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ARIEL Top Level Requirements – P0342

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History of Changes

Release Number	Date	Description of Changes	Author(s)
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2	2016-02-27	Re-authored taking Pierre's REV1 as a basis Added budget statement Added performance metrics Redefined e-Linac and AETE specifications with Phase 5 removed Re-sectioned to include general requirements and area dependent requirements Added results and conclusions of Operation Model Added requirements for driver beamlines and beam spot Added requirements for beamlines and target height Added requirements on LEBT Added requirements on target infrastructure Modified requirements on target processing Added requirement for LEBT weather enclosure	R. Laxdal
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1 Overview

1.1 Introduction

ARIEL (Advanced Rare IsotopE Laboratory) will add two new independent production targets and two new driver beams (one electron and one proton) to augment the existing production via protons at the ISAC target station. Beams will be produced in ARIEL and then sent via low energy beamlines to connect to the ISAC beamlines. Presently the ARIEL building is complete. A new high intensity electron linac (up to 10mA) with 30-MeV capability (upgradeable to 50-MeV) has been installed as a second driver to produce radioactive ion beams via photo-fission. By 2020 a new proton beamline will be added (BL4N) from the existing cyclotron and the new target areas will be outfitted with target modules and support facilities.

We anticipate that the 500 MeV cyclotron will continue to operate 8 months a year. Other assumptions for the operation of the full facility are summarized in the Operation Model document (Document-129655). The operational model takes a comprehensive look at the constraints affecting beam delivery that can help inform the ARIEL technical and infrastructure requirements. The operation model will also help in estimating the capital cost and personnel cost of operations. Part of the operations cost will be waste management. A waste management strategy is being developed. The waste management has important implications for the target hall infrastructure most particularly the storage facility and the hot cell.

ARIEL is being deployed in three major stages. This document covers deployment up to the completion of Phase II. ARIEL-III (future) is considered only as much as ARIEL-II design choices should not preclude ARIEL-III implementation as we understand them today.

ARIEL-I (including ARIEL 1.5) consists of:

- the construction of conventional facilities
- the first phase (to 30MeV) of the superconducting electron linear accelerator (e-linac)
- an electron beamline from the electron linac to the AETE target area

ARIEL-II (including the P0310 CANREB project) consists of:

- the installation of two target stations - AETE for electron bombardment and APTW for proton bombardment
- the installation of a proton beam line, BL4N, from the cyclotron to APTW
- the installation of the low energy ion beam transport including mass separation hardware, charge breeding capability and beamlines to bring ions from ARIEL to join the low energy beamlines in ISAC.
- related operational infrastructure for the production of isotopes as described in P0342 ARIEL-II CFI funding application, Document-114911.

ARIEL-III consists of:

- installation of a second accelerator cryomodule and an additional rf source to bring the e-Linac to 50MeV and 500kW capability

- the installation of a second low energy linac section in ISAC to allow two simultaneous accelerated RIB beams
- the upgrade of AETE to higher beam powers up to 500kW at 50MeV
- the upgrade of the e-Hall to include a recirculating ring to operate in ERL mode or RLA (energy augmentation) mode
- additional operational on-line or support infrastructure removed from the ARIEL-II scope to meet the ARIEL-II budget.

This document states the top level requirements for the ARIEL-II program. This document supersedes any previously stated top level requirements for the ARIEL facility.

1.2 Definitions and Acronyms

RIB:	Radioactive Ion Beams.
ARIEL	Advanced Rare IsotopE Laboratory.
AETE	ARIEL Electron Target East.
APTW	ARIEL Proton Target West.
LEBT	Low Energy Beam Transport
ERL	Energy Recovery Linac
RLA	Recirculating Linear Accelerator
MRS	Medium Resolution Spectrometer
HRS	High Resolution Spectrometer
% reliability	Hours of actual operation compared to hours of scheduled operation
Delivered RIB hours	Hours of RIB delivery to a scheduled destination at rates above the agreed minimum threshold established in a run plan meeting
Hot Cell	A heavily shielded enclosure for highly radioactive material used to protect workers against radiation (Alpha, Beta and Gamma) while performing work on active material.
Decay Storage Vault	Shielded location in the Target Hall to place irradiated target canisters to allow decay down to acceptable levels for further handling.
Operation model	A document that summarizes the strategy for operating the ARIEL/ISAC facility
LIS	Laser Ion Source
SIS	Surface Ion Source
Febiad	Forced Electron Beam Induced Arc Discharge ion source
EM stripping	Electro-magnetic stripping of the H- ion
PIE	Post Irradiation Examination – inspecting spent target as development feedback
CNL	Canadian Nuclear Laboratories

1.3 References

The following documents can be used to better understand the scope and requirements

- ARIEL-II project plan - Document-118283
- P0342 ARIEL-II CFI funding application, Document-114911
- Operation model, Document-129655, TRI-DN-16-05
- Preliminary Decommissioning Plan, Document-8810
- ARIEL-II Accounting Module – Docushare Collection-13895

2 Requirements

In this document, a “shall” is a mandatory requirement. A “should” is a recommended requirement. The term “shall be designed” is used where a test won’t be able to be performed within the scope of the project. The requirement is satisfied by design documentation.

2.1 Facility

RS 1. The ARIEL facility shall be designed such that implementation will fall within the project budget as defined in the ARIEL-II Accounting Module.

Rationale: Successful completion can only be realized if the project implementation falls within the available capital.

RS 2. The ARIEL facility shall be designed to be capable of producing radioactive isotope beams covering elements from helium to thorium.

Rationale: The range of elements will give a broad physics program.

RS 3. The ARIEL facility shall produce reference beams with the properties listed in Table 1.

Rationale: Achieving these reference beam properties will indicate that ARIEL-II is capable of producing a variety of world class beams in terms of intensity, yield, and purity.

Table 1: Reference beams for ARIEL-II

RS 4. The combined ARIEL-ISAC facilities shall be able to deliver three RI beams simultaneously to the ISAC experimental areas.

Rationale: More beams produce more science - central to the ARIEL proposal (ARIEL-II CFI Application, Document-114911) is the eventual capability to deliver three beams simultaneously to allow greater utilization of the ISAC experimental facility infrastructure.

Isotope	Driver / Source	Destination	Rate pps	Purity
^{8}Li	**e-Linac SIS**	**LE**	**$1x10^{7}$**	**+99%**
^{100}Rb, ^{98}Sr	**e-Linac SIS e-Linac LIS**	**LE and HE (better)**	**$1x10^{4}$ $1x10^{6}$**	**50%**
^{98}Kr	**e-Linac Febiad**	**LE and HE**		**50%**
^{144}Ba	**e-Linac SIS/LIS**	**HE**	**$1x10^{5}$**	
^{146}Xe	**e-Linac Febiad**	**LE and HE**		
^{150}Cs	**e-Linac SIS**	**LE and HE**	**1**	
^{11}Li	**500MeV p SIS**	**HE**	**$2x10^{3}$**	**+99%**
^{72}Kr	**500MeV p Febiad**	**HE**	**$5x10^{2}$**	**50%**
^{74}Rb	**500MeV p SIS**	**HE**	**$1x10^{3}$**	**50%**
$^{209-211}$Fr	**500MeV p SIS**	**LE fund. symmetries**	**$1x10^{7}$**	

RS 5. The reliability performance goal for the facility shall be ≥90% for drivers, ≥80% for non-accelerated RIBs and ≥75% for accelerated RIBs.

Rationale: These goals are based on experience gained at ISAC and are a balance between maximizing science while operating a complex beam delivery chain.

RS 6. The performance goal for delivered RIB hours per year from each ARIEL target station shall be ≥3000 hours for a total TRIUMF RIB production of ≥9000 hours.

Rationale: More hours means more science –replicating the RIB hour goal at ISAC for each ARIEL target station means that with the addition of ARIEL we will triple our present RIB hour output. An operational model (Document-129655) will provide feedback on how this requirement impacts infrastructure requirements.

RS 7. The driver beam performance goal for beam trips on any RIB target shall be ≤ 50 trips/week.

Rationale: Beam trips thermally cycle the target and cause premature aging. The number of allowed trips is based on experience at ISAC.

RS 8. The intended lifetime of the project shall be 30 years.

Rationale: Equipment choice and engineering should be based on a 30 year time window.

RS 9. The ARIEL project should be built to allow decommissioning in 30 years at a cost of ≤10% of the initial capital investment (in 2015 dollars).

Rationale: The project needs to plan for decommissioning and it needs to be affordable. A preliminary site decommissioning plan is presented in Document-9910.

2.2 Driver beams

RS 10. The ARIEL-II e-Linac driver shall be capable of accelerating electrons with E≥30MeV at beam powers up to 100kW upgradeable to 50MeV and 500kW.

Rationale: Isotope yield from photo-production is dependent on electron energy and rises dramatically from 20 – 30MeV while production increases are modest from 30-50MeV. Production is roughly proportional to electron intensity but target technology gets more difficult with increasing power. It is felt that 100kW is manageable with present understanding. 50MeV and 500kW is a possible long term goal for the e-Linac capability and matches the initial linac design specification.

RS 11. The ARIEL electron beam-line shall be capable of transporting electrons with 10 ≤ E(MeV) ≤ 75.

Rationale: A minimum energy is specified to limit the required stability of beam transport elements for energies where RIB production is not efficient and an energy of 75MeV to enable high energy explorations of beam production in the future. 75MeV is the maximum energy foreseen in single pass if the cavities are pushed to the cryogenic limit. Since this energy would be delivered at a lower current the 50MeV/10mA beam sets the upper limit for shielding.

RS 12. BL4N shall be capable of delivering 475 ≤ E(MeV) ≤ 500 at beam intensities up to 100 µA to APTW.

Rationale: The ARIEL proton target yields increase with intensity. Existing target technology is capable of dealing with driver beams of up to 50kW. The driver energy matches the maximum extractable energy from the cyclotron and the lower range gives an energy where EM stripping is reduced while the yield is not critically affected.

RS 13. The proton beam size (FWHM) and position (centroid) on target shall be variable to efficiently irradiate the target by static tuning or rastering, repeatable to ≤1mm (for rastered delivery the size requirement is averaged over one raster cycle).

Rationale: The precise irradiation of the target is important to establish the correct temperature profile, increasing yield and reducing aging.

RS 14. The electron beam position at the converter shall be variable to efficiently raster the beam onto the converter, repeatable to ≤1mm.

Rationale: The precise irradiation of the target is important to establish the correct temperature profile, increasing yield and reducing aging.

RS 15. The stability and reproducibility of the beam position centroid on either target shall be ≤±1mm respectively for static delivery or for rastered delivery averaged over one raster cycle.

Rationale: The precise irradiation of the target is important to establish the correct temperature profile, increasing yield and reducing aging.

RS 16. The beam transmission in the beamlines shall be sufficient to allow hands on maintenance within one hour of beam off for beamlines not impacted by radiation from the target.

Rationale: Access to the tunnel for service should be timely to avoid unnecessary down-time. Remote handling for general beamlines is not foreseen in the project scope.

2.3 Target areas

RS 17. The ARIEL target hall shall accommodate two target stations, one for the proton driver beam and the second for the electron driver beam.

Rationale: There are two driver beams for ARIEL – one proton and one electron. Having dedicated target areas reduces the technical difficulty of maintaining full flexibility without limiting the facility performance.

RS 18. The target areas shall allow simultaneous operation.

Rationale: In order to achieve three simultaneous beams, satisfying the Operation Model and RS4.

RS 19. The target areas shall allow target exchange in one target area while delivering beam from the other.

Rationale: This is necessary to maximize the number of hours of RIB production and provide RIB delivery flexibility (see Operation Model).

RS 20. The target/ion sources shall produce beams with energy (E<=60kV) and emittance (eps<=100pimm-mrad), compatible with ISAC LEBT for all masses.

Rationale: The energy and emittance should be compatible with the ISAC infrastructure so that beams from ARIEL can be transported to low energy experiments.

RS 21. The beams for acceleration should have an energy of 2.04keV/u and emittance eps<=100pimm mrad for A<30 and compatible with the ARIEL CSB for A≥30.

Rationale: The energy and emittance should be compatible with the ISAC infrastructure so that beams from ARIEL can be accelerated to high energy experiments with good efficiency.

RS 22. The target exchange process for APTW and AETE shall be done within ≤7 twelve hour shifts (from driver beam off to new target conditioned with beam and ready for RIB tuning/yield).

Rationale: To achieve the required RIB hours from each target station given the proposed Operation Model.

2.3.1 Proton target area (APTW)

RS 23. APTW target station shall be capable of receiving protons with 475≤E (MeV)≤500 at beam currents up to 100μA.

Rationale: Spallation yields favour higher energies - the specified energy range matches the high energy capabilities of the TRIUMF cyclotron and the beam power matches known engineering capabilities based on ISAC experience.

RS 24. The proton target vertical elevation shall be the same as the proton beam vertical elevation at the exit of the cyclotron.

Rationale: Due to the rigidity of the high energy proton beam it is advantageous not to manipulate them vertically but only horizontally.

RS 25. The APTW shielding shall be compatible with operation at 50kW with up to 500MeV protons.

Rationale: This corresponds to the target specification and is the maximum beam power that will be put on the target in the foreseeable future.

2.3.2 Electron target area (AETE)

RS 26. AETE target shall be capable of receiving electrons with 25≤E (MeV)≤50 at beam powers up to 100kW and electrons ≤ 75MeV for beam intensities requiring comparable shielding and cooling

Rationale: Follows from RS10 and RS 11.

RS 27. The Target Hall and ARIEL building shielding shall be compatible with operation at 500kW at up to 50MeV.

Rationale: Follows from RS10 for potential future upgrades of e-Linac. Operation at 75MeV for development would be done at lower beam powers.

RS 28. The AETE target height shall be such that the AETE RIB height is equal to the APTW RIB height as constrained by RS24.

Rationale: This simplifies the ARIEL LEBT allowing common, modular design.

2.3.3 Target and target ancillary systems

RS 29. The target station design shall allow for high-efficiency RIB production and delivery using different ion sources and transfer lines (surface, FEBIAD, LIS, ion guide, quartz line, cold line), controlled high temperature operation for the target, transfer line and ionizer as well as a suitable ion extraction optics.

Rationale: A cutting-edge science program will depend on the yield of the ions of interest. A broad range of production sources are required to be able to optimize yields and purities for specific isotopes.

RS 30. The electron and proton targets shall be contained in hermetic vessels (canister) prior to irradiation.

Rationale: Irradiation of the target will activate the target – a hermetic target enclosure reduces the risk of spreading loose activation. The hermetic vessel will permit the use of air sensitive target materials.

RS 31. The target design, hot cell, irradiated storage and target infrastructure shall be compatible with the use of standard ISAC target materials (SiC, Ta, Nb, ZrC, UO and UC), new material BeO and should be compatible with other new target materials (LaC, ThC, UC*) including those with nano-graphite fibers(*) and nano-carbides(*).

Rationale: The efficient release of short half-life radioisotopes of a wide variety of ions requires a range of target materials. For example Li8 production from electrons will require a BeO target.

RS 32. The on-line use of target materials shall be predicated on the off-line development of procedures for safe handling and post-processing requiring safety approval to be determined on a case-by-case basis.

Rationale: ARIEL operation depends on safe, reliable, tested procedures.

RS 33. A waste management strategy shall be developed utilizing infrastructure in the target hall included within the budgeted scope of ARIEL-II.

Rationale: From RS1 the waste management strategy must fall within the budgeted scope of the project.

RS 34. An irradiated target decay storage facility shall be available in the target hall. The facility is required to receive irradiated targets, safely store them for a time determined by the waste management strategy and to allow retrieval and delivery to the hot-cell for analysis and/or disposal.

Rationale: Moving irradiated target canisters comes with some risk. Limiting the temporary storage facility to the target hall reduces the risk of transporting the newly irradiated target canisters around the site (consistent with ALARA).

RS 35. Target storage shall be available assuming a spent target rate of 26 targets/year and satisfying the waste management strategy.

Rationale: Based on the proposed operation model each of the three target areas will operate in three week cycles with a new target coming on line each week from one of ITE/ITW, APTW or AETE. Based on the Operation Model a total of 12 targets/year could be expected at APTW and 14 targets/year from AETE.

Comment: A waste management strategy developed with the Operational Model suggests that a 72 slot storage facility is compatible with storing AETE targets for an average of 2 years and APTW targets for an average of 3.5 years.

RS 36. There shall be a capability of separating high activity materials from lower activity materials after sufficient decay in the decay storage.

Rationale: This allows the opportunity to customize target waste disposal for the waste storage plan within the ARIEL-II facility.

RS 37. There should be a possibility of doing post-irradiation examination (PIE) of the target within 6 months of irradiation.

Rationale: This feature would allow direct physical feedback on a target's end of life physical status compared to target performance and for failed targets would give feedback on failure modes.

RS 38. There should be provision to process a target to a level of stability compatible with present practice for long term storage.

Rationale: The waste disposal strategy calls for removing the waste to an off-site location with requirements for the level of reactivity. Presently we ship to CNL – the level of stability attained in the present targets before shipping can be used as a guideline for future processing.

C**omment**: The use of air sensitive materials on-line shall be predicated on the prior off-line development of procedures for safe handling and post-processing requiring safety approval to be determined on a case-by-case basis.

RS 39. There should be provision to allow irradiation and retrieval of materials that can be utilized for the development of isotopes for nuclear medicine.

Rationale: The high intensity driver beams bombard the ARIEL targets to create unstable isotopes. The targets are designed to release isotopes for ionization, acceleration and separation. A second set of targets could be designed to allow bombardment, simultaneous to the ISOL target bombardment, where the isotopes are created and contained within the target material. Some of the isotopes may find use in nuclear medicine.

2.4 RIB Low Energy Beamlines

RS 40. Each target station shall have a dedicated pre-separator section in the shielded target hall capable of separating mass numbers.

Rationale: The pre-separator section will remove the bulk of the activity extracted from the target and keep it within the heavily shielded area

RS 41. A beam switchyard shall allow beams from either AETE or APTW to pass through a single High Resolution Spectrometer with a resolution of 20000.

Rationale: This specification allows isobar separation in the mid mass regime (A~100). Even though isobars produced in the target for heavier species will require a higher resolution this resolution is an achievable and state of the art compromise.

RS 42. Space shall be made available in the switchyard to provide a second spectrometer path with a resolution of 5000 (Medium Resolution Spectrometer - MRS).

Rationale: Tuning for high resolution takes significant time and many experiments will only require a MRS – (the MRS was removed from the scope for budgetary reasons - an MRS is planned for ARIEL III).

RS 43. Beams from AETE or APTW shall be able to bypass the MRS and HRS.

Rationale: In some cases (ie for lighter beams) the resolution of the pre-separator will suffice and bypass lines will generate higher transmission and faster tuning than a magnetic element.

RS 44. The ISAC low energy experimental area shall be divided into at least two zones served by at least two independent beam lines – for the purpose of this document they are called LEBT-1 and LEBT-2.

Rationale: This will allow beam delivery to two low energy experiments simultaneously.

RS 45. The low energy beam switchyard shall allow beam from either target to reach the ISAC accelerator and ISAC LEBT-1 or ISAC LEBT-2 while beam is being delivered from ISAC ITW/ITE to ISAC LEBT-2 or ISAC LEBT-1.

Rationale: This allows flexibility in beam delivery and the possibility of three simultaneous beams compatible with the Operation Model.

2.5 RIB Low Energy Ancillaries

RS 46. The ARIEL low energy area shall be outfitted with a Charge State Booster (CSB) compatible with the ISAC infrastructure.

Rationale: For masses with A≥30 a CSB is required to boost the charge state from 1+ to n+ to allow acceleration in ISAC.

RS 47. The ARIEL low energy area shall include a station to collect/implant long lived radioactive ions.

Rationale: An implantation station would augment the scientific program by allowing the selection and collection of long-lived species using the ISOL method.

RS 48. The ARIEL low energy area shall include a Yield station.

Rationale: The Yield station is required to identify beam products and to determine their intensity and purity both to characterize target performance and to aid beam delivery.

RS 49. There shall be an all-weather enclosure on the LEBT section between the ARIEL building and the ISAC building.

Rationale: Need to protect the beamline and workers servicing the section from the weather.