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ARIEL Electron Target East Design Requirement Specification

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1 ARIEL Overview

Refer to the ARIEL Top Level Requirements document for an overview of ARIEL (1).

2 Scope

The scope of this document is based on the ARIEL-II System Architecture (2), release 3. Work Breakdown Structure (WBS) number 1.1, the ARIEL Electron Target Station East (AETE) is defined as the system comprised of a replaceable target, a replaceable photo-converter, a means of dissipating beam energy not deposited in the target or converter (i.e. heat shield), a set of supporting systems that maintain the temperature, ion beam and vacuum conditions necessary for Radioactive Ion Beam (RIB) generation and extraction, as well as shielding above the target and a set of equipment to remotely operate the Target Station.

The scope of the Target Station design envelope is bounded by the following interfaces:

- The remote handle-able connection of the driver beam-line entrance diagnostics module (WBS 1.2.1) and the Target Station (WBS 1.1),
- The remote handle-able beam-line connection to the RIB beam-line Front-End (WBS 2.1.2), before the pre-separator,
- The interface between the Target Station vacuum tank / inert gas enclosure and the permanent shielding surrounding the Target Station (WBS 10.3),
- The connection point to the Remote Module Transport System and/or Remote Target Transport Tool (lifting points for removing components from the Target Station to connect with spreader bars and below-the-hook lifting devices, WBS 10.2.1),
- The interface with any vacuum generation (interface with WBS 1.1.7),
- The high voltage and ground potential service disconnects for each service connection (high-active coolant, power, control) (WBS 1.1.2).

The specific locations and requirements of each interface will be defined, as per the interface control plan (3).

“Shall” is a mandatory requirement. “Should” is a recommended requirement.

3 AETE-APTW Common Interfaces

The electron and proton Target Stations are required to be independently operable, but share some services and support systems.

The following interfaces are expected to be common between the East and West Target Station (2):

- The target hall crane and remote handling service (WBS 10.2.1 and 10.2.4),
- The hot-cells (WBS 10.1),

- The irradiated target storage vault and the spent targets assessment station (WBS 10.2.2),
- Module Storage Pit (WBS 10.2.2)

4 AETE Design Requirements

4.1 High Level Requirements

Design requirements are listed in this section as specific guidance intended to ensure consistency with *ARIEL Top Level Requirements* (1). In case of a conflict the top level requirements document takes precedence.

RS 1. The Target Station design shall maintain an inert environment for target materials throughout the Target lifecycle.

Rationale: To meet the top level requirement that air sensitive target materials are usable and that the target can fully be conditioned offline, the target will be kept in a Target Vessel in an inert environment. The process is defined in the ARIEL Target Process Flow (4).

RS 2. The design of the target/ion source assembly shall allow for testing and conditioning up to the intended high voltage and target operating temperature before release for on-line operation.

Rationale: Testing of stable beam extraction and conditioning of targets prior to installation at the Target Station reduces the risk to isotope production in the event of a target problem. The benefits and drawbacks of various possible conditioning processes (e.g. conditioning station vs. target assembly conditioning, etc.) are to be determined.

4.2 Converter, Target and Ion Source

RS 3. AETE shall have an electron to photon converter which accepts a rastered beam as defined in *AETE driver beam raster requirements* (5) .

Rationale: A converter is required to convert electrons to photons that can drive the photo fission in the target. The power density can be reduced by rastering the beam on a larger area.

RS 4. The target heaters shall be able to heat the target to 2200 °C with a heat homogeneity throughout the entire target better than 60°C (+/- 30°C).

Rationale: The target must operate at an elevated temperature for the radioactive species to migrate efficiently out of the target into the ion source. The temperature is determined by the maximum allowable operating temperature of the target material and/or target container.

RS 5. The AETE shall have the capability to determine the temperature in the target and have an accuracy better or equal to 55 °Cat 2200 °C and a reproducibility better or equal to 22 °C at 2200 °C.

Rationale: The target temperature has been identified as an important parameter in the Target Station operation. The appropriate correlation between the temperature distribution throughout the target and the discrete temperature measurement will be dependent on the target geometry and operating conditions. The appropriate location of the temperature sensor, and the interpretation of the measured value is excluded from scope of the Target Station design. The accuracy and reproducibility (repeatability of the temperature measurement between heating cycles) requirements are suggested values based on TRIUMF experience.

RS 6. AETE shall satisfy the requirements of *ARIEL Ion Sources and Ion Beam Extraction Optics Requirements Specifications* (6).

RS 7. The Target and Ion Source shall be part of a replaceable assembly that can be exchanged with every new Target.

Rationale: This allows changing the target material and properties, as well as the ion source for each operational cycle. It will also facilitate incremental improvements of the target and ion source.

RS 8. Electrodes for the RIB extraction and acceleration which may become coated by material from the target shall either be part of the replaceable target vessel, remotely replaceable or cleanable and, if applicable, consistent with the maintenance plan.

Rationale: Lesson learned from ISAC.

RS 9. The target and converter lifetime shall be as long as required by the Operational Model (7) plus the time required for off-line testing and conditioning.

Rationale: The target and converter can only be replaced during the target exchange cycles. Based on ISAC experience, it is expected that the target container will be heated for an additional 1-2 weeks off-line before it goes online to be irradiated.

RS 10. The target and converter shall tolerate frequent beam trips resulting in thermal cycling; the yield shall not change after a trip and the structural integrity of the target shall be maintained. The limit of beam trips is specified in the top level requirement (1).

Rationale: The driver beam will trip off occasionally, which will remove the heating arising from the deposited beam power and cause rapid thermal cycling. The driver beams have an operational goal of less than 50 beam trips per week.

4.3 Operation, Maintenance, and Remote Handling

RS 11. It shall be possible to routinely exchange a fully irradiated target with a new one within the constraints specified in the Operational Model (7). At the end of the exchange, the shielding will be restored and the target will be under vacuum, at temperature, conditioned with beam and yields measured.

Rationale: The time allotted in the model is two days (4 shifts) starting Monday 8:30am, after 12 h (1 shift) cool down.

RS 12. All components of the AETE that could fail within the lifetime of the facility, shall be repairable or replaceable. If the expected radiation dose from activation or contamination does not allow hands-on work on the component, it must be designed for remote repair or replacement in-situ or in the Hot Cell.

Rationale: Components close to the target will become activated which will prevent hands-on work.

RS 13. All components and equipment expected to need repair or replacement shall be incorporated into a maintenance plan. The maintenance plan for all components and equipment shall comply with the restrictions in the Operational Model (7).

Rationale: The target hall will house multiple components that need maintenance. The available time for maintenance will be restricted by operational requirements and availability of resources such as the Hot Cell, Target Hall Crane and manpower.

RS 14. All components designed for remote repair or replacement shall be installed remotely or have installation and removal validated on a mock-up.

Rationale: To ensure that the components can actually be removed and reinstalled using remote handling procedures.

RS 15. Any mechanical drive systems in AETE which cannot be serviced hands-on should be designed according to ASTM C1615-10.

Rationale: Such systems will be exposed to harsh radiation environments and will have to be serviced using remote handling procedures.

RS 16. All operation and maintenance tasks for AETE shall be compatible with the ARIEL remote handling services consisting of: an overhead crane (20 Metric Ton), two auxiliary cranes (6.8 Metric Ton) capable of covering the ARIEL target hall area (8); hot-cells for target exchange and maintenance equipped with "master-slave" manipulators.

Rationale: The environment of the Target Station will become radioactive in the first several months of operation. Hands-on service is not considered as a valid option due to the long cool down period required for personnel access after end of beam. To satisfy the top-level requirements specification the target replacement and routine servicing must be done using remote handling tools.

RS 17. Components that could conceivably need to be assembled / disassembled in the hot cells for routine maintenance or non-routine operations should be designed in consultation with the ASTM standard guides for hot cell equipment (ASTM C1533-015 ASTM C1725-10 and ASTM C1615-10).

Rationale: It is expected that most maintenance and repair activities will be performed in hot cells. The standard guides include specific design features and considerations to facilitate hot cell work. This could include using components modified for ease of use with manipulators, and / or designing tools / jigs to facilitate these maintenance activities.

RS 18. Components within the Target Station shall be designed to "fail-safe" such that it is possible to enact a back-out strategy to remove failed components in-situ and/or remove the host module to the Hot Cell in the event of any single point failure.

Rationale: The Target Station will become radioactive after operating requiring modules to be removed from the installed location before maintenance can be performed. As a result, the failure mechanisms of all subsystem and components must be considered to ensure components cannot fail in a manner that prevents removal of the modules.

4.4 Radiation Protection, Contamination Control, and Personnel Safety

RS 19. The design of AETE should prevent spread of contamination requiring use of respirator in the target hall (for maximum levels refer to *Personal Protective Equipment Requirements for Radiological Work at TRIUMF* (9)).

Rationale: Contamination of air, areas and components will put restrictions on access to the target hall.

RS 20. The gas in any voids in AETE can become activated by the radiation. The hazard from activated air in voids shall be quantified and if warranted, a strategy must be developed to safely deal with the activated gas.

Rationale: It is TRIUMF's goal to minimize the additional impact from ARIEL of radioactive emissions to the environment. The potential need for mitigation measures will be assessed by Environmental Health and Safety (EH&S).

RS 21. The Target Station shall have functionality to collect any leaked water and drain to the active sump.

Rationale: Any water leakage must be collected. The active sumps are designed to collect any leakage water from the operating stations. Refer to ARIEL Building Plumbing Foundation Plan (Drawing 19350). The routing of this piping will have to be coordinated with shielding and other services running through the shielding.

RS 22. All waste generated during target change and maintenance activities should be consistent with a documented waste management strategy.

Rationale: A lesson learned from the operation of the ISAC facility is that the disposal of the waste resulting from operation must be carefully considered at the target design stage. At the time of release a waste management strategy document is not available. A waste management concept was presented in DR.P0353.06 (Document-131403).

RS 23. The result of nuclear activation and contamination, including decay time, should be considered for all components that could be activated during normal operation. Considerations related to nuclear activation could affect downtime between maintenance activities as well as storage and decontamination requirements or target change activities. When possible, aluminum and aluminum-magnesium alloys are preferable to steel to reduce the long-term activation.

Rationale: Such activation may prevent or restrict hands-on work or occupancy in the vicinity of these components.

RS 24. The waste generated in routine and non-routine operations such as target changes, refurbishments, as well as decommissioning should be considered in design. Important considerations include the total volume of waste, the ability to separate materials of different levels of radioactivity, and the how the waste can be handled. The target waste is to be disposed of in disposal containers dimensionally equivalent to those used in ISAC (10) (11).

Rationale: Radioactive waste presents additional handling and disposal challenges compared to conventional waste.

4.5 Target Station Modules

RS 25. The Target Station shall be built using a modular system, where individual modules can be removed from the Target Station to the Hot Cell for maintenance and repair.

Rationale: A modular system allows the module to be brought to the Hot Cell where repair and maintenance can be more practical. This approach is serving ISAC well.

RS 26. Modules (including the target module) shall make use of common systems to limit complexity.

Rationale: This will make for more efficient production assembly, maintenance and operation.

RS 27. The AETE and APTW target modules should be interchangeable.

Rationale: This will allow a greater flexibility and potentially reduce the need for spares.

RS 28. The height of each module shall be compatible with clearance between the maximum lifting height of the crane hook and the floor of the ARIEL Target Hall

Rationale: The Modules must clear the shielding for transport to the hot cell. Details of the assumed height stack-up is provided in Figure 6 of the *ARIEL Target Hall Remote Handling Crane Requirements Specification* (12).

RS 29. Each module, other than passive shield plugs, shall fit in the Hot Cell (13).

Rationale: Modules containing equipment that may need service or repair must fit in the Hot Cell for the repair to take place.

RS 30. Each module shall have guiding features and maintain a nominal clearance, between the modules and the void into which they are inserted, of 9.5 mm (3/8”) on all sides.

Rationale: To ensure the modules can reliably be inserted remotely into AETE, the minimum clearance between TM2 and the ISAC Target Stations has been duplicated in this requirement. Vessel= 33” x 33” Module = 32.25” x 32.25”; Gap = (33 - 32.25)” / 2 = 0.375”. Reference drawings: ITA0042D, ITA2007D. The gap may be smaller where the insertion is guided.

RS 31. There shall be no parts protruding beyond the insertion guides. If a clearance gap is used, all protruding features must be designed not to interfere with the module insertion or extraction.

Rationale: This is a lesson learned from ISAC.

RS 32. The mounting subsystem should be modular in design to allow for upgrade of the Target Vessel, Converter, and Ion source for higher power operation.

Rationale: The target and the systems the target is mounting to will be designed to meet the requirements of phase I (β-NMR). However, the intention is to incrementally upgrade the targets to 100 kW with this module.

RS 33. All joints in the cooling system shall be evaluated for reliability. The evaluation must consider how manufacturing, inspection and long term operation affects failure rates.

Rationale: A major source of failure for the ISAC facility is water-leaks in cooling-line joints in vacuum. In particular, the many soldered and brazed joints are common failure points and should be avoided.

RS 34. It shall be possible to exchange a target while at the same time performing maintenance on a module in the Hot Cell.

Rationale: Based on experience from ISAC, the need for long term maintenance is expected also for the ARIEL facility. Thus is must be possible to keep a module in a maintenance Hot Cell while the target is exchanged elsewhere.

4.6 AETE Location and Connections

RS 35. The center of the target in plan-view shall be positioned at the intersection of the driver beam axis and the RIB axis, as defined in the driver beam and front-end design notes (14) (15).

Rationale: The position of the driver beam-line and RIB beam-lines are defined elsewhere.

RS 36. The Target Station shall mate with the driver beam line at the electron beamline elevation, as defined in the *Optics Design for Electron high Energy Beam Transport specification* (14)[1].

Rationale: The elevation of the connection to the beam-line is defined in another document.

RS 37. The centerline of the RIB beam line shall be at the elevation specified in the *ARIEL Front-End Design Note* (15)

Rationale: The elevation of the connection to the RIB beam-line is defined here as a reference for the design of the RIB beam-line, and is based on the ISAC offset of 3/8”. ARIEL target may be different, in which case this requirement must be updated.

[1]Elevation is in TRIUMF coordinates with 268’- 6” corresponding with the Cyclotron Mid-Plane Elevation. This elevation does not correspond with the elevation above sea level.

RS 38. The design of the Target Station shall follow the guidelines for beam line component designers specified in the *ARIEL Alignment Strategy* (16).

Rationale: The target and optics in the Target Station will be aligned by the beamlines group according to the *ARIEL Alignment Strategy*.

RS 39. The position and alignment of the target and Ion Source shall provide a beam within the beam acceptance envelope of the RIB beam line (15).

Rationale: This is required to transport the RIB beam.

RS 40. The position and alignment of the target and Ion Source shall conform to any alignment requirements of the ionization lasers (17).

Rationale: This is required to laser ionize the isotopes. A line of sight is required for the laser to enter the target and ionize the isotopes for extraction.

RS 41. The position and alignment of the target and converter must be made such that it can accept the electron beam with the variability and stability of beam position as defined in the *ARIEL Top Level Requirement* (1), release 2.

Rationale: Misalignment of the driver beam with respect to converter and target may result in unsafe conditions and/or reduce RIB yield.

4.7 Cooling System

Detailed requirements of the cooling system can be found in *ARIEL High Active Water Package Requirements Specification* (18).

The ΔT that the Target Module must be designed to work with is to be determined. An initial analysis indicates the limit could be as low as 15 °C (19). The return temperature in the ISAC facility is limited to 50 °C, based on the polymer tube used to pass the coolant off the high voltage plane while mitigating current leakage through the coolant. Electrical resistance requirements on the low conductivity water may put further restrictions on this temperature[2]. Determining the temperature limit must be in consultation with the design of the high-active cooling system (WBS 1.5.3) (18).

RS 42. AETE station shall be capable of maintaining the components inside the Target Station at or below their design temperature with total heat input (beam plus heating current) of 120 kW.

Rationale: The electron linear accelerator (LINAC) in phase 3 will deliver 100 kW beam power, adding 20 kW for the Target Station heaters (conservative upper limit based on ISAC experience).

RS 43. Components that are part of the AETE high active cooling system shall not combine materials that pose corrosion and electrolysis issues, such as combining Al and Cu.

[2] Ref Table II in (22)

Rationale: The chemical compatibility of materials in the cooling circuit must be chosen to mitigate corrosion or other electrochemical interactions between components. To meet this requirement requires coordination with the design of the low conductivity high active cooling system (18).

RS 44. The AETE high active cooling system shall be able to handle up to 20% of the total electron beam power directly deposited in the water.

Rationale: Water cooling of parts close to the electron interaction point will cause direct absorption of electrons in the water, which causes radiolysis and activation. The high active cooling system must be able to deal with resulting gases and radioactive species.

RS 45. Beam energy not stopped in the target shall be captured and dissipated to prevent heating of shielding or other structures downstream of the Target Station.

Rationale: The heat input into the system must be accounted for to prevent unexpected thermal effects in the shielding.

RS 46. AETE shall require a supply of low conductivity water, with water resistivity determined from the tolerable leakage current given the high voltage bias at the maximum return temperature and with wetted materials compatible with low conductivity water.

Rationale: The water must be brought from the ground to the high voltage plane with a sufficiently high resistance to prevent excessive leakage current.

RS 47. The Target Station shall be equipped with a system allowing remote actuation of the valves for purging and filling the Target Module cooling system.

Rationale: It is expected that cooling valves will be located in high radiation fields, and will need to be actuated as part of various routine operation and maintenance tasks. To avoid unnecessary personnel dose and facilitate fast target-exchange turn-around, remote actuation is expected to be necessary.

4.8 Nuclear Ventilation

RS 48. The target station shall have a secondary confinement envelope that prevents the migration of radioactivity into any area that is accessible during operation.

Rationale: To protect personnel from the radiation hazards.

RS 49. The Target Station shall include functionality to purge gas present during operation to the nuclear ventilation with dry air, following a decay period, if necessary.

Rationale: The nuclear ventilation both removes activated air and maintains the required zoning depression between adjacent zones. To satisfy the top-level requirement specification regarding the simultaneous RIB delivery (1)

RS 50. The AETE nuclear ventilation zoning shall ensure the bulk air flow is in the direction from the Service Space to the Beam Line elevation.

Rationale: To ensure that air flow-from the less active Service Space[3] above into the more active areas at the beamline.

RS 51. The nuclear ventilation zoning shall be maintained during the removal and installation of modules.

Rationale: Depending on the shape and size of the modules, air may be forced out or drawn into the void where the module is located.

4.9 Vacuum System

RS 52. The ARIEL Target Station vacuum system shall offer pumping speed and conductance to reach an operating base pressure low enough to prevent degradation of the target container within the expected length of operation, maintain ionization efficiency, have a mean free path sufficiently long to prevent interactions with residual gases before entering the RIB transport section and not compromise the vacuum of these sections. The pressure shall be maintained with the expected outgassing load at 100 kW electron beam power and additional resistive heating of conductors, target, ion source, etc., to be determine in a design study.

Rationale: Contrary to ISAC where the power deposition from the 50 kW beam is at maximum ~15 kW in the target with the ARIEL electron beam the full beam power is deposited inside the converter, target and heat-shield, inside the containment box under vacuum. The interaction of the scattered electrons and photons may produce high out-gassing. The ARIEL target module pumping will have to be sized accordingly. A design study must be completed to determine the outgassing rate in the containment box and leak rates from gas leaks (gas supply for molecular beams and FEBIAD ion source) to adequately size the vacuum system. As a reference, ISAC operates (measured at PNG1) around 5E-6 to 1E-5 Torr (mean free path of a few meters).

RS 53. AETE vacuum shall initially be separated from the driver beam line vacuum by a replaceable physical barrier, e.g. a “gamma window”.

Rationale: The driver beam-line must be protected from contamination spread, particularly in the event of unintentional target vaporization.

RS 54. It shall be possible to isolate the vacuum of the electron beam line and the RIB beam line from the vacuum of the vessel used to replace the target.

[3] The area on top of the Target Modules where services are connected.

Rationale: This preserves good vacuum conditions in the remaining part of the system and may keep the required pumping time at a minimum.

RS 55. The vacuum envelope of the vessel used to replace the target shall allow for an independent pumping path and pumps to bring the vacuum back down to a level where it will not compromise the vacuum of the remaining vacuum systems when the vacuum envelopes are reconnected.

Rationale: This preserves the vacuum condition in the remaining vacuum system.

RS 56. Each isolatable vacuum envelope shall be equipped with vacuum gauges to measure the vacuum from atmospheric pressure down to at least 1 decade below the vacuum requirement of that envelope. Dual filament gauges should be used to simplify maintenance and minimize down-time.

Rationale: To verify that the vacuum requirement is met at all times.

RS 57. The vacuum gauges used shall be capable of operating at the expected radiation level at its installed location.

Rationale: Radiation can interfere with electrical and magnetic components used in vacuum gauges.

RS 58. The design of vacuum volumes shall conform to the *TRIUMF Vacuum Specification* (20)

Rationale: TRIUMF has developed best practices and requirements for vacuum system.

RS 59. AETE vacuum and optics shall be connected to the RIB beam line vacuum.

Rationale: The RIB do not have sufficient energy to pass through a thin window. The vacuum envelope of the target containment box and the heavy ion beam line must be continuous without any obstruction.

4.10 AETE High Voltage System

RS 60. AETE shall fulfill the high voltage requirements of *ARIEL Ion Sources and Ion Beam Extraction Optics Requirements Specifications* (6). To fulfill this requirement reliably, it shall be designed to 75kV.

Rationale: A design study of the high voltage service in the target module is necessary, and the features relevant to high voltage must be determined through analysis by a high voltage expert. The required acceleration voltage is 60 kV. A design “safety factor” can be estimated from ISAC based on experience with the target modules. The target modules operate reliable at about 10% below 60 kV. Doubling this safety factor and rounding up results in a required design voltage of 75 kV.

RS 61. The services required by the Target Station are defined in *ARIEL Electron Target Module Services List* (21) and shall be implemented in the design.

RS 62. All high voltage components including, terminals, conductor chase, conductor feed-through, and target module, shall be inside a grounded, lockable enclosure.

Rationale: To protect personnel from high voltage electrical hazard during operation, and to minimize electrical interference with external equipment.

RS 63. It shall not be possible to open/remove the enclosure until the power supplies have been de-energized and the system properly grounded.

Rationale: To protect personnel from the electrical hazard

5 Environmental Conditions

The target station is expected to be housed in a controlled environment at all times. The ambient conditions are assumed to be:

Temperature: 15 to 35 ºC

Humidity: 10 to 90%

Pressure: 1 atm

6 References

The document version at the time of writing has been included in the list of references where available.

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