ARIEL RADIOACTIVE GAS MANAGEMENT SYSTEM

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Abstract

The Advanced Rare Isotope Laboratory (ARIEL) facility expands TRIUMF's isotope production by adding two new target stations operating in parallel with the existing infrastructure, enabling high-intensity Radioactive Ion Beam (RIB) production. At the core of this facility, a complex vacuum system is designed to maintain the conditions required for RIB production while safely managing radioactive gases generated during beam-material interactions. The activated gases from the target and RIB modules are continuously evacuated and transferred via a radioactive gas management system to storage tanks for controlled decay. The radioactive gas management system is designed to support parallel and independent target station operation, prevent cross-contamination between exhaust streams, enable future scalability, and provide fault tolerance to ensure uninterrupted operation in the event of equipment failure. This system incorporates controlled gas recirculation and sampling capabilities to ensure the collection of a uniform sample for radiological assessment prior to release to the nuclear ventilation system. In addition, this system is operated and controlled remotely, enabling remote control of devices, data archiving, and implementation of interlocks for machine protection. This work presents the key design features and operational principles of the ARIEL radioactive gas management system.

INTRODUCTION

The vacuum system for the ARIEL electron and proton stations is designed to maintain a high-vacuum environment while managing radioactive gases released during operation. These highly radioactive gases are continuously evacuated at a rate that ensures the required vacuum level during operation and are transferred to decay storage tanks via the ARIEL radioactive gas management system. This system allows operators to direct gases to designated storage volumes for controlled decay [1]. Turbo-molecular pumps handle the continuous evacuation of the released gases during operation, while hermetically sealed and oil-lubricated backing pumps manage their exhaust. The exhaust from these backing pumps is routed to the ARIEL radioactive gas management manifold via the vacuum pump manifold, which will then be directed into pre-evacuated storage tanks.

Once stored, the gases undergo radioactive decay. After a designated period, a sample is drawn from the decay tanks through the sampling system for radioactivity assessment [2]. If the sample meets regulatory safety requirements, then the radioactive gas management system evacuates the decay tank and releases the gases into the Nuclear Ventilation System (NVS) for controlled atmospheric discharge [3]. A schematic representation of the ARIEL radioactive gas management system and its interfaces with other systems is provided in Fig. 1.

The design challenge is multidisciplinary. The system must maintain leak-tight vacuum service, be compatible with a radiation environment, support remote operation, minimize contamination spread, and remain maintainable in a constrained installation envelope. It must also support operational modes such as tank selection, pre-evacuation, gas transfer, sampling, tank evacuation, and discharge to NVS after verification that stored gases meet release requirements.

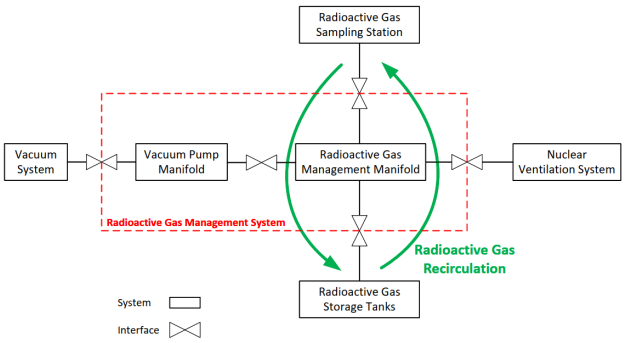

Figure 1. Schematic illustration of the radioactive gas management system interfacing and interacting with other systems.

CONCEPTUAL DESIGN

ARIEL Radioactive Gas Management P&ID

The conceptual design of the ARIEL radioactive gas management system is built around two major assemblies: i) the radioactive gas management manifold and ii) the pump manifold. This system is designed to safely and efficiently control the storage, monitoring, and release of radioactive gases. Figure 2 presents a high-level P&ID, showing the main equipment layout, process connections, and control interfaces. The system can be operated remotely and is connected to multiple decay storage tanks, which provide dedicated storage volume for radioactive gas decay.

A key function of the system is the ability to select a specific decay tank for gas storage. The system also allows operators to collect gas samples for radioactivity assessment, confirming that each stored gas batch satisfies safety and regulatory requirements before release to the environment.

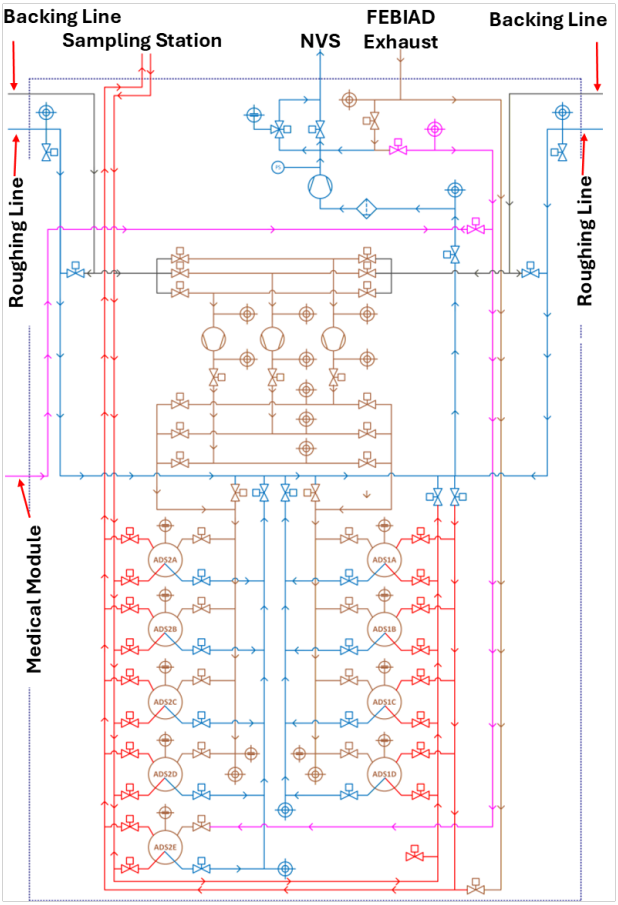

Figure 2. High-level P&ID of the ARIEL radioactive gas management system [4].

All major operations, including tank selection, vacuum system control, and gas sampling, are managed through the Experimental Physics and Industrial Control System (EPICS). This centralized control platform supports real-time monitoring, remote operation, and automated control of the radioactive gas management process.

Materials and Instrumentation Selection

All components of the ARIEL radioactive gas management system are expected to operate in a radiation environment. Therefore, all materials and components should be as radiation resistant as practically achievable. Components such as mechanical pumps, valves, gauges, and cables that may degrade in a radiation field or components that require annual calibration and inspection should be installed in a way that can be easily accessed. Considering the complexity of this system, priority is given to metal seals, as practically achievable, to ensure minimal to zero leakage from the system.

Control System

This system is operable and controlled through EPICS, which is PLC-based and allows the following activities:

- Remote operation of the pumps, gauges, and valves,
- Record and archive data collected by the gauges,
- Implementing interlocks to provide and maintain a level of machine protection during operation, and
- Upgradability and expandability of the control system.

GENERAL LAYOUT & LOCATION

The system is installed in the ARIEL Target Hall. The radioactive gas management manifold is located below a false floor to optimize the available space, while removable floor panels provide access for calibration, maintenance, and component replacement. The vacuum pump manifold is mounted on the wall above the backing and roughing pumps located on the false floor. This arrangement reduces congestion around the decay tanks and keeps equipment requiring maintenance more accessible.

Figure 3 shows the developed layout using 3D modelling to evaluate physical envelopes, installation clearances, routing, maintenance access, and coordination with adjacent ARIEL systems. This step was important because several components require periodic inspection or calibration, including gauges, valves, cables, and pump-related items. The design balances compact installation with the need for safe access in a radiation-controlled environment.

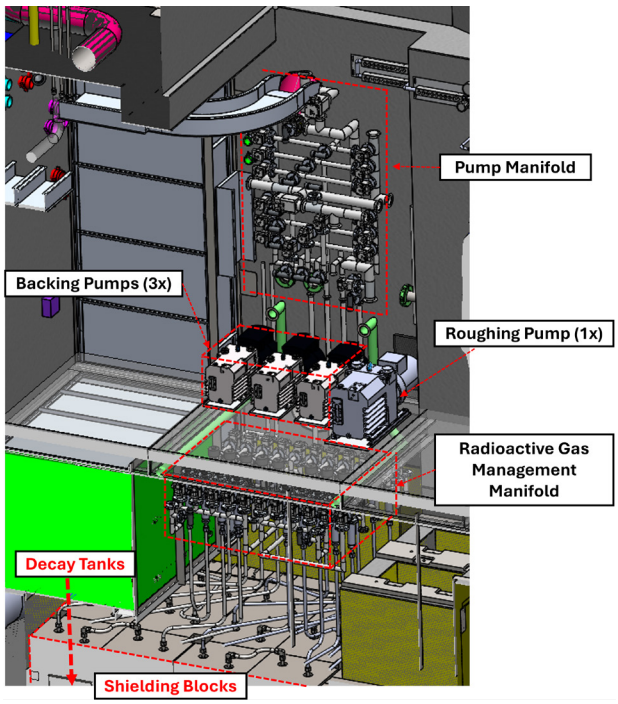

Figure 3. 3D model showing the general layout of the ARIEL radioactive gas management system with the decay tanks.

SYSTEM INSTALLATION

The ARIEL radioactive gas management system implementation included the installation of the radioactive gas decay storage tanks, assembly of the radioactive gas management manifold, pump manifold, and completion of piping installation and testing activities.

The installation is an ongoing effort; however, the following key implementation activities have been completed thus far:

- The storage tanks have been installed with the required shielding and piping, as shown in Fig. 4,
- The radioactive gas management manifold was assembled and bench tested before installation in the ARIEL Target Hall, as shown in Fig. 5 (a), and
- Following a successful bench test, the manifold and associated piping to the decay storage tanks are installed and tested to verify proper assembly, system integrity, and functionality, as shown in Fig. 5 (b).

Figure 4. (a) Decay storage tank installation; and (b) decay tanks with shielding blocks.

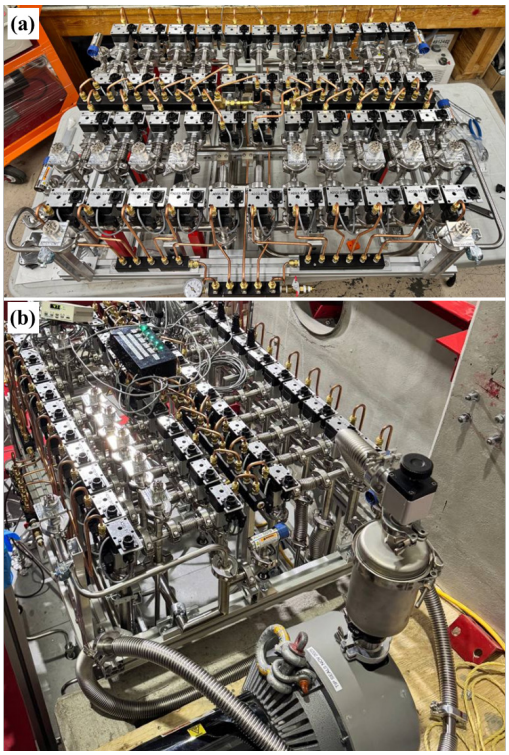

Figure 5. (a) Assembly of the radioactive gas management manifold, and (b) piping installation and testing.

CONCLUSION

The ARIEL radioactive gas management system is a key support system for the safe operation of ARIEL target stations. It provides a controlled pathway for gases exhausted from the vacuum system to be stored, sampled, and discharged through the NVS when acceptable. This system supports containment, operational flexibility, maintainability, and future expansion, which offers a robust solution for radioactive gas management in modern accelerator facilities.

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