

UPGRADE AND OPERATION OF THE ATLAS RADIATION INTERLOCK SYSTEM (ARIS)*

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Abstract

ATLAS (the Argonne Tandem Linac Accelerator System) is a superconducting heavy ion accelerator which can accelerate nearly all stable, and some unstable, isotopes between hydrogen and uranium. Prompt radiation fields from gamma and or neutron are typically below 1 rem/hr at 30 cm, but are permitted up to 300 rem/hr at 30 cm. The original ATLAS Radiation Interlock System (ARIS), hereafter referred to as ARIS 1.0, was installed 30 years ago. While it has been a functional critical safety system, its age has exposed the facility to high risk of temporary shutdown due to failure of obsolete components. Topics discussed will be architecture, hardware improvements, functional improvements, and operation permitting personnel access to areas with low levels of radiation.

THE ATLAS FACILITY AND ARIS

ATLAS

ATLAS is a DOE user facility [1] located at Argonne National Laboratory outside Chicago, Illinois in the United States. ATLAS has three ion sources: two ECR sources, and an EBIS source used as a charge breeder coupled to the CARIBU radioactive ion source [2]. ATLAS can deliver beams consisting of stable and unstable isotopes from protons through uranium. Superconducting Radio Frequency (RF) cavities accelerate ions from 10 to 20 MeV/A for light mass ions. During a typical year, ATLAS hosts several hundred users from as many as a dozen countries. Experiments at ATLAS range from 2 days to a month, with the average length being a week. At the end of which the ATLAS operations staff will reconfigure the facility and tune a new beam of differing mass, energy, and current, all in under 24 hours. Despite the constant reconfiguring for new experiments and regular maintenance, ATLAS delivers ~6000 operational hours per year.

The ATLAS operations group and Argonne Physics Division Radiation Safety Committee have developed controls to allow users and staff access to accelerator and experimental areas with low-level radiation (< 5mrem/hr @ 1m from source), including areas which may have beam present. Given the wide range of ion species, energies, and various experimental end stations, this level of facility access is vital for setup and debugging new experiments in 24 hours or less.

The main safeguard against unnecessary radiation exposure includes a combination of training, administrative controls, and shielding. ARIS is an engineered control (safety system), designed to protect personnel from radi-

ation exposure should the other safeguards fail. ARIS serves as active monitoring of radiation in 16 experimental and accelerator areas as well as adjacent areas, these areas are referred to as ARIS-controlled areas. ARIS-controlled areas are equipped with radiation monitors, interlocked gates, and area status displays that are connected to ARIS. Access to these areas is allowed, provided certain conditions are satisfied and the area is in the correct access state (access states will be discussed in greater detail later).

ARIS 2.0

ARIS 1.0 has been in operation since August 1st, 1992 [3], during which time there has been no accidental personnel radiation exposure. However, the system's age has presented various limitations concerning system improvements and expansion. Additionally, an upgrade was needed to avoid accelerator operation interruptions caused by possible malfunctions of outdated components of the ARIS 1.0 system and to add functionality to the system that augments administrative controls with engineered controls. ARIS 2.0 was developed as an extension and upgrade of ARIS 1.0 system and began service on June 22nd, 2021. Below is an overview of ARIS 2.0 architecture, operating principles, and improvements over ARIS 1.0.

Architecture

The ARIS system uses a computer-PLC network composed of the following nodes (Fig. 1) [4]:

- A Programmable Logic Control computer system, the ARIS PLC, which has sensing, control, and some informational functions.
- A Linux-based PC, the ARIS Linux PC, which performs only sensing, informational, and logging/recording functions.
- Ancillary Linux PC, which performs informational and logging/recording functions.

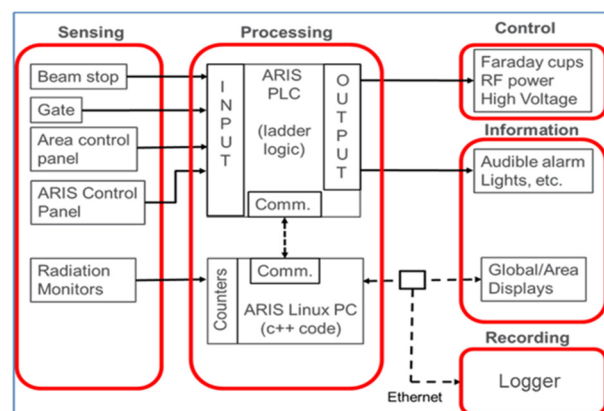


Figure 1: Schematic overview of the ARIS computer-PLC network.

* This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under contract number DE-AC02-06CH11357

Hardware Improvements

ARIS 2.0 includes several hardware improvements over its predecessor, the two most notable of which are an improvement in the hardware used for the processing side of the system architecture. The ARIS 1.0 PLC system was a SY/MAX manufactured by squared. This was replaced with an M580 safety PLC by Schneider. The new PLC has a Safety Integrity Level (SIL) of 3 while ARIS 1.0 was manufactured before SIL ratings were in use. Sensing of the radiation monitors, data logging, and information for area and global displays was initially performed via an IBUS computer with counting cards. The IBUS computer was replaced with a Linux PC and new counting cards to measure counts (pulsed outputs) from radiation monitors. Additionally, the ARIS 1.0 IBUS computer used serial communication to send information to the data logger and displays. The new Linux PC hosts servers with the displays and logger acting as clients which receive data and information via ethernet communication. This system provides a significant boost in speed to the system.

Area displays and global displays were replaced with new displays which use Raspberry Pi's, which serve as a client to the ARIS Linux PC.

ARIS 1.0 used a dot matrix printer to print off information regarding radiation monitor counts, changes to access states and changes to beam paths. This was replaced with a Raspberry Pi which tracks far more information and graphically displays it in the ATLAS control room on a Grafana dashboard.

Functional Improvements

ARIS 2.0 includes several functional improvements over ARIS 1.0. It is more user-friendly, reduces downtime, and improves the facility's overall safety.

ARIS 1.0 monitored 13 areas within the ATLAS facility and was only capable of monitoring areas on the beam path; adjacent areas were not monitored and thusly were required by administrative controls to be locked until a health physics technician could perform a survey of the area to assess radiation levels. ARIS 2.0 expanded the number of monitored areas to 16. Additionally, all areas are simultaneously monitored, removing the frequent need for surveys from health physics technicians.

Each ARIS monitored area previously had an area display at the main entrance to that area; with ARIS 2.0, we added area displays to every entrance from within the building (not from outside) and significantly increased the information displayed. This increased information helps operators more quickly diagnose problems and gives ATLAS staff a better idea of the potential radiation hazards in that area and the effect of opening a gate will have on the access state.

Previously, ARIS had one global display, which was located in the ATLAS control room. Two other global displays were added to high-traffic areas throughout the facility; this provides information on the accessibility of ARIS-controlled areas without the need to contact the control room.

ARIS 2.0 has a consistent set of logic to change each area from one access state to another, whereas previously ARIS-controlled areas had their own unique logic. This consistent set of rules across all areas reduces training time for operators, makes diagnosing problems more straightforward, and sets a standard - should ARIS ever be expanded to include additional ARIS-controlled areas.

As mentioned above, the new ARIS logger tracks a wealth of information not previously tracked, and this information is stored on a computer, whereas it was originally printed out. This change makes it far easier to look at current and historical data.

Access to ARIS-Controlled Areas

An advantage of the ATLAS facility is access to one of 18 areas (Fig. 2) [4] with the possibility for low levels of radiation. Each area is equipped with interlocked gates or access gates at each entrance. These gates have redundant sense switches that allow ARIS to detect if the gate is open or closed. ARIS-controlled areas fall into two categories: radiation generating, and adjacent areas.

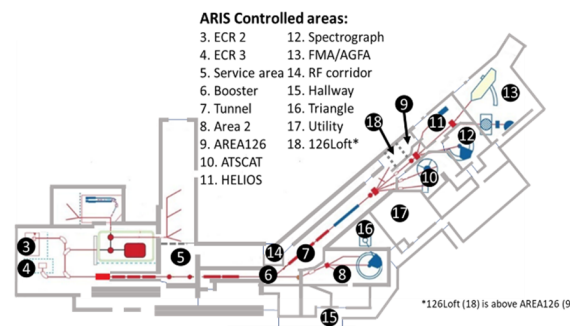


Figure 2: ATLAS floor plan indicating ARIS-controlled areas. 16 areas are shown but counting starts at 3 as we plan to add 2 additional areas.

Radiation generating areas are divided into two sub-categories, beam areas, and RF areas. An RF area is any area with accelerating structures that may have RF power applied to them. Beam areas are anywhere in which beam may potentially be delivered into the area. The ATLAS facility has several forks in the beamline, which lead to different target areas. The beam can only be delivered down one path to one target area at a time. Each fork in the beam path is defined by a single open beam stop at the exit of the fork. An adjacent area can be changed to a radiation generating area by either putting the area on the beam path through the opening of an ARIS beam stop or requesting RF power be applied to the accelerating structures.

Adjacent areas are any areas adjacent to a radiation generating area. These areas are not on the beam path and do not have any RF cavities on that could potentially produce radiation. Radiation detected by monitors is scaled to account for monitor efficiency and distance from source. Radiation monitors in adjacent areas are scaled differently from monitors in radiation generating areas. For example, they are scaled to assume the highest point of radiation is from the shared wall between that area and an adjacent radiation-generating area.

ARIS-controlled areas can be in one of seven different access states. The access state of an ARIS-controlled area depends on the current radiation level and past radiation history in the area. The ARIS PLC system assigns the actual ‘access state’ for an ‘ARIS-controlled area’ based on its various sensors, including radiation level information transmitted by the ARIS Linux PC. The seven areas and their associated maximum allowed radiation at 1 m distance from the source of radiation can be seen in Table 1.

Table 1: Possible Access States for ARIS Controlled Areas and their Associated Max Radiation

Access State	Max allowed radiation
Open	2 mrem/hr
Restricted Access Occupied	5 mrem/hr
Restricted Access Not Occupied	5 mrem/hr
No Access	100 mrem/hr
Locked	20 rem/hr
Inhibit	2 mrem/hr
Tripped	2 mrem/hr

Personnel are only permitted in ARIS-controlled areas in the Open, Restricted Access Occupied, Inhibit, and Tripped States. ATLAS operators can change the access state of an ARIS-controlled area from an Open or Restricted Access Occupied state to a Restricted Access Not Occupied or Locked state via a sweep (search and secure) procedure. This same procedure can be used to change from a Tripped or Inhibit state to a Locked or Restricted Access Not Occupied state. This procedure is executed by pressing an interior reset button, walking a specific path through the area, closing the access gate, and pressing an exterior reset button.

In the Inhibit state, ARIS inhibits all radiation sources in the area from beam by inserting an ARIS-controlled Faraday cup (Fig. 3) [4] and RF-generated sources by deactivating relays to the power supplies. Inhibit states are the result of the regular operation of the interlock system. In the Tripped state, ARIS uses the same means to stop all radiation sources in the area, both beam-generated and RF-generated, in response to an unwarranted occurrence. The Tripped state also inhibits beam upstream via the F1 cup (Fig. 3). An occurrence of a Tripped state must be investigated and reported by the ATLAS operators.

An ARIS-controlled area can only be set to Open if the following criteria are met: the area is an adjacent area, radiation in the area is below 2 mrem/hr and has been below 2 mrem/hr for the last 30 minutes. In this state, ARIS permits free access. If the radiation goes above the maximum allowable (2 mrem/hr), ARIS will set the area to the Inhibit state.

In the Restricted Access Not Occupied state, low-level radiation may be present in the area, but the system has verified that the area is absent of personnel via a valid sweep procedure. The area will remain in this state so long as no access gates are opened, and the radiation remains below the max allowed listed in Table 1.

ARIS Controlled Faraday Cups

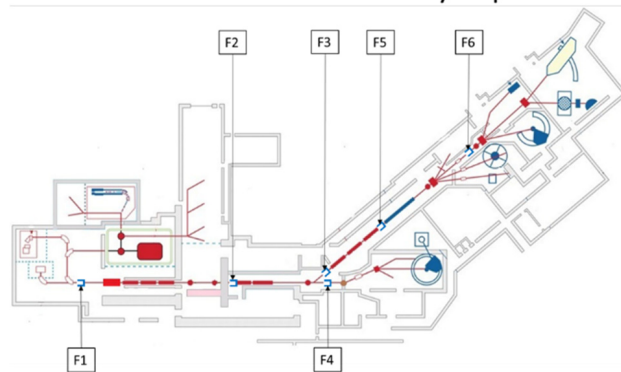


Figure 3: Location of ARIS-controlled Faraday cups.

If an access gate is opened after the area has been swept into a Restricted Access Not Occupied, the area will switch to Restricted Access Occupied. In this access state, ARIS assumes personnel is present in the area. Low-level radiation may be present, but ARIS permits access without inhibiting RF or beam so long as the radiation is below the max listed in Table 1 for this state. Should the radiation exceed the max allowable while in this state, the area will switch to the Inhibit state.

If an ARIS-controlled area is in the Restricted Access Not Occupied state and the radiation exceeds the max allowed for this state, the area will automatically enter the No Access state. The system has verified that the area is absent of personnel since a sweep procedure was required to enter the Restricted Access Not Occupied state, and no access gates have been opened. If the max allowable radiation is exceeded, the area will be placed into the Tripped state.

ARIS-controlled areas can be set to the Locked state after a sweep procedure, and additionally, locking the covers on the access gate handles so they cannot be opened from the outside. The area will be placed in the Tripped state if the radiation exceeds the max allowable or if an access gate senses it has been opened.

Additionally, for the Open and Restricted Access Occupied states, ARIS only allows an accumulated dose, from the previous 8-hour period, of 20 mrem. Anything above this and ARIS will set the area to the Tripped state.

SUMMARY

Access to radiation-producing areas is not allowed at most accelerator facilities. Since the conception of the original ARIS, the ATLAS operations group has leveraged this safety system to increase access throughout the facility and productivity. ARIS 1.0 proved successful in keeping the physics division staff’s total measurable dose below the physics division ALARA goals, and in its first year of operation (Fig. 4), starting in 2021, ARIS 2.0 has continued this trend in radiation safety all while improving operational efficiency.

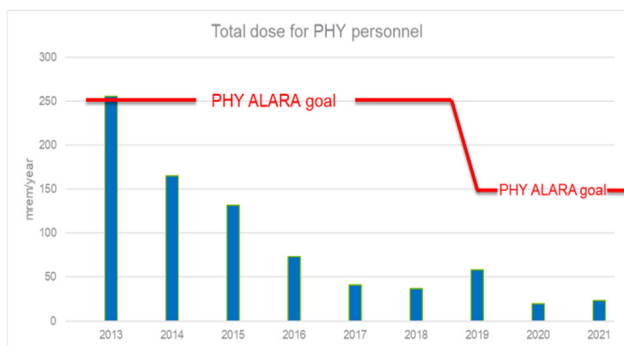


Figure 4: Dosimetry for all Argonne physics division staff.

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