of versatility and flexibility. In this respect it is also recommended to investigate the isotope sharing of several fragment separators behind a common production target.

References

[1] A1900 (NSCL)
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[5] BigRips (RIKEN) Kubo, et al., EMIS-14 and ANS meeting San Diego, June 2003.
[6] Range Bunching & Isotope Separation H. Geissel et al. NIM A282 (1989) 247 and H. Weick et al. NIM B164 (2000) 168;
[7] Grunder report
[8] G. Savard et al.

8. Post Acceleration: (Gene Sprouse)

The post accelerator system will be called upon to deliver a wide variety of beams to a wide variety of users. The requirements on this system must:

- Provide continuously variable output beam energy;
- Accelerate the full mass range of ions to energies above the Coulomb barrier;
- Provide the state-of-the-art beam quality and purity;
- Exhibit high overall efficiency and maximize beam current;
- Accept ions of low charge state.

A design for accelerating ions up to mass 132 was presented earlier[1] and recent R&D efforts have made significant gains in meeting the overall objectives of the project. Plans of a low charge to mass ratio linac for post acceleration were presented at this conference, which shows a feasible and cost-effective design to accelerate all possible ions produced at RIA to energies in excess of 10 MeV/u and lighter ions up to 20 MeV/u. The design is based on existing superconducting technology for all elements, except for a room temperature RFQ capable of accelerating $^{240}U^{1+}$. This device, which includes both accelerating gaps and focusing sections in the same structure, has been modeled at half scale, and after some initial adjustments, agrees extremely well with the models that would be used to build the full scale device. The 12.125 MHz frequency will provide large acceptance for the beams coming from a mass separator fed either from an ISOL target, or from the gas-cell system.

One of the most important issues of the post accelerator is its efficiency. As many of the rare isotopes as possible that have been created in the high power ISOL or fragmentation targets must be kept. Different strategies were presented that addressed this issue. First, design of the post accelerator can benefit from the idea of Peter Ostrumov to accelerate multiple charge states[2]. The emittance of the beam may suffer from this, but it appears that the beams will still be of sufficient quality for most experiments, with intensities increased by at least a factor of two.

Efficiency of utilization of the facility can also be improved over the baseline design by development of a charge booster system. Highly charged ions could be injected into a structure similar to the PI system at Argonne, and then fed directly to the high-energy part of the post acceleration linac. This would then accommodate a parasitic high-energy user when the primary experiment is at a lower energy, as is anticipated for many experiments in nuclear astrophysics.

With these developments, it is clear that a credible design exists that will have more capability than was in the original design, and this will greatly enhance the experimental program.

Future R&D requirements

Post acceleration LINAC

- Although the Post Acceleration system will only begin operation after commissioning of the driver accelerator, R&D in this area can have an important impact on the total efficiency of the accelerator. Some of the most important outstanding issues are:
    - Prototyping of 12 MHz Hybrid RFQ. Testing with full level of rf power testing with beam for q/A=1/132;
    - Prototyping of 4-gap SC resonators to demonstrate E_{peak}=20 MV/m;
    - Prototyping of 15 Tesla solenoids together with a SC resonator;
    - Study the properties of high-resolution isobar-separator in terms of tolerances and technical feasibility;
    - Study beam dynamics options for focusing of low q/A heavy-ion beams.

Diagnostic devices

- Although much work to develop the necessary diagnostics for RIA has been performed, there remain significant diagnostics issues that must be addressed in order to insure the successful operation of the RIA facility. Some of these are:
    - The development and demonstration of beam position monitors (BPM) for the driver linac;
    - Design and test a compact diagnostic assembly to be mounted in the very limited space between cryostats and containing a BPM, phase detector, current toroid, and wire scanner;
    - Develop a beam halo detector for the driver linac;
    - Develop high precision beam energy measurement system for secondary beams. (A microchannel-plate time-of-flight system is a possible example);
    - Absolute energy determination diagnostics (such as diode detectors) are also necessary to provide unambiguous beam determination.

References
[1] K.W. Shepard and J.W. Kim, Proc. of the 1995 IEEE PAC, Dallas, TX, IEEE, 0-7803-3053, Vol. 2, p. 1128, 1996.
[2] Pasin and Laxdal, http://www.triumf.ca/download/lax/multicharge_note.pdf

9. Multi User Considerations (Paul Schmor)

The proposed RIA facility offers a unique opportunity to carry out a broad range of exciting forefront, world-class science. Many potential users have been identified and the competition for adequate beam time will be intense. It is technically feasible, economically prudent, and scientifically essential that the facility be capable of providing independent radioactive ion beams to various experiments simultaneously. In addition to the multi-user consideration, target development will be an essential and an ongoing activity at RIA. Target development must be done on-line, on an independent target station, and must have independent control of the driver beam power to that target station. Beam availability/reliability will also be an important consideration for RIA. Multiple simultaneous targets will improve the availability and reliability of exotic beams for experiments.

The currently proposed multi-user schemes, which divide the driver beam into 50% fractions with rf deflectors into separate high energy beam transport sections, while technically credible, fail to properly take into account the actual ISOL target constraints. Each time a new ISOL target is installed, it will be essential to increase the current (power) to that target slowly to its operating value. The ramp up to full power on a target might be several days, dependent on the particular properties of the target material. Users of beams from other operating targets will be impacted negatively, unless the current (power) to the new target can be ramped up independently from the current (power) to the other operational targets.

Typically, ISOL targets enhance RIB yields by optimizing the target material to a particular exotic isotope. Each target material has a unique, ideal, maximum driver-beam species and beam-power limit. The power to other targets (i.e., radioactive ion yield) should not be determined by the power limit of the weakest target. Several operating modes for sharing the driver beams are foreseen by the RIA design teams. The various modes include: 1) splitting the driver accelerated beam to multiple ISOL targets, 2) splitting the beam to multiple ISOL and fragmentation targets, 3) splitting the beam to multiple fragmentation targets, and 4) stopping and singly ionizing one of the isotopes from a fragmentation target in a gas catcher.

Of particular concern here are the modes that include an ISOL target. Mode 2 will be of limited use, as fragmentation production prefers the use of heavy ions whereas ISOL production favors the use of light ions from the driver. Mode 3 would also benefit by having the driver beam power variable on the fragmentation targets. The gas catcher approach of mode 4 has recently been experimentally validated except for determining the intensity limitation of the approach. It is anticipated that modes 1 & 3 (which could include mode 4) will dominate the operating schedule.

Effective multi-user capability requires multiple, 'simultaneous', beams from the driver with each having independent control over the beam intensity. A realistic concept for driver beam sharing in RIA with operating mode 1 is urgently required since, depending on the preferred technique, the additional components could impact the civil construction footprint as well as the remote handling and radiation safety requirements. Aspects of the system concept could conceivably be technically challenging and require some R&D funding for prototyping. Ideally, but not necessarily, the beam current would be controlled on a pulse-to-pulse basis and the individual pulses with the desired intensity would be routed to the appropriate target station. One potential scheme might have a low energy rf deflector with downstream slits used to scrape off unwanted intensity from pulses that are directed to various targets after acceleration in the driver. Another approach might be to use a dc septum similar to the approach used on the beam at PSI.

It is envisaged that initially the effort would go into a paper study of the multi-user system that takes into account the beam dynamics and engineering constraints for modes 1, 2 & 3. The preferred technique might require the construction of an rf deflector. Mode 2 will be used infrequently only when a particular exotic isotope is best produced by a heavy ion, unless a technique is devised to vary the driver beam species in a pulse-to-pulse basis. At present multiple, 'simultaneous' beam acceleration in one driver appears technically not practical. At this point mode 2 requires no additional R&D. Modes 3 & 4 require additional R&D to establish the intensity limitation for the gas catcher technique. The outcome could still have a significant impact on the civil design if the intensity limit turns out to be too low to be practical.

10. RIA R&D Program Outlook:

R&D Areas/
Priority R&D Items

Beam Simulation

High: **Continue the collaborative work to develop end-to-end parallel computing tools for high statistics simulation to optimize the overall system, and to accurately compute beam losses. This R&D is essential to the driver linac technology choice.**

Front End

High **Perform the emittance measurements of the source as soon as possible, to feed into linac simulations.**

High **Demonstrate stable CW operation of an RFQ (one segment) over a wide power range (factor of 70) needed when going from p to U.**

Normal Continue the driver ion source development with an eye toward getting a higher heavy ion current.

Driver Linac

High **Establish the performance parameters of strippers, including experiments to measure the scattering and energy loss in the stripper materials.**

High **Determine the level of activation and radiation in the second stripper area as soon as possible to see if remote handling is necessary in this area.**

Normal Bring ongoing cavity development work, including different types of cavities, to a conclusion that is sufficient to provide performance parameters for the end-to-end simulation and ultimately for the choice of the technology.

Normal Develop transverse and longitudinal diagnostics for the measurement and tuning of the high-power ion beams.

Normal Study and evaluate driver linac cost saving schemes, e.g., microphonics reduction schemes and Nb sputtered structures.

Normal Develop a beam halo detector for the driver linac.

ISOL

High	**R&D to optimize targets, driven by neutrons from a proton to neutron converter, and verify these results with data obtained from the low-power two-step targets now routinely in operation.**
High	**R&D on Resonant Ionization laser ion source and ECR and EBIS charge breeding, which are very promising techniques for ISOL-RIB.**
Normal	R&D to investigate if Hg, instead of molten Li, has advantages as a target and as the target coolant.
Normal	Develop directly irradiated targets as the interim source of RI beams before the 2-stage source is commissioned.

Fragment Separation
For fragment separators:

High	**Continue development of fragment separator simulation codes for the collection, separation, and stopping process, and continue the process to verify these codes.**
High	**R&D on beam dumps including: simulations of the beam dump locations; beam power and power densities for various production scenarios; and power requirements of collimator slits and magnet liners for a range of production scenarios and failure modes.**
High	**R&D on high-power fragmentation targets including: stability of windowless liquid lithium at power densities for 1-mm diameter uranium beams at 400MeV/u with minimum powers of 100-kW; and target scenarios for lower Z beams.**
High	**Simulations to characterize radiation doses to magnets and other components near the production targets and beam dumps, and development of appropriate containment for activated coolants such as liquid lithium and water**
High	**Develop magnet design concepts that are consistent with the radiation doses calculated above and the field and aperture requirements set by the optics calculations.**
High	**Develop concepts for remote handling/maintenance that may be required for radiation damaged and activated magnets and other components.**

For Gas Cell:

High **Study intensity limitations and efficiency of the gas cell, and explore options to increase the efficiency and/or reduce space charge effects in the cell.**

Normal Determine by detailed simulations the limitations of the range bunching technique and the optimum energies for range bunching and overall production yields

Normal Study the matching of the separator, gas cell, and post acceleration stages

Normal Explore alternative gas cell geometries that have promise to increase the overall efficiency of the system and investigate possible alternative catchers for very high intensities or specific ions species.

Post Acceleration

R&D in the post acceleration LINAC system can have an important impact on the total efficiency of the accelerator. While study of design efficiency and possible alternatives is encouraged, some of the important outstanding issues are:

High **Study issues with combined 15-Tesla solenoid and SC resonator unit.**

High **Study the properties of a high-resolution isobar-separator in terms of tolerances and technical feasibility.**

Normal Develop beam position monitors for very low intensity secondary RI beams.

Normal Prototype hybrid RFQ, and test with full range of rf power, and with beam for q/A=1/132.

Normal Prototype SC resonators to demonstrate E_{peak}=20 MV/m.

Normal Study the beam dynamics options for focusing low q/A heavy-ion beams.

Normal Develop high precision beam energy measurement system for secondary beams.

Multi User Considerations

High **Investigate & incorporate a capability that permits and enhances realistic simultaneous independent RIB experiments.**

High **Conceptual study of beam splitting with variable intensity on several targets for effective multi-user operation; develop equipment to support this scheme.**

High **Study of the nuclear facility aspect of parts of the RIA facility must be carried out soon.**

High **A realistic overall concept of the accelerator facility design is urgently required, since the concept will impact R&D requirements for conventional facility, remote handling, radiation safety, and nuclear facility consideration.**

High **Develop an algorithm to assess the overall reliability and availability of the facility, based on mean-time between failures and mean-time for repair models, and evaluate engineering options to include redundancy and to reduce unscheduled shutdowns.**

Department of Energy
Office of Science
Washington, DC 20585

July 17, 2003

Dr. Satoshi Ozaki
Director's Office
Building 510F
Brookhaven National Laboratory
Upton, NY 11973-5000

Dear Dr. Ozaki:

Thank you for agreeing to organize and chair a Rare Isotope Accelerator (RIA) Research and Development (R&D) Workshop. As you know, RIA is the nuclear physics community's highest priority for new construction and will provide compelling research opportunities in nuclear structure and astrophysics studies. The community and the Office of Nuclear Physics are preparing for RIA through a number of activities, including the RIA R&D program that started in FY 2000.

The purpose of this workshop is to understand the present status of and needs for R&D efforts for RIA and to identify opportunities for international collaboration in and coordination of R&D activities relevant to RIA. The workshop will examine and document the current pre-conceptual design for RIA, identifying areas where decisions on technical options remain. The status of the current RIA R&D program will be documented, identifying areas where efforts are needed in light of what has been learned. The ongoing and planned R&D activities for operating and planned rare-isotope facilities will be presented, enabling the workshop to be a venue to develop coordinated R&D efforts of mutual benefit to U.S. and international efforts.

We envision that the workshop will provide the opportunity to collect both written and oral information from RIA R&D researchers, international participants and the community interested in RIA that can be assembled and summarized by you and your workshop team into a report to be delivered to the Office of Nuclear Physics. This report should include: (1) a high level technical paper documenting the reference RIA facility pre-conceptual design; (2) a compilation of the current U.S. RIA R&D program; (3) a compilation of reports of ongoing and planned R&D efforts at operating and planned rare-isotope facilities world-wide; and (4) a list of promising RIA R&D opportunities suitable for guidance to the FY 2004 solicitation for RIA R&D proposals.

We believe an ideal time for this workshop is in late August 2003, and that it should take place in the Washington, DC area. Dr. Gene Henry, Program Manager for Low Energy Nuclear Physics, will be the contact in our office to work with you to provide what information or help you might need. Our office is prepared to provide support for the organization of the workshop as necessary.

We believe that this workshop is timely and important and thank you again for agreeing to make it happen.

Dennis Kovar
Acting Associate Director of the Office of Science
for Nuclear Physics

Appendix 2

2003 RIA R&D Workshop, August 26-28, 2003
Four Point Sheraton at Bethesda, Bethesda, MD

List of Panel Members

Jim Alessi	BNL	Ion source, LEBT and RFQ
Jean Delayen	Jefferson Lab	Superconducting RF
Anthony Gabriel	SNS/ORNL	High Power Target
Hans Geissel	GSI	Fragment Separation
Satoshi Ozaki	BNL	Coordination and Chair
Vincenzo Palmieri	LNL/INFN	Superconducting RF
Helge Ravn	CERN	ISOL
Paul Schmor	ISAC/TRIUMF	Overall Facility
Gene Sprouse	SUNY/Stony Brook	Post Acceleration
Tom Wangler	LANL	Beam Physics, Driver Linac

Consultant to the Panel

Jerry Nolen	ANL
Richard York	NSCL/MSU

Appendix 3

List of Participants

	Last Name	First Name	Institution	email address
Mr.	Ahle	Larry	Lawrence Livermore National Laboratory	ahle1@llnl.gov
Dr.	Alessi	James	Brookhaven National Laboratory	alessi@bnl.gov
Dr.	Alton	Gerald	Oak Ridge National Laboratory	altongd@ornl.gov
Dr.	ANGERT	Norbert	GSI Darmstadt	N.Angert@gsi.de
Mr.	Arenius	Dana	T. Jefferson National Accelerator Facility	arenius@jlab.org
Dr.	Baktash	Cyrus	Oak Ridge National Lab	BaktashC@ornl.gov
Dr.	Beene	Jim	Oak Ridge National Laboratory	beenejr@ornl.gov
Dr.	Blosser	Henry	Michigan State University	blosser@nscl.msu.edu
Mr.	Boles	Jason	Lawrence Livermore National Laboratory	boles1@llnl.gov
Prof.	Bollen	Georg	NSCL, Michigan State University	bollen@nscl.msu.edu
Dr.	Boyd	Richard	National Science Foundation	rboyd@nsf.gov
Mr.	Boyle	Michael	L-3 Communications Electron Devices	michael.boyle@L-3Com.com
Mr.	Brown	Thomas	Argonne National Laboratory	tmbrown@anl.gov
Mr.	Bullis	Robert	Advanced Energy Systems, Inc.	bob_bullis@mail.aesys.net
Dr.	Carter	Ken	UNIRIB/Oak Ridge Associated Univ.	carter@mail.phy.ornl.gov
Dr.	Chattopadhyay	Swapan	T. Jefferson National Accelerator Facility	swapan@jlab.org
Dr.	Coon	Sidney	Department of Energy	Sidney.A.Coon@science.doe.gov
Mr.	Daly	Edward	T. Jefferson National Accelerator Facility	eddaly@jlab.org
Mr.	Davis	Kirk	T. Jefferson National Accelerator Facility	kdavis@jlab.org
Dr.	Delayen	Jean	T. Jefferson National Accelerator Facility	delayen@jlab.org
Dr.	Draayer	Jerry	SURA	draayer@sura.org
Mr.	Favale	Anthony	Advanced Energy Systems	tony_favale@mail.aesys.net
Dr.	Fivozinsky	Sherman	Consultant	fivo.sc@verizon.net
Mr.	Fuerst	Joel	Argonne National Laboratory	fuerst@anl.gov
Dr.	Gabriel	Tony	Oak Ridge National Laboratory, SNS	tag@ornl.gov
Prof.	Gai	Moshe	University of Connecticut	gai@uconn.edu
Dr.	Garnett	Robert	Los Alamos National Laboratory	rgarnett@lanl.gov
Dr.	Geesaman	Donald	Argonne National Laboratory	geesaman@anl.gov
Prof.	Geissel	Hans	GSI Darmstadt	h.geissel@gsi.de
Prof.	Gelbke	Konrad	Michigan State University	gelbke@nscl.msu.edu
Dr.	Gomes	Itacil	I.C.Gomes Consulting & Investment Inc.	icgomes@comcast.net
Mr.	Gorelov	Dmitry	NSCL, Michigan State University	gorelov@nscl.msu.edu
Mr.	Greene	John	Argonne National Laboratory	greene@anl.gov
Prof.	Greife	Uwe	Colorado School of Mines	ugreife@mines.edu
Dr.	Grimm	Terry	NSCL, Michigan State University	grimm@nscl.msu.edu
Dr.	Gupta	Ramesh	Brookhaven National Laboratory	gupta@bnl.gov
Ms.	Hanlin	Cathy	Department of Energy	cathy.hanlin@science.doe.gov
Dr.	Hartouni	Edward	Lawrence Livermore National	hartouni1@llnl.gov

			Laboratory	
Dr.	Hartung	Walter	NSCL, Michigan State University	Hartung@NSCL.MSU.Edu
Dr.	Harwood	Leigh	T. Jefferson National Accelerator Facility	harwood@jlab.org
Mr.	Hawkins	James	Office of Nuclear Physic	James.Hawkins@science.doe.gov
Dr.	Henry	Gene	Department of Energy	gene.henry@science.doe.gov
Ms.	Hofler	Alicia	T. Jefferson National Accelerator Facility	hofler@jlab.org
Mr.	Hogan	Patrick	Jacobs	patrick.hogan@jacobs.com
Prof.	Hong	Seung-Woo	Sung Kyun Kwan University	swhong@skku.ac.kr
Mr.	Hovater	Curt	T. Jefferson National Accelerator Facility	hovater@jlab.org
Dr.	Janssens	Robert	Argonne National Laboratory	janssens@anl.gov
Dr.	Jason	Andrew	Los Alamos National Laboratory	ajason@lanl.gov
Dr.	Johnstad	Harald	Argonne National Laboratory	hjohnstad@anl.gov
Dr.	Kelly	Mike	Argonne National Laboratory	kelly@phy.anl.gov
Mr.	Knight	Charles	L-3 Communications	charles.knight@L-3Com.com
Mr.	Knutson	Dale	Argonne National Laboratory	deknutson@anl.gov
Ms.	Koski	Elizabeth	Jacobs	elizabeth.koski@jacobs.com
Dr.	Kovar	Dennis	Department of Energy	dennis.kovar@science.doe.gov
Dr.	Kreisler	Michael	NNSA (National Nuclear Security Administration) / Livermore / Univ. of Massachusetts	kreisler1@llnl.gov
Dr.	Leemann	Christoph	T. Jefferson National Accelerator Facility	leemann@jlab.org
Dr.	Leitner	Daniela	Lawrence Berkeley National Laboratory	dleitner@lbl.gov
Dr.	Lessner	Eliane	Argonne National Laboratory	esl@phy.anl.gov
Prof.	Lynch	William	NSCL & Dept of Physics and Astronomy	lynch@nscl.msu.edu
Dr.	Lyneis	Claude	Lawrence Berkeley National Laboratory	cmlyneis@lbl.gov
Mr.	Marti	Felix	NSCL, Michigan State University	marti@nscl.msu.edu
Ms.	May	Brenda	Department of Energy	brenda.may@science.doe.gov
Dr.	May	Donald	Cyclotron Institute, Texas A&M Univ.	may@comp.tamu.edu
Dr.	Merminga	Lia	T. Jefferson National Accelerator Facility	merminga@jlab.org
Prof.	Morrissey	David	NSCL, Michigan State University	morrissey@nscl.msu.edu
Dr.	Mustapha	Brahim	Argonne National Laboratory	mustapha@phy.anl.gov
Mr.	Myers	Timothy	Advanced Energy Systems, Inc.	tim_myers@mail.aesys.net
Dr.	Nolen	Jerry	Argonne National Laboratory	nolen@anl.gov
Dr.	Ostroumov	Petr	Argonne National Laboratory	ostroumov@phy.anl.gov
Dr.	Ozaki	Satoshi	Brookhaven National Laboratory	ozaki@bnl.gov
Prof.	Palmieri	Vincenzo	LNL, INFN, Italy	palmieri@lnl.infn.it
Dr.	Pardo	Richard	Argonne National Laboratory	Pardo@phy.anl.gov
Dr.	Peiniger	Michael	ACCEL Instruments	peiniger@accel.de
Dr.	Piechaczek	Andreas	Louisiana State University	Piechaczek@lsu.edu
Mr.	Preble	Joseph	T. Jefferson National Accelerator Facility	prebles@jlab.org
Dr.	Ravn	Helge L.	CERN/EP	Helge.Ravn@cern.ch
Dr.	Reed	Claude	Argonne National Laboratory	cbreed@anl.gov
Dr.	Reyes	Susana	Lawrence Livermore National Laboratory	reyessuarez1@llnl.gov

Mr.	Rode	Claus	T. Jefferson National Accelerator Facility	rode@jlab.org
Dr.	Ronningen	Reginald	Michigan State University	ronningen@nscl.msu.edu
Mrs.	Rueger	Doris	Brookhaven National Laboratory	rueger@bnl.gov
Mr.	Rusnak	Brian	Lawrence Livermore National Laboratory	rusnak1@llnl.gov
Dr.	Ryne	Robert	Lawrence Berkeley National Laboratory	RDRyne@lbl.gov
Prof.	Savard	Guy	Argonne National Laboratory	savard@phy.anl.gov
Dr.	Schmor	Paul	TRIUMF	schmor@triumf.ca
Dr.	Schriber	Stan	Michigan State University	schriber@nscl.msu.edu
Dr.	Shapira	Dan	Oak Ridge National Lab., Physics Div.	shapira@mail.phy.ornl.gov
Dr.	Shepard	Kenneth	Argonne National Laboratory	kwshepard@anl.gov
Prof.	Sherrill	Bradley	Michigan State University	sherrill@nscl.msu.edu
Dr.	Simon-Gillo	Jehanne	Department of Energy	jehanne.simon-gillo@science.doe.gov
Prof.	Sprouse	Gene	SUNY Stony Brook	gene.sprouse@sunysb.edu
Dr.	Steadman	Stephen	Department of Energy, Office of Science	Stephen.Steadman@science.doe.gov
Dr.	Stein	Werner	Lawrence Livermore National Laboratory	stein1@llnl.gov
Dr.	Stoyer	Mark	Lawrence Livermore National Laboratory	mastoyer@llnl.gov
Dr.	Stracener	Daniel	Oak Ridge National Laboratory	stracener@phy.ornl.gov
Dr.	Symons	James	Lawrence Berkeley National Laboratory	tjsymons@lbl.gov
Prof.	Tabor	Samuel	Florida State University	tabor@nucmar.physics.fsu.edu
Dr.	Tanihata	Isao	RIKEN	tanihata@postman.riken.go.jp
Dr.	Thoennessen	Michael	Michigan State University	thoennessen@nscl.msu.edu
Dr.	Tribble	Robert	Texas A&M University	tribble@comp.tamu.edu
Dr.	Verde	Giuseppe	NSCL, Michigan State University	verde@nscl.msu.edu
Dr.	Vieira	David	Los Alamos National Laboratory	vieira@lanl.gov
Dr.	Vinogradov	Nikolai	Argonne National Laboratory	vinogradov@phy.anl.gov
Prof.	Walters	William	University of Maryland	ww3@umail.umd.edu
Dr.	Wangler	Thomas	Los Alamos National Laboratory	twangler@lanl.gov
Prof.	Wollnik	Hermann	Oak Ridge National Laboratory	wollnik@uni-giessen.de
Dr.	Wu	Xiaoyu	NSCL, Michigan State University	xwu@nscl.msu.edu
Dr.	Yamin	Peter	Brookhaven National Laboratory	yamin@bnl.gov
Dr.	York	Richard	Michigan State University	york@nscl.msu.edu
Dr.	Young	Glenn	Oak Ridge National Laboratory	younggr@ornl.gov
Dr.	Zeller	Al	NSCL, Michigan State University	zeller@nscl.msu.edu
Mr.	Zinkann	Gary	Argonne National Laboratory	zinkann@phy.anl.gov

Appendix 4

2003 RIA R&D Workshop, August 26-28, 2003
Four Point Sheraton at Bethesda, Bethesda, MD

Agenda of the Scientific Program with Link to Papers (PDF Format) Presented at the workshop

Time	Description	Speaker	Inst.	Paper #
Tuesday, August 26, 2003				
8:30	Welcome and Charge	Dennis Kovar	DOE	1.0.1
8:45	Science of RIA and RIA Facility Performances-1	Robert Janssens	ANL	1.0.2
9:10	Science of RIA and RIA Facility Performances-2	Brad Sherrill	MSU	1.0.3
9:35	Discussions			
9:55	Coffee Break			
10:20	Reference RIA Facility pre-conceptual design on the NSAC cost exercise	Richard York Jerry Nolen	ANL MSU	1.0.4
11:00	Latest Perspectives on RIA Facility Design: ANL	Ken Shepard	ANL	1.0.5
11:20	Discussions			
11:30	Latest Perspectives on RIA Facility Design: MSU	Richard York	MSU	1.0.6
11:50	Discussions			
12:00	Lunch			
13:30	GSI Plan and R&D Activities	Norbert Angert	GSI	1.1.2
14:00	ISAC/TRIUMF Plan and R&D Activities	Paul Schmor	TRIUMF	1.1.3
14:30	ISOLDE/REX ISOLDE Overview and R&D Plan	Helge Ravn	CERN	1.1.4
15:00	Coffee Break			
15:30	RIKEN RI Beam Facility Plan and R&D Activities	Isao Tanihata	Riken	1.1.5
16:00	Summary Report from "Workshop on the Experimental Equipment for RIA": Oak Ridge 2003	Mike Thoennessen	MSU NSCL	1.2.1
16:30	Stockpile Stewardship and RIA: The LLNL Perspective	Ed Hartouni	LLNL	1.2.2
17:00	RIA R&D Overview (Invited)	Gene Henry	DOE	1.3.1

17:20	RIA R&D: Risk and Opportunity	Dale Knutson	ANL	1.3.2
17:40	A View on the R&D Priorities	Richard York	MSU	1.3.3
18:00	Adjourn for the day			

Wednesday, August 27, 2003

Parallel Session I

8:30	Advanced Beam-Dynamics Simulation Tools for the RIA Driver Linac/ Part 1: Low Energy Beam Transport and Radiofrequency Quadrupole	Thomas P. Wangler	LANL	2.0.1
8:45	Advanced Beam-Dynamics Simulation Tools for the RIA Driver Linac/ Part 2: Superconducting Linac	Robert D. Ryne	LBNL	2.0.2
9:00	Beam Dynamics Studies for RIA at MSU	Xiaoyu Wu	MSU-NSCL	2.0.3
9:15	Driver Linac Beam Dynamics	P.N. Ostroumov	ANL	2.0.4
9:30	Multiple-Charge-State-Beam Steering in the RIA Driver Linac	Eliane S. Lessner	ANL	2.0.5
9:45	Large Scale Computing for Beam Dynamics Simulations and Target Modeling	Brahim Mustapha	ANL	2.0.6
10:00	Coffee			
10:30	Front End of the RIA Driver Linac	P.N. Ostroumov	ANL	2.1.1
10:45	ECR Ion Sources for RIA	C.M. Lyneis	LBNL	2.1.2
11:00	Development of ECR Ion Source VENUS for the RIA Driver Linac	Daniela Leitner	LBNL	2.1.3
11:15	Progress with the Room Temperature Structures for the RIA Linacs	N.E. Vinogradov	ANL	2.1.4
11:30	Medium Beta Cavity and Cryomodule Prototyping for RIA	J.D. Fuerst	ANL	2.2.1
11:45	Cavity Development for RIA	M.P. Kelly	ANL	2.2.2
12:00	Lunch			
13:30	805 MHz Beta=0.47 Elliptical Accelerating Structure R&D	Terry L. Grimm	MSU-NSCL	2.2.3
13:45	Alternative Superconducting Drift Tube Linac R&D	Terry L. Grimm	MSU-NSCL	2.2.4
14:00	Jefferson Lab R&D Activities in Support of RIA	Jean Delayen	J-Lab	2.2.5
14:15	Fast Tuner R&D for RIA	Brian Rusnak	LLNL	2.2.6

14:30	RF Coupler and Tuner Design for the RIA Superconducting Cavities	G.P. Zinkann	ANL	2.2.7
14:45	Solutions for Beam Stripping at RIA	Uwe Greife	Col Sch. Min	2.2.8
15:00	Coffee			
15:30	Charge-State Boosting for Post-Acceleration	Georg Bollen	MSU-NSCL	2.4.1
15:45	Preparations to Investigate Charge Multiplication via 1+ to n+ Scheme in a Large Volume ECR Ion Source	Don P. May	Texas A&M	2.4.2
16:00	Development of a Low Charge-to-Mass Ratio Post-Accelerator for the RIA Project	P.N. Ostroumov	ANL	2.4.3
16:15	Driver and RIB Linac Diagnostics and Beam Tuning	R.C. Pardo	ANL	2.4.4
16:30	Beam Diagnostic Development for the RIA Facility	Dan Shapira	ORNL	2.4.5
16:45	RIA R&D for Enabling Direct Neutron Cross-Section Measurements	Larry Ahle	LLNL	2.5.1
17:00	Adjourn			

Parallel Session II

8:30	Design of a TPC for EOS Studies at RIA	William Lynch		3.0.1
8:45	Design of High-Power ISOL Targets for Radioactive Ion Beam Generation at the RIA (Overview)	Gerald Alton	ORNL	3.1.1
9:00	Design of High-Power ISOL Targets for Radioactive Ion Beam Generation at the RIA (different set of authors)	Gerald Alton	ORNL	3.1.2
9:15	Thick and Thin Liquid Lithium Targets	Claude B. Reed	ANL	3.1.3
9:30	RIA Gas Cell Development	G. Savard	ANL	3.1.4
9:45	Characterization of Ion-Stopping and Extraction from a High Pressure Gas Cell	Dave J. Morrissey	MSU-NSCL	3.1.5
10:00	Coffee			
10:30	An Experimental Apparatus for Effusive-flow Characterization of Arbitrary Size and Geometry Target/Vapor Transport Systems for Radioactive Ion Beam Applications	Gerald Alton	ORNL	3.1.6

10:45	A New Method for Coating Highly Permeable Matrices for High Power ISOL Production Targets	Dan W. Stracener	ORNL	3.1.7
11:00	Characterization of Secondary Radiation from Pre-Conceptual High Power Targets	Reginald M. Ronningen	MSU-NSCL	3.1.8
11:15	Nuclear Safety Issue for the RIA	Jason Boles	LLNL	3.1.9
11:30	High Power ISOL Target Development - R&D Report	John P. Greene	ANL	3.2.1
11:45	ISOL Target and Beam Development	Georg Bollen	MSU-NSCL	3.2.2
12:00	Lunch			
13:30	Beam Cooling of High-Intensity ISOL Beams	Georg Bollen	MSU-NSCL	3.2.3
13:45	Radiation Resistant and Disposable ECRs	A.F. Zeller	MSU-NSCL	3.2.4
14:00	Laser Ion Source Development for ISOL Systems at RIA	Yuan Liu	ORNL	3.2.5
14:15	A Multi-Pass Time-of-Flight Mass Spectrometer for Beam Purification	Hermann Wollnik	ORNL	3.2.6
14:30	Collecting Separated Isotopes at RIA for the Production of Radioactive Targets	David J. Viera	LANL	3.2.7
14:45	Development of the Fragment Separator Designs for RIA	Brad M. Sherill	MSU-NSCL	3.3.1
15:00	Coffee			
15:30	RIA Fragment Separator Studies	G. Savard	ANL	3.3.2
15:45	High Power Heavy-Ion Beam Interactions in Matter	A.F. Zeller	MSU-NSCL	3.3.3
16:00	Testing a Liquid Lithium Cooled Beryllium Target	Dave J. Morrissey	MSU-NSCL	3.3.4
16:15	Development of Radiation Resistant Quadrupoles based on High Temperature Superconductors for the Fragment Separator	Ramesh Gupta	BNL	3.3.5
16:30	Radiation Resistant Magnets R&D for Fragment Separation	Al Zeller	MSU-NSCL	3.3.6
16:45	RIA Fragmentation Line Beam Dumps	Werner Stein	LLNL	3.3.7
17:00	Adjourn			

Thursday, August 28, 2003

8:30	Panel Discussion with Participation of Participants
10:30	Coffee Break
10:50	Executive Session
12:30	Lunch
13:30	Report Writing
16:30	Executive Session
17:00	Adjournment of the Workshop