Safety Assessment Document
The Physics Division ATLAS Accelerator

Version 1a

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Note: This is the only guaranteed current version of the ATLAS SAD
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This version (1a) of the ATLAS Accelerator Safety Assessment Document incorporates modifications that define and expand the boundaries of the ATLAS Facility to include several offices, work areas and storage areas associated with the accelerator.

ACRONYMS & DEFINITIONS

ALARA	As Low As Reasonably Achievable
ARIS	The ATLAS Radiation Interlock System.
Average Radiation Dose Rates	The radiation dose rate as measured in the facility by ARIS detectors is integrated over at least a one second time interval. Beam inhibits due to levels of radiation associated with dose rates in excess 0.1 rem/hr are based on a one second average. Beam inhibits because of radiation levels less than 0.1 rem/hr but that are incompatible with existing area access states are based on a 30 second average.
Beam-stop	Any object that can be struck by the beam and is thick enough to stop the beam (Faraday cups, beam-defining slits, valves, etc.)
E/A	Energy per mass number of the accelerated ion. A quantity expressing the ratio of beam energy (E), in millions of electron-volts (MeV) and the atomic mass number (A). The unit of this quantity is MeV/u, where u implies unit mass number. The atomic mass number A, an integral number as used in this document, is also called the ion mass number and the nucleon number
ECR	Electron-Cyclotron resonance
ERL	Estimated Radiation Level. The dose rate (in mrem/h at 1 m) generated by the beam striking any unshielded surface 90º from the beam direction. This dose rate is estimated by calculations and confirmed by measurement with the same beam species and at the applicable full energy, and extrapolating it to the maximum beam current for a given experiment. This dose rate is calculated at 90° because it is an angle readily accessible for measurements at ATLAS in all cases.
MCI	Maximum Credible Incident
MeV	Million Electron Volts. A measure of particle energies. One eV is equal to the amount of energy one electron acquires by accelerating (from rest) through a potential difference of one volt. 1 eV = 1.602 x 10^{-19} Joule
PBCS	Physical, Biological and Computing Sciences
PII	Positive Ion Injector
pnA	Particle nanoampere. The electrical current in nanoamperes (10^{-9} A) that would be measured if all beam ions were singly charged. 6.25×10^{9} ions/second
Secondary Beam	A beam of exotic nuclei produced at ATLAS through a nuclear reaction of a primary beam with a target. Following the production, the secondary beam is transported by the accelerator system and focused on a target for an experiment.

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1. Introduction and General Description of the ATLAS Accelerator

1.1. Objective of Document

This Safety Assessment Document is written to analyze those hazards that have the potential to exist at the ATLAS accelerator facility and to describe the engineered and administrative controls in place to mitigate those potential hazards. The document is based on DOE Order 420.2A, "Safety of Accelerator Facilities" and the Accelerator Safety Procedures Manual.

The Safety Assessment Document encompasses the operations of the entire ATLAS facility, including the accelerator system, the beam transport equipment and the experimental stations that use the beams produced by the facility, as well as the facilities and equipment used to support the above.

This analysis followed a systematic review of all possible hazards and a determination of the probability of each occurring at the facility. It included an analysis of the accident that is seen to present the worst potential harm to workers, visitors or the population surrounding ANL-E.

The Accelerator Safety Envelope (ASE) for the ATLAS accelerator was developed to ensure that hazards associated with an accident, called the maximum credible incident (described in Section 5.6), are mitigated. The ASE consists of a set of rules and operating parameters (see Section 5.1) that may not be violated.

The ATLAS facility has also developed another set of guidelines called the ATLAS Operations Envelope (see Section 5.2). One of the purposes of this set of more detailed guidelines is to ensure that the ASE is not approached. The guidelines in the Operating Envelope are based on lower limits and, thus, are more restrictive than those in the ASE.

1.2. Description of ATLAS

The Argonne Tandem-Linac Accelerator System (ATLAS) is a low-energy heavy-ion accelerator facility that was developed in several stages over 24 years. The facility evolved out of an existing, in-house 9 MV tandem electrostatic accelerator that still serves today as one of two injectors at the facility. The development at Argonne of the world's first use of RF superconductivity to accelerate ions led to the construction of the 'Booster' linac section and then to the completion in 1985 of the ATLAS linac section and the construction of new target areas to make use of the new accelerator capability. Later, a second injector for the facility, the Positive Ion Injector (PII) was put in use. Today, the PII injector consists of two ECR (electron-cyclotron resonance) ion sources that provide ions in high charge states to a 12-MV superconducting linac section. ATLAS is a DOE National User Facility.

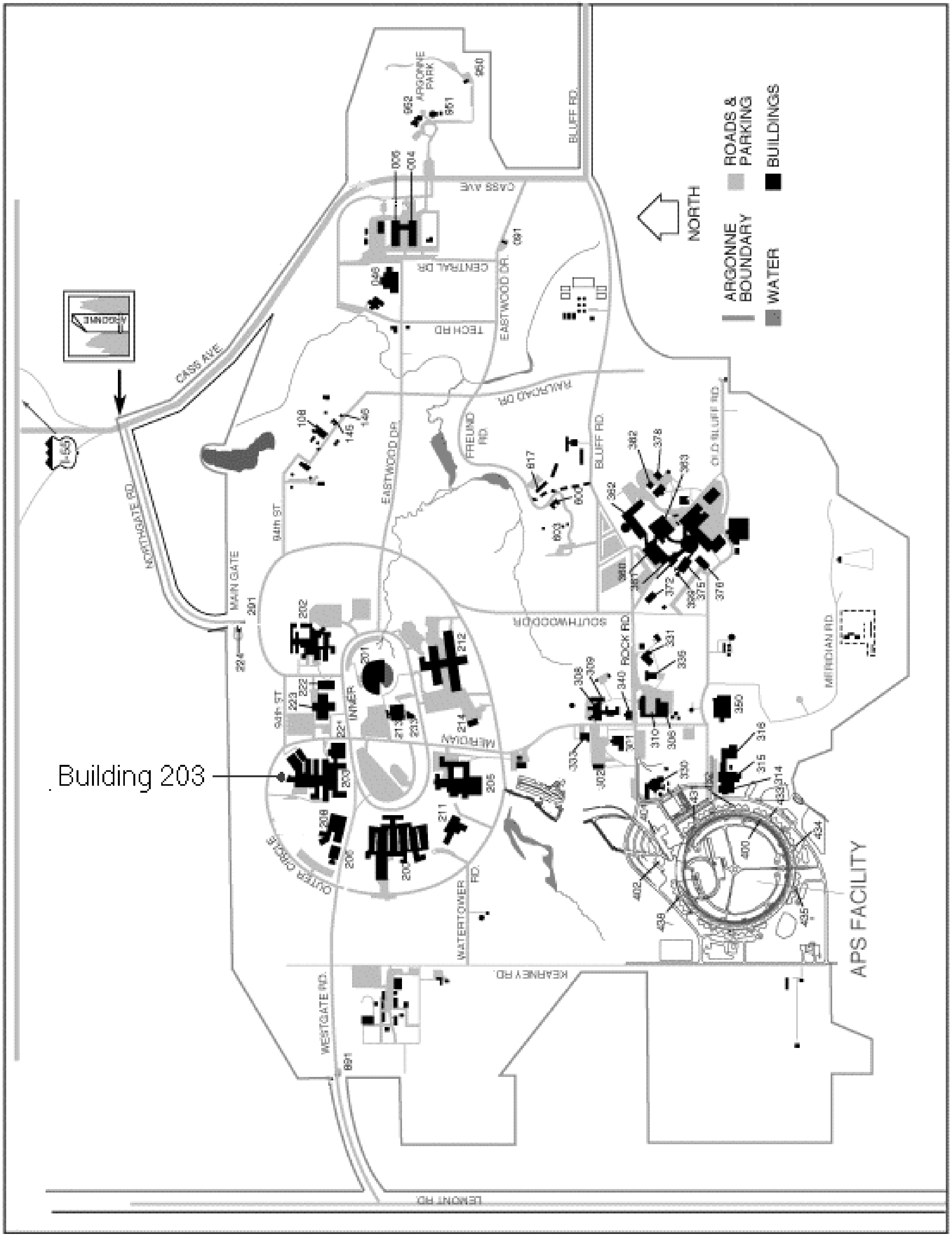

Figure 1-1

Location of Building 203

ATLAS SITE PLAN

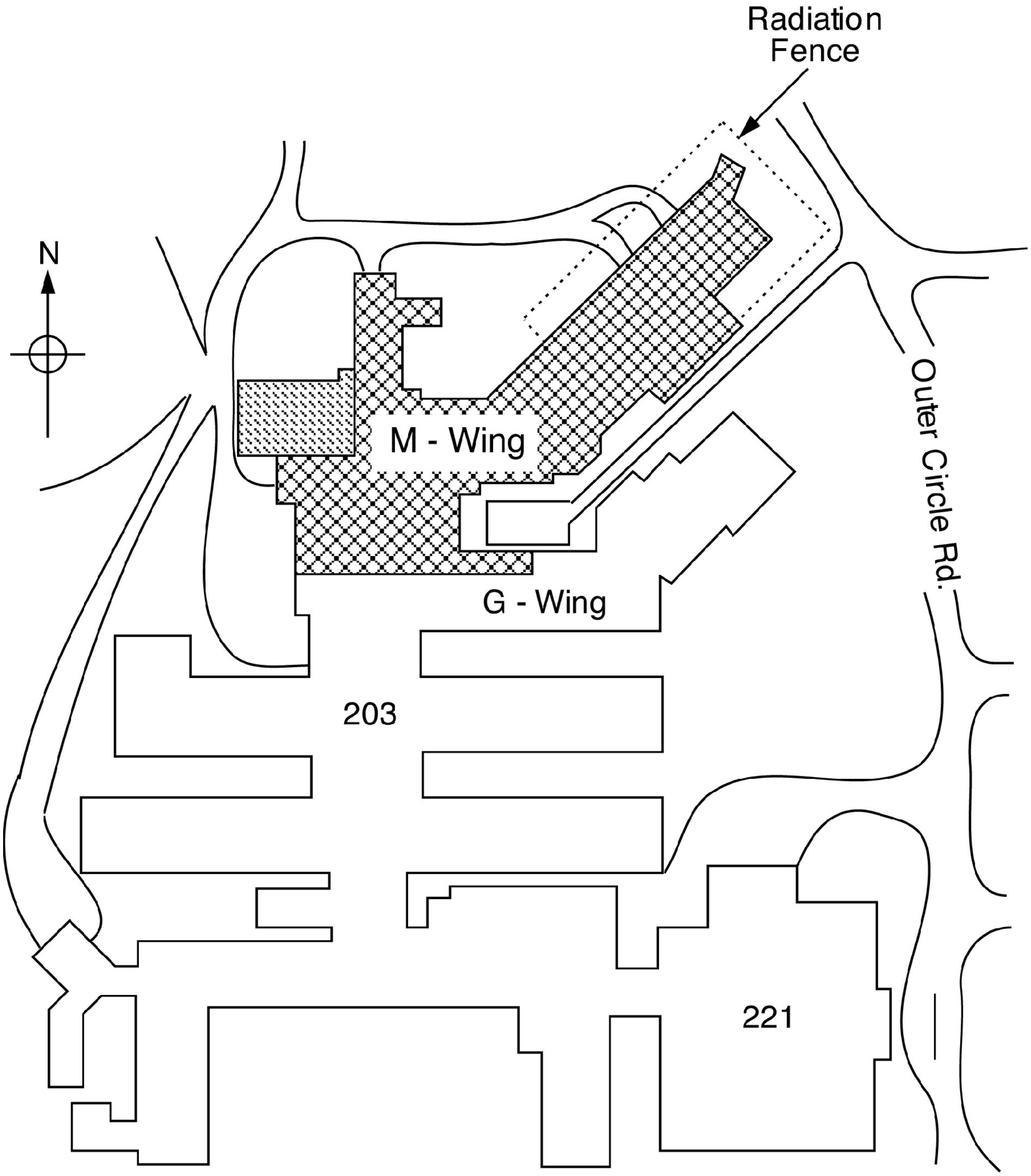

Figure 1-2

ATLAS Site Plan

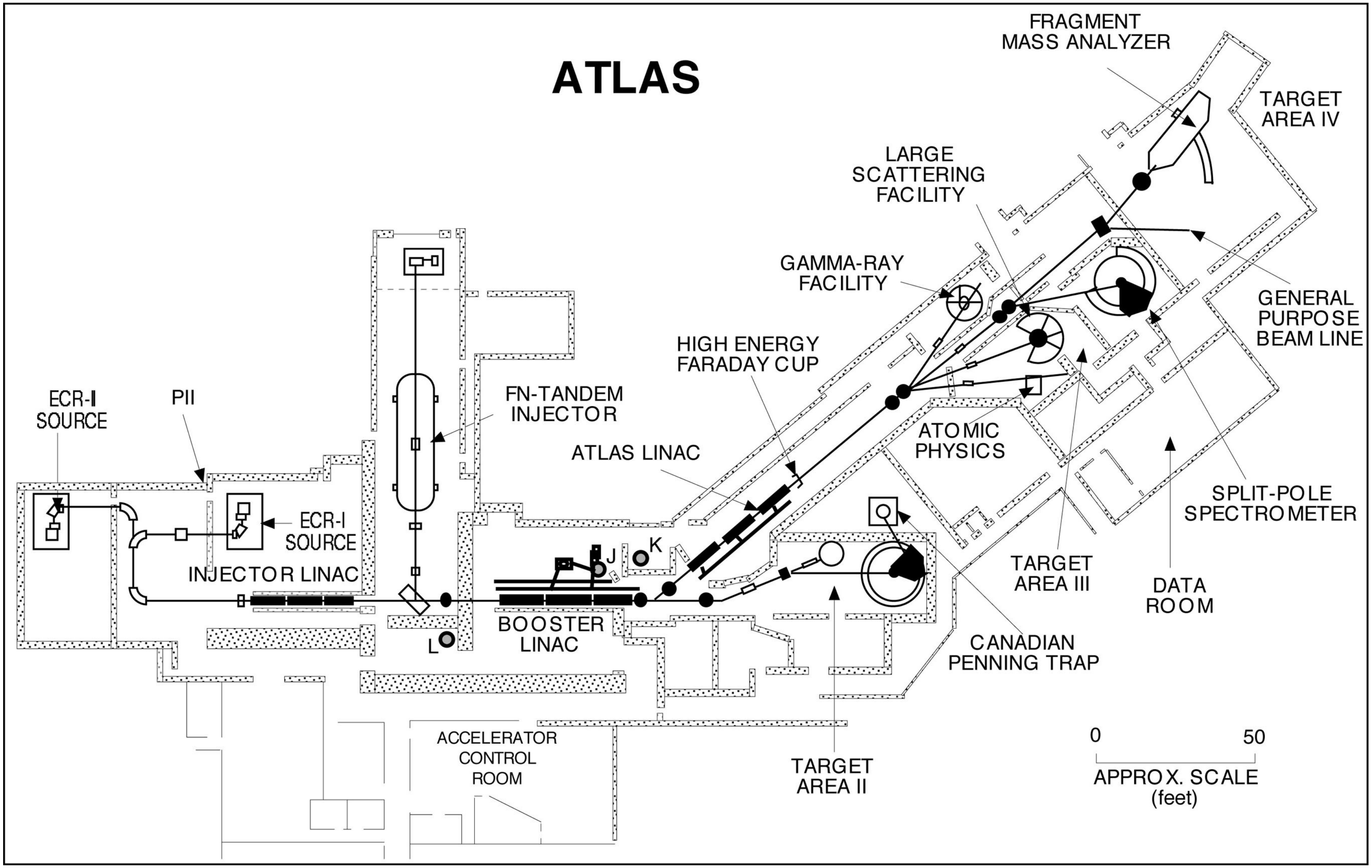

Figure 1-3

The ATLAS Accelerator

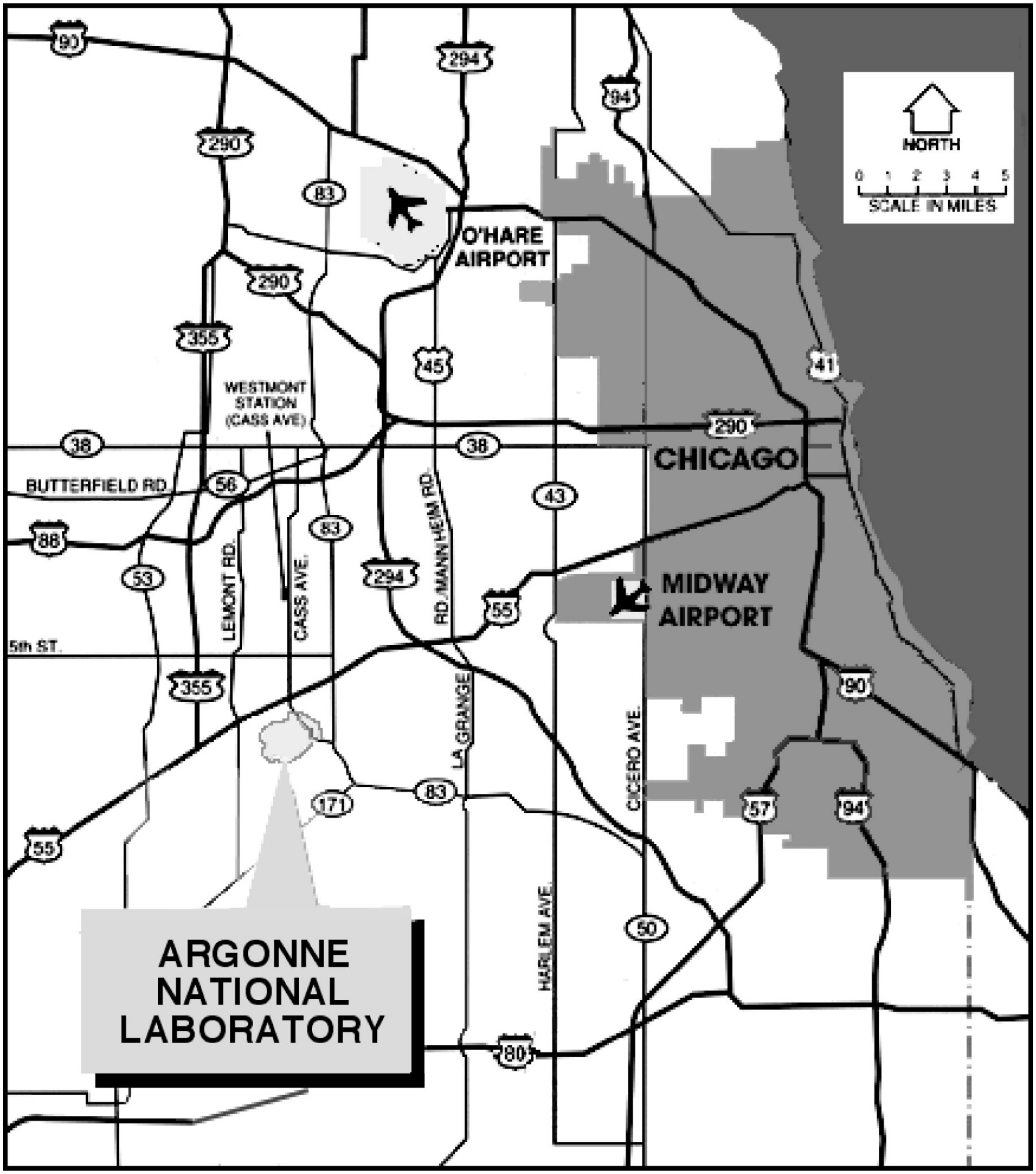

Figure 1-4

ANL-E Location

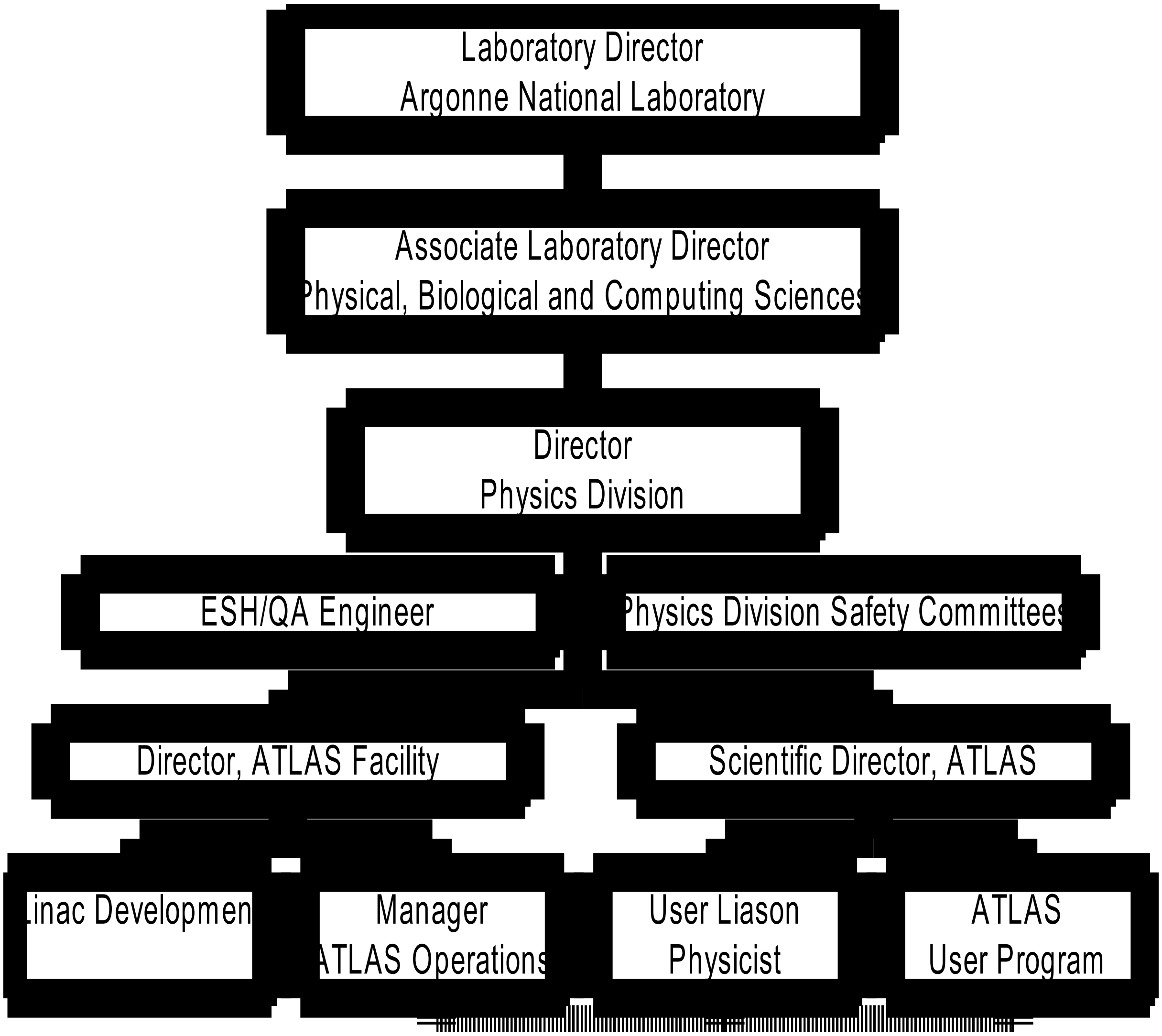

Chart 1-1

Lines of Responsibility

The Physics Division is located in Building 203, in the northwest sector of the Argonne site, as shown in Figure 1-1. The ATLAS accelerator is located on the ground floor of the M-wing in that building, as shown in Figure 1-2. The layout of the accelerator structure is shown in more detail in Figure 1-3. ATLAS can accelerate beams of nuclei of all masses, from protons to uranium. The maximum energy of these beams is less than 25 MeV/u for all ions.

In addition to the portions of the facility shown in Figure 1-3, the ATLAS Accelerator Facility consist of the following areas that support accelerator operations:

- Rooms
  - G-042 (accelerator staff office)
  - G-049 Electronics Lab)
  - G-050 (accelerator staff office)
  - G-053 (Electronics Lab)
  - G-058 (accelerator staff office)
  - G-066 (detector storage)
  - G-090 (accelerator engineering drawing storage)
  - G-096 (accelerator spare parts)
  - G-097 (accelerator spare parts)
  - G-018 (Detector Lab)
  - G-118 (Gammasphere Lab)
  - H-166
  - H-174
  - R-154 (Target Fabrication Lab)
- Storage areas ("cages")
  - For Accelerator Operations: Cages G1, G5, E1, E2 and H8
  - For Accelerator Research: Cages E3, E4, F3, F5, F7, F7B, H5, H6 and H7

The primary function of ATLAS is to provide heavy-ion beams for basic research in nuclear physics. The accelerator is operated a small fraction of the time for research in atomic physics, condensed matter physics, and occasionally for other purposes. The research activities are carried out in several target areas, as shown in Figure 1-3. These target areas house a variety of experimental equipment. The descriptions of the equipment used in these areas, as well as copies of the safety reviews conducted on the equipment, are maintained in the folder titled ATLAS Experimental Area Safety Documents, located in the ATLAS Data Room. A separate copy is maintained in the Division ESH/QA Engineer's office.

Safety is integrated into all aspects of work both within the Physics Division and at the ATLAS Accelerator. The Physics Division Safety Policy states:

"It is the policy of the Physics Division that all activities within the facilities for which the Physics Division is responsible shall be conducted in a manner such that all reasonable precautions are taken to protect the health and safety of employees and of the general public, as well as the environment."

1.3. Protection for the Public and Workers

1.3.1. Lines of responsibility at Argonne for ATLAS are shown in the organizational chart depicted in Chart 1-1.

1.3.2. Programs for the protection of the public and workers in the Physics Division include fire protection, protection against natural disasters, primarily tornados, protection from beam induced radiation and from X-ray generating machines, as well as protection from electrical, asphyxiation, mechanical, and chemical hazards.

1.3.3. Protection of the environment is assured by the proper disposal of all hazardous chemicals and/or radioactive materials and by the installed radiation shielding.

2. Summary/Conclusions

2.1. Safety Analysis Summary

This Safety Assessment Document analyses the safety issues presented by the ATLAS accelerator facility. The conclusion reached as a result of this process is that there is no compromise to the safety of employees, the general public or the environment. All potential hazards have been either eliminated or mitigated through the use of engineered and/or administrative controls. Engineered safety controls are used where necessary, such as the ATLAS Radiation Interlock System (ARIS), designed and developed to prevent any radiation exposure in excess of DOE, Argonne and Physics Division limits, as found in the ATLAS Operating Procedures and the Physics Division ALARA goal.

3. Site, Facility and Operations Description

3.1. Site and Facility Description

3.1.1. Site Description

The ATLAS accelerator is operated by the Physics Division at Argonne National Laboratory - East (ANL-E). ANL-E occupies a 1,275 acre site of gently rolling land in the Des Plaines River Valley of DuPage County, Illinois, about 35 km (22 mi) southwest of downtown Chicago, and 40 km (25 mi) west of Lake Michigan. Laboratory facilities occupy about 200 acres of the total ANL-E site area. Surrounding the ANL-E site is the 2,040 acre Waterfall Glen Forest Preserve, a greenbelt forest preserve of the DuPage County Forest Preserve District. Nearby highways are Interstate 55 to the north, Interstate 355 to the north and west and Illinois Highway 83 to the east (Figure 1-4). About 1.6 km (1 mi) south of ANL-E are the Des Plaines River, the Chicago Sanitary and Ship Canal, and the Illinois Waterway (Illinois and Michigan Canal). The principal stream on site is Sawmill Creek, which drains southward to the Des Plaines River. The forest preserve and the area between the river and ANL-E are undeveloped, while urban developments predominate in other surrounding areas.

3.1.1.1. Population Distribution

The ATLAS Facility at ANL-E is within the Chicago Standard Metropolitan Statistical Area. This area comprises six Illinois and two Indiana counties around the southwest corner of Lake Michigan. More than 3.5 million people live within 32 km (20 mi) of ANL-E. About 8 million people live within the 80 km (50 mi) radius, which includes portions of Lake and Porter counties in Indiana; portions of Kankakee, Grundy, LaSalle, DeKalb, McHenry and Lake counties in Illinois; and all of DuPage, Will, Cook, Kendall and Kane counties in Illinois.

Beyond the forest preserve at the ANL-E perimeter, the population density increases rapidly, especially to the northeast. A high-density residential area (with several thousand residents) is 610 m (2000 ft) east of the perimeter. The closest large, populated subdivision is located west of the ANL-E West Gate entrance, on the west side of Lemont Road. The center of this development is approximately 2.1 km (1.3 mi) from the project centerline. Lemont to the southwest and Darien to the north are urban populations closest to the project site.

3.1.1.2. Environmental Features

3.1.1.2.1. Meteorology

The regional climate is characterized as being continental, with relatively cold winters and hot summers, and is slightly modified by Lake Michigan.

The predominant wind direction is from the south, and wind from the southwest quadrant occurs almost 50% of the time. The average wind speed at ANL-E at a height of 5.8 m (19 ft) is 3.4 m/s (7.6 mph), with calm periods occurring 3.1 % of the time.

The average annual precipitation at ANL-E is 800 mm (31.5 in) and is primarily associated with thunderstorm activity in the spring and summer. The annual average accumulation of snow and sleet at ANL-E is 830 mm (32.7 in). Snowstorms resulting in accumulations greater than 150 mm (5.9 in) occur only once or twice each year on the average, and severe ice storms occur only once every 4 or 5 years.

The area experiences about 40 thunderstorms annually. Occasionally these storms are accompanied by hail, damaging winds, and/or tornadoes. Tornadoes frequently occur in Illinois, with more than 65% occurring during the spring months. The theoretical probability of a 67 m/s (150 mph) tornado strike at ANL-E is 3.0×10^{-5} each year, a recurrence interval of one tornado every 33,000 years. The ANL-E site has been struck by milder tornadoes, with minor damage to power lines, roofs, and trees.

3.1.1.2.2. Hydrology

Several drainages that may have intermittently flowing water are located on the ANL-E site. Freund Brook flows to the east-northeast and enters Sawmill Creek, which flows south to the Des Plaines River. Raw flow data from Freund Brook are not available. However, field observations of the stream size and channel configuration suggest that the discharge averages less than 0.08 m^3/s (3 ft^3/s) and peaks at 0.6 m^3/s (21 ft^3/s) during the maximum flood stage. The ANL-E site in general has a network of ditches and culverts that transport surface runoff, without treatment, toward the streams.

3.1.1.2.3. Geology and Seismology

3.1.1.2.3.1. Stratigraphy

The ANL-E site is underlain by 34-37 m (113-123 ft) of glacial till (Wisconsin stage of the Pleistocene series). It is clayey to silty-clayey till with few pebbles and cobbles and the base of this unit is locally rich in gravel. Gravel deposits are probably confined to the valleys carved in the bedrock surface that now lies buried beneath the Pleistocene sediments (alluvium and glacial till). The till is overlain by less than 0.3-0.6 m (1-2 ft) of loess and modern soil. Strata immediately underlying the till are identified as probably belonging to the Kankakee Formation of the Alexandrian Series lowermost Silurian System. The subcropping weathered zone is up to 10 m (33 ft) thick. This zone shows significant evidence of the solution weathering and fracturing, below which rock is generally unfractured and unaltered.

Silurian aquifers (including the Kankakee Formation) are separated from deeper Cambro-Ordovician aquifers by an aquitard, the Maquoketa Group (Ordovician). This group consists primarily of shale units. The top of the Maquoketa Group lies 75 m (246 ft) beneath the surface, and is about 45 m (148 ft) thick.

3.1.1.2.3.2. Soils

According to the USDA, the site consists mainly of upland soils belonging to the Morley Series. These soils formed in silty clay loam glacial till. Locally, a thin layer of overlying silty material is present.

3.1.1.2.3.3. Seismicity

No tectonic features within 100 km (62 mi) of ANL-E are known to be seismically active. The longest of these features is the Sandwich fault. Smaller local features are the Des Plaines disturbance, a few faults in the Chicago area, and a fault of apparently Cambrian age. Although a few minor earthquakes have occurred in northern Illinois, none has been positively associated with a particular tectonic feature. Most of the recent local seismic activity is believed to be caused by isostatic adjustments of the earth's crust in response to glacial loading and unloading, rather than by motion along crustal plate boundaries.

There are several areas of considerable seismic activity at moderate distances (hundreds of kilometers) from ANL-E. These areas include the New Madrid Fault zone (southeastern Missouri), the St. Louis area, the Wabash Valley Fault zone along the southern Illinois-Indiana border, and the Anna region of western Ohio. Although high-intensity earthquakes have occurred along the New Madrid Fault zone, their relationship to plate motions remains speculative at this time.

Ground motions induced by near and distant seismic sources in northern Illinois are minimal. However, peak accelerations in the ANL-E area may exceed 10% of gravity (approximate threshold of major damage) once in about 600 years, with an error range of between -250 and +450 years.

3.1.1.2.4. Environmental Compliance

3.1.1.2.4.1. Clean Air Act

There are no radiological emissions that have the potential to impact air quality produced in the operation of ATLAS.

3.1.1.2.4.2. Clean Water Act

Only normal facility discharges are produced, such as retention tank volume, storm-water runoff and sanitary wastes. Building 203 retention tank water is tested before being discharged into the ANL-E sanitary sewer system and treated at the laboratory's waste treatment facility, which has a National Pollutant Discharge Elimination (NPDES) permit. Domestic water is monitored quarterly and reported in the annual site environmental surveillance report.

3.1.1.2.4.3. Resource Conservation and Recovery Act (RCRA)

Hazardous wastes are handled in accordance with established ANL procedures. ANL-E has a RCRA Part B permit under the IEPA-RCRA regulations. The ANL Waste Handling Procedures Manual is adhered to. The quantity of hazardous wastes is small and readily managed within the laboratory's hazardous waste management program. Hazardous wastes are placed into appropriate receptacles, labeled, and documented for pickup by ANL Waste Management Operations personnel. Handling, treatment, storage, and disposal of the hazardous wastes by the Waste Management Operations Department is in accordance with RCRA regulations.

3.1.1.2.4.4. Safe Drinking Water Act

Drinking water is obtained from Lake Michigan via the existing laboratory system. There are no drinking water wells within the ATLAS Facility.

3.1.2. Facility Description

The ATLAS facility was designed and built in conformance with design criteria applicable at the time of its construction, per the applicable guides, codes, standards and requirements of the time.

The shielding at ATLAS has been designed, in combination with other systems, to limit the dose rate to acceptable levels at accessible locations from all radiation sources associated with normal operation of the facilities. (See section 3.7.6.3.) A radiation monitoring and control system (ARIS, see section 3.7.6.4) operates at ATLAS, and ensures that radiation exposure to personnel is kept ‘As Low As Reasonably Achievable’. During the past ten years, this combination of engineered safety systems, along with administrative policies, has kept the total yearly dose to ATLAS personnel to less than 100 mrem. For most of those years, neither ATLAS personnel nor facility visitors have received any recordable dose.

3.1.2.1. Injectors

As has been stated, the ions accelerated by ATLAS are provided by one of two alternate injector systems: a 9-MV tandem electrostatic accelerator with its negative-ion source, and a positive-ion injector (PII). The PII ion sources produce X-radiation and all ion sources utilize high voltage electricity in their operation. All sources utilize an interlocked cage to control access to them. The cages serve to limit access to the sources both when radiation and/or hazardous electrical voltages are present. Access to the ion sources is controlled through a high-voltage interlock system, and for the PII ion sources by the ATLAS Radiation Interlock System (ARIS).

The FN-Tandem accelerator (Figure 1-3) consists almost entirely of commercial components. The beam current that can be injected into the tandem is limited, for most beams, by the characteristics of the accelerator tube and the lifetime of the thin (~2 $\mu g/cm^2$) carbon stripping foil in the tandem terminal. The ion source is a sputter type source on a 200 kV platform located in an interlocked caged area. The insulation gas for the tandem tank is SF_6 at a pressure less than 80 psig. When not in use, this gas is stored in liquid form at a pressure of 500 psig in a 317 ft^3 tank located in a service area above the tandem vault. The piping system used to transport the SF_6 between the tandem tank and the storage tank, as well as the tandem tank and the storage tanks themselves, all contain over-pressure devices to ensure that no explosive pressures develop within the system.

Figure 3-1

ARIS Monitored Areas

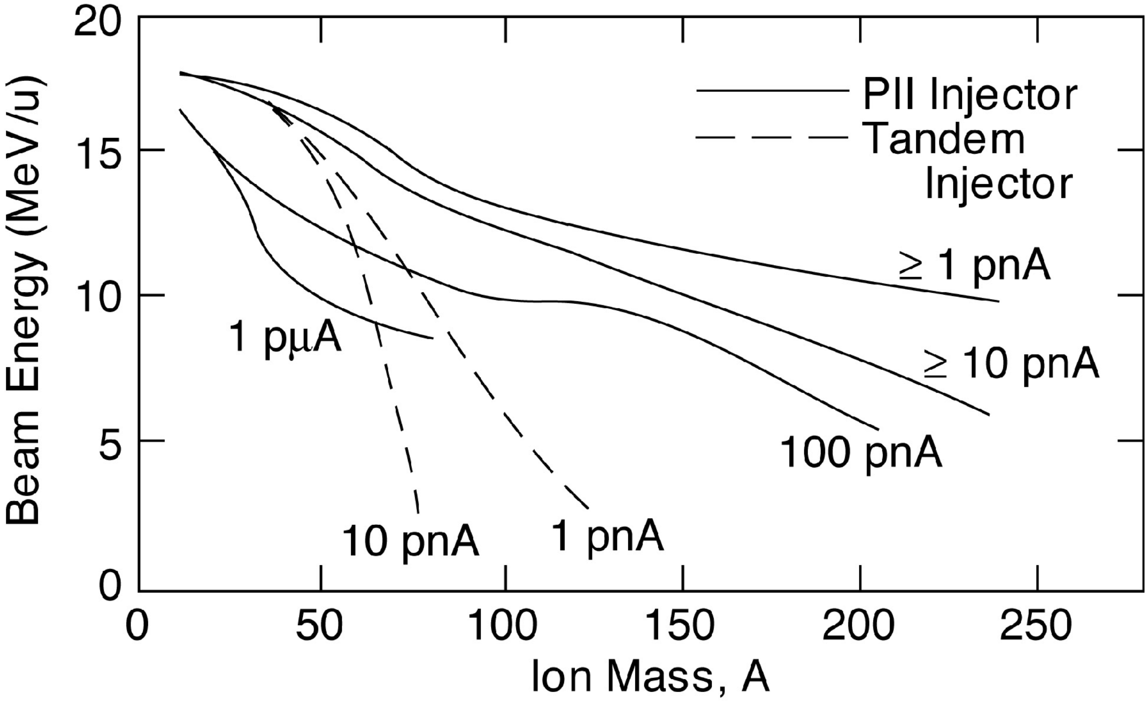

Figure 3-2 Maximum beam energies feasible at ATLAS at the present time for several levels of beam current, plotted as a function of ion mass

(1 pnA = 6.25×10^9 particles / second)

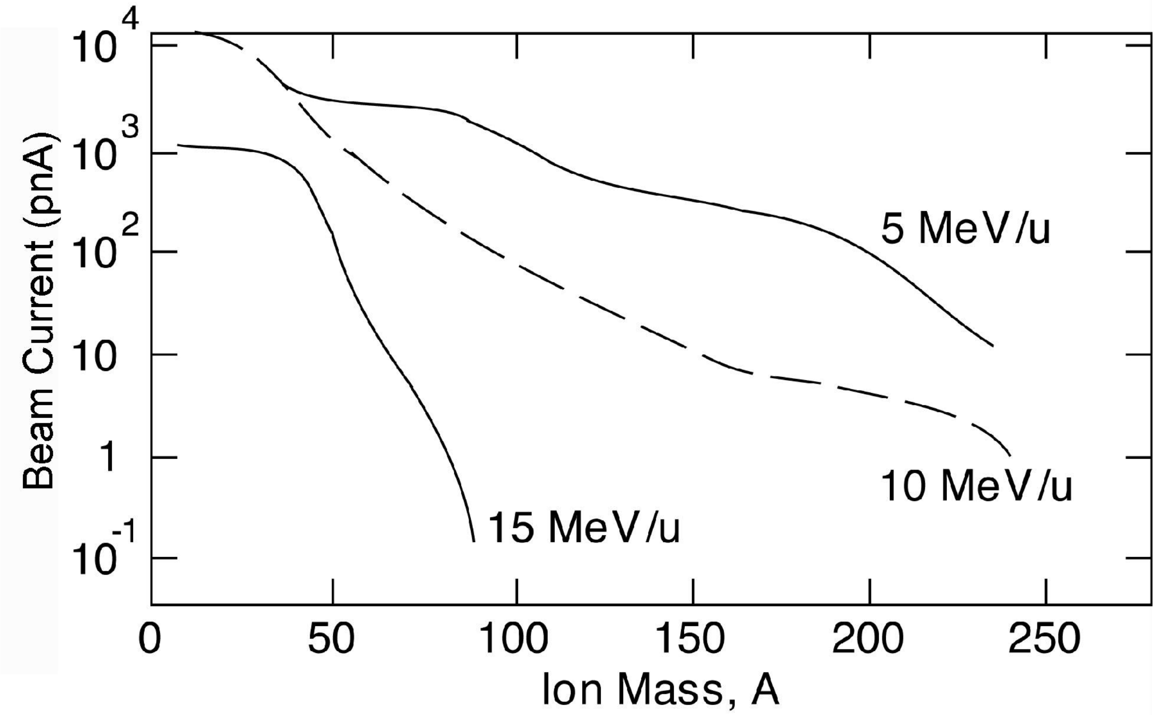

Figure 3-3 Maximum beam currents feasible at ATLAS at the present time for several beam energies, plotted as a function of ion mass.

The two ion sources of PII provide ions produced by one of two ECR ion sources mounted on high voltage platforms (350 kV for ECR l, the original ECR source, and 300 kV for ECR II, the second ion source.) These ions are then accelerated by a 12-MV superconducting injector linac. This linac is the same in general concept as the main ATLAS linac, but its components are different in design because of the low velocity of the ions involved. The installed RF power for the injector linac is ~4 kW. The maximum beam power that can be generated by the PII is, in principle, ~ 350 watts. The PII linac is cooled by the same cryogenic system as is used to cool the main ATLAS linac. The beam-induced radiation generated by PII is a minor hazard because the maximum beam energy that can be achieved is small (under 2.5 MeV/u).

3.1.2.2. Accelerator

The main superconducting linac of ATLAS consists of 46 independently-phased accelerating structures (resonators). These are grouped into two main sections, the booster linac and the ATLAS linac (see Figure 1-3) and four single cavity cryostats used as bunchers. Each resonator is excited by a 250 watt RF amplifier at a frequency of 97 MHz. These units are cooled by flowing liquid helium at a pressure in the range 3-15 psig and a temperature of ~ 4.6 K. The nominal accelerating voltage provided by this linac is ~40 MV and the installed RF power is ~ 11 kW. However, other technical factors limit the steady-state beam power to ~2.7 kW and, because of the nature of the research program, the beam power is usually less than 10 W.

Focusing, steering and bending magnets are used throughout the accelerator area to control the beam. Magnetic fields as high as 10 gauss at 2 feet from their outer surface can be produced by these magnets. The magnets operate at various voltages, up to a maximum of 500 volts.

3.1.2.3. Beamlines in the Experimental Areas

The beamlines in the experimental area form "trees" that branch at switch magnets. At the end of each line is an experimental station. The equipment located at the experimental stations is described in the document <u>ATLAS Experimental Area Safety Documents</u>, which is located in the ATLAS Data Room. This document includes a description of each piece of equipment, as well as the reviews conducted on it. Each Experimental Area is posted as either a Radiation or a High Radiation area when the beam is present because of the possibility of radiation fields within the area at that time. Access to these areas is controlled by the ATLAS Radiation Interlock System (ARIS), an engineered safety system which is designed to allow access to areas in a way which minimizes the possibility of personal harm due to radiation. These areas are shown in Figure 3-1.

3.1.2.4. Performance

Figure 3-2 summarizes the maximum beam energies available from ATLAS for various ion species and beam currents. Figure 3-3 gives the performance of ATLAS in a different way, by plotting maximum beam current vs. nucleon number A for several values of maximum beam energy.

3.1.2.5. Building Structure

The ATLAS accelerator building, which is attached to building 203, was formed by means of several independent construction projects during the period 1961-1997. The total area of the building is about 48,000 ft^2, as shown in Figure 1-3. The floor of the west end of the building is at ground level and the east end is approximately 3 feet below ground level.

The construction of the building varies from the most robust parts, which have walls and roof made of concrete about 3 feet thick to those that have thinner concrete walls and relatively thin metal roofs. The main experimental halls (Areas III and IV) have concrete walls at least 1.5 feet thick to a height of at least 11.5 feet. The outside walls are banked by earthen berms about 15 feet thick at their base.

The target rooms are all high-bay areas. All of the Target Rooms and the areas in which the main components are housed have overhead cranes with capacities in the range from 2 to 10 tons.

3.1.2.6. Utilities

The conventional building utilities provided to the ATLAS building are HVAC (heating, ventilation and air conditioning), electricity, laboratory and drinking water, chilled water and compressed air. Only two of these have significant safety implications. One is the ventilation system, because of the presence in the facility both of flammable gasses in small quantities, and cryogens and SF_6 in substantial quantities. An independent air-handling unit in each work area causes the air in its area to be replaced with fresh outside air at least twice hourly. The other system is the electrical supply, because of the potential for electrical shock in all electrical systems.

In addition to the standard building utilities, ATLAS requires several less common utility-like services: liquid nitrogen, liquid helium and SF_6 insulation gas.

The liquid nitrogen is piped into several parts of the building from a 20,000 gallon storage dewar outside the building.

The liquid helium is generated by three commercial refrigerators, with a total cooling capacity of ~ 1000 W located in the accelerator area. In closed-cycle operation, flowing liquid helium from these refrigerators cools the superconducting linac and then returns to the refrigerators in the form of cold gas, which is recondensed. Almost no helium is lost in normal operation. Excess warm gas is stored at a pressure less than 250 psig in a 12,000 gallon storage tank outside the building. The helium-gas compressors for the refrigerator are located in the service area above the tandem vault.

3.2. Organization

The Physics Division is one of seven divisions under the Associate Laboratory Director for Physical, Biological and Chemical Sciences (PBCS.) The Division's primary mission is to conduct basic research.

The organizational structure of the Physics Division in relation to the development, operation, and use of ATLAS is summarized in Chart 1-1. The role that non-divisional safety experts of various disciplines play at ATLAS is not shown, but a number of them are deeply involved in safety activities at ATLAS. For example, the PBCS Health Physicist provides Health physics expertise for ATLAS.

The Director of the Physics Division has overall line-management responsibility for the oversight of all programs and facilities within the Physics Division. As such, he is accountable to the Associate Laboratory Director for Physical, Biological and Chemical Sciences (PBCS) and the Laboratory Director. The overall quality of work and the efficiency of operations is assured by external and internal review processes. Additionally, the Division Director maintains independent oversight of environment, safety and health (ESH) issues through the Division ESH/QA Engineer and various reviews and audits. The Scientific Director of ATLAS, appointed by the Division Director, oversees the scientific selection of the research to be carried out with the assistance of the Program
Advisory Committee.

The Director of the ATLAS facility has primary responsibility for all aspects of ATLAS including technical, administrative, and budgetary. He is responsible for assuring that the ATLAS facility and the accelerator development program respect and comply with the objectives of Laboratory and governmental ESH policies and requirements.

The Operations Manager of ATLAS is responsible for planning, organizing, and supervising the technical and administrative staff and activities involved in the operation of ATLAS. He is responsible for implementing applicable ESH policies and directives as required to provide for the safety of personnel and facility operations as well as compliance with governmental ESH requirements.

The responsibilities of personnel directly involved in the operation and maintenance of ATLAS are documented and described in the ATLAS Operating Procedures Manual. Copies of this manual are kept in the ATLAS Control Room and the ATLAS Operations Manager's office.

The key persons in the implementation of the safety policies and procedures at ATLAS are the ATLAS Operations Manager, the User Liaison Physicist, the Physics Division ESH/QA Engineer, the Operations Supervisor and the responsible PBCS Health Physicist.

The Physics Division Director is responsible for appointment of safety committee members to perform the functions described below. The Physics Division ESH/QA Engineer is a member of each safety committee and is responsible for monitoring compliance with the applicable safety rules.

The Physics Division has four specific safety committees: The General, Electrical, Radiation, and Cryogenic Safety Committees. In addition, the Division has a Safety Coordinating Committee, composed of the ESH/QA Engineer and the chairs of the four

other committees, which coordinates the efforts of those other committees. The Safety Coordinating Committee reports directly to the Director of the Physics Division.
The safety committees have the following responsibilities:

- Inspect the entire area of Building 203 occupied by the Physics Division ~~at least once~~ twice a year. Line managers or their delegates may assist the committee during these inspections.

- Identify unsafe conditions and/or practices and assist in the development of remedies.

- Provide an opportunity for the discussion of accidents, near misses and preventive measures.

- Conduct safety reviews of new or significantly revised apparatus or procedures prior to operation.

- Document meetings, inspections and other activities.

- Review all experiments prior to their being performed at ATLAS. The ESH/QA Engineer and the chair of the Radiation Safety Committee review a description of the experiment, including any new or modified apparatus used. If necessary, a written description of the apparatus used, or the procedure, is submitted to the Safety Coordinating Committee. That committee then determines which of the other standing committees need to review it. The responsible committees then review the experiment and report in writing the results of those reviews. If the experiment involves radiation issues not already reviewed, the full Radiation Safety Committee (including the PBCS Health Physicist assigned to the Division) must review it. No experiment may be run without the signatures of both the ESH/QA Engineer and the Radiation Safety Committee Chair signifying their concurrence in the safety of the experiment.

In addition to the above standing committees, ad-hoc committees are appointed to review particular apparatus or safety issues that fall outside the technical competence of the standing committees. These ad-hoc committees usually include people with appropriate expertise for the committee's responsibilities from outside the Physics Division.

3.3. Safety Services - Site Wide

ATLAS is served by all the safety services provided through the Argonne National Laboratory - East site. These include:

- Health Physics: The Physics Division uses the services of health physics professionals, including a health physicist. They perform such services as monitoring the radiation conditions at ATLAS, providing and maintaining radiation instrumentation for use at ATLAS, assistance in implementing the Division's ALARA goals, radiation exposure evaluation and control, shielding design and review, external radiation dosimetry, survey instrument calibration, internal radiation dosimetry and area support with surveillance. All trash removed from ATLAS is surveyed by health physics personnel to ensure it is not activated or radioactively contaminated. The Health Physicist is a permanent member of the Division's Radiation Safety Committee, and as such, participates in the review of all activities that involve radiation issues. The Physics Division ESH/QA Engineer is usually a member of the Laboratory's ALARA Committee.

- Emergency Management: Building 203, in which ATLAS is situated, is included in the ANL-E Comprehensive Emergency Management Plan and has developed a Local Area Emergency Plan. This local emergency plan incorporates documentation, including a map of the designated tornado shelters in the building, a description of the assembly and relocation areas and control points, assignment of area emergency response responsibilities and periodic drill requirements. ATLAS facilities and personnel are fully integrated into Building 203's local emergency plan.

- The Laboratory's Emergency Management Organization functions under the management and oversight of the Laboratory Director, the ESH/QA Oversight Director, the Chief Operations Officer and the various division directors.

- Training: The ATLAS facility participates in the ANL-E Training Management System. This system includes a comprehensive method for determining the training needed to prepare employees for the hazards to which they may be exposed in the course of their duties, as well as an organized system for delivering and documenting that training. Included in this system is such ATLAS and Physics Division-specific training as the ATLAS Site Specific Training and the Physics Division's Open Source Training. By participating in this system, ATLAS assures itself that the proper training is received by each of its employees.

- Fire Department: ATLAS participates in the Laboratory-wide program for fire safety analysis and assessment. The Plant Facilities Services (PFS) Division coordinates an on-going program of Fire Protection Safety Improvements. This program was initiated as a result of a fire safety assessment coordinated by the Fire Protection Section.

ATLAS has both fire detection and fire suppression systems installed throughout the facility. Although there is very little combustible material in the facility, if a fire did occur it would comprise an industrial safety issue. No significant radioactivity would be released to the public or the environment. The fire detection system alarms both locally and at the ANL-E Fire Department headquarters, which are centrally located on the Laboratory site. Portable fire extinguishers are placed at key locations throughout the facility. Fire Department personnel conduct CPR training for those ATLAS personnel who require it. All fire extinguishers in the facility are inspected quarterly by Fire Department personnel. The Fire Department also monitors the Oxygen Deficiency Hazard (ODH) alarms located in the ATLAS facility. The ANL-E Fire Department is available to respond to fire, medical and other emergencies which might occur at ATLAS on a 7 day a week, 24 hours a day basis and has the ability to respond to any on-site location within three minutes. In addition to standard training and certifications, Fire Department personnel receive ATLAS site-specific training. The Fire Chief or his alternate serves as the incident commander for all on-site emergencies.

In addition to the above services, the Laboratory maintains key health, safety, and environmental protection documents for operational and historical purposes.

The Laboratory also supports project and programmatic activities through other formalized functions established within the division that include dosimetry services, industrial hygiene, medical surveillance and environmental project coordination.

3.4. Safety Services - Facility

Automatic wet-pipe fire sprinklers are installed throughout the facility. Air sampling smoke detection and/or spot-type smoke detectors are also installed throughout.

A gaseous suppression system is located in a modular data room in one experimental area. The system is used to protect data gathering electronic equipment associated with Gammasphere. Its design is such that its operation would not cause an oxygen deficiency condition to exist in the room. The system controls are tested annually by an outside inspection contractor under the direction of PFS-SES. The same contractor performs a visual inspection of all controlled devices in this system twice a year. A separate contractor, also under the direction of PFS-SES, performs a visual inspection of the container containing the extinguishing agent, associated manifolds and piping twice a year. During these inspections, the contractor also verifies that the proper amount of extinguishing agent is in the container.

Fire alarm bells with strobe lights are installed throughout the facility and manual pull stations are located at all the exits.

Fire extinguishers are located throughout the facility. Their locations are clearly marked where necessary with OSHA approved signs. Several fire hydrants are located within 300 feet of the facility, in keeping with ANL policy.

A formal Fire Protection Analysis of the ATLAS facility was last completed in 1994. All improvements recommended by that analysis have been completed.

A formal Life Safety Analysis of the ATLAS Facility was last completed in 1991. All improvements recommended by that analysis have also been completed.

The Division ESH/QA engineer performs documented life safety inspections monthly. Also, the Physics Division Safety Committee and the OQA SME for industrial safety inspect the ATLAS facility twice a year as a part of their Division-wide inspections. Any deficiencies found during these inspections are noted, and followed until corrected by the appropriate personnel.

Argonne has begun an inspection and testing program consisting of quarterly and annual inspection/testing routines to achieve compliance with National Fire Protection

Association (NFPA) 25. It has also initiated a fire detection and alarm system testing/inspection program consisting of semi-annual inspections and annual operational testing to achieve compliance with NFPA 72. The ATLAS facility is included in both these programs.

The facility is in compliance with DOE Order 420.1 "Facility Safety".

In the event of a power failure, the emergency power lighting system is activated. When necessary, personnel will evacuate the area to secure areas within the building, or outside, as appropriate. They will be guided in their evacuation by exit signs within the facility and throughout the building.

Emergency procedures to be followed in the event of tornadoes, high winds, or other natural phenomena are contained in the Building 203 Local Area Emergency Plan. When notified by the building or site-wide notification system, all personnel will evacuate to secure areas of the building, or outside, as appropriate. Designated gathering places are listed in the Local Area Emergency Plan for Building 203, to ensure all personnel are accounted for. A copy of the Local Area Emergency Plan is on file in the Control Room.

3.5. Accelerator Safety Review Committee

The ATLAS accelerator is reviewed triennially by the ANL Accelerator Safety Review Committee (ASRC), which directly reports to the Laboratory Director. The mission of the ASRC is to provide assurance to top management of ANL that particle accelerator facilities operated by the Laboratory have processes to ensure the facilities conduct their operations in a safe manner and meet all relevant Laboratory policy requirements, conform to all relevant DOE Orders and comply with all relevant federal and state laws and regulations pertinent to the safety of operations.

3.6. Experiments and Experimental Activities

Experiments are run at ATLAS to perform basic research in the field of nuclear physics, especially research requiring the use of low-energy heavy-ion beams. A small fraction of the experiments run at ATLAS are in the field of atomic physics or other scientific disciplines or applications.

The Experimental equipment used at ATLAS is described in the document "Experimental Equipment at ATLAS". Copies of this document are located in the ATLAS Data Room, as well as the offices of the User Liaison Physicist and the Physics Division ESH/QA Engineer. This document also contains the records of the yearly safety review of each piece of equipment.

The records of the safety reviews and the approvals of each experiment performed at ATLAS are maintained in the ATLAS Control Room.

	CATEGORY OF REVIEW	REVIEW BODY			
		TechnicalExperts	Standing Physics Div.Safety Committees	Ad-hoc Physics Division Committee	ANL AcceleratorSafety Review Committee
1.	Individual Experiment		X		
2.	Technical details of new or modified equipment	X			
3.	Minor changes in equipment or ATLAS procedures	X	X		
4.	Significant changes in equipment or ATLAS procedures			X	

5.	Changes in the SAD			X	
6.	Acceleration of low mass materials (except Deuterium or Tritium)			X	
7.	Acceleration of Deuterium or Tritium, or beams with an Estimated Radiation Level (ERL) greater than 5 rem/h			X	
8.	Programs or equipment that raise safety issues not previously reviewed			X	
9.	ORR, COO, Etc, Documents			X	
10.	Changes in the Safety Envelope			X	
11.	Safety Program Processes				X

Table 3-1

Matrix of Reviewers for categories of subjects requiring documented safety review

3.7. Operations/Process Description

3.7.1. General Description

ATLAS is a low energy, heavy-ion accelerator. It is located on the ground floor of Building 203. The beam originates in one of several ion sources. It then is accelerated by a superconducting heavy-ion linear accelerator (linac). The beam accelerated in the linac is delivered by one of several beamlines to equipment in the various target areas. Beam switching magnets determine which beamline receives the beam for a particular experiment.

3.7.2. Normal Operating Conditions

Normal operating conditions are described in the ATLAS Operating Procedures. The purpose of that manual is to provide procedures used in the operation of the accelerator. The manual provides detailed documentation for accelerator trainees and is available for reference to operators.

3.7.3. Non-Standard Operating Conditions

Conditions that fall outside ‘Normal Operations’, but are permitted within the Safety Envelope require approval by the Division Director, usually after specific reviews by the relevant safety committees. Procedures to be followed during these conditions are part of the specific instructions given to the ATLAS operators.

3.7.4. Emergency Shutdown of ATLAS

Procedures to be taken, including immediate shutdown of the accelerator in the event of emergency conditions, are described in the Building 203 Local Area Emergency Plan and the ATLAS Operating Procedures Manual.

3.7.5. Safety Review System

All aspects of the operation, maintenance, modification and use of the ATLAS accelerator are examined in documented reviews if a significant safety issue may be involved. The scope of the review and the person(s) responsible depend on the nature of the subject to be reviewed. One or more of the standing safety committees of the Physics Division or an ad-hoc committee reporting to an appropriate level of management usually conduct such reviews. The membership of all such committees consists of a majority of persons not directly associated with ATLAS. The person responsible for approving the recommendations of the review committee will inform the next higher level of management (up to and including the Division Director) concerning the nature of the review and its conclusions.

The review processes for various categories of equipment, procedures or documents are summarized in Table 3-1, and the persons responsible for the review are indicated in the following explanatory paragraphs. The relationships given in this table and in the text may be changed from time to time as needed because of changed circumstances.

3.7.5.1. Each individual experiment to be performed at ATLAS undergoes a safety review by the Operations Manager, the Division ESH/QA Engineer, the Physics Division Radiation Safety Committee and other Physics Division Safety Committees, as appropriate. Based on these reviews, and the needs of the experimenter and the capabilities of the accelerator, the beam energy and beam current approved for delivery to the experimental area during each running period are specified in an "Authorization to Operate" form. Appropriate signatures are required on this document. These signatures include those of the Operations Supervisor, the Spokesperson for the experiment and the Division ESH/QA Engineer, or their delegates. The Chief Shift Operator is responsible for implementing the requirements of the "Authorization to Operate".

3.7.5.2. Technical details of new or modified accelerator equipment are reviewed by individual technical experts or small groups of experts.

3.7.5.3. Minor changes in safety procedures are reviewed by one or more of the standing Physics Division Safety Committees, as necessary.

3.7.5.4. More substantial changes and major new equipment require a review of the entire sub-system involved. Such reviews are carried out by a technically competent ad-hoc committee reporting to the Physics Division Director.

3.7.5.5. Revisions to the ATLAS Safety Assessment Document are reviewed by an ad-hoc committee appointed by the Physics Division Director.

3.7.5.6. Any proposed experimental configuration that involves a beam of mass less than 12, or with a high Estimated Radiation Level, or involving a beam of deuterium or tritium (see sections 5.3.2 through 5.3.4) is reviewed by a committee reporting to the Physics Division Director.

3.7.5.7. Any new research program that has the potential to have new hazards is reviewed by an ad-hoc committee reporting to the Physics Division Director.

3.7.5.8. Operational Readiness Review documents and Conduct of Operation documents and other such documents concerned with the whole ATLAS Facility or major parts thereof are reviewed by an ad-hoc committee reporting to the Physics Division Director.

3.7.5.9. All changes to the Safety Envelope are reviewed by an ad-hoc committee that reports to the Physics Division Director and are submitted to the Associate Laboratory Director for transmittal to the Department of Energy for approval.

3.7.5.10. The processes used to generate and implement the safety systems of all accelerator facilities at Argonne, including the ATLAS accelerator, are reviewed by the

ANL Accelerator Safety Review Committee (ASRC), a standing committee that reports to the Laboratory Director.

3.7.6. Worker Safety

3.7.6.1. Worker Safety Features

A number of safety features are incorporated into the facility to prevent and mitigate potential exposures and accidents caused by radiation, electricity, confined spaces and cryogenics.

3.7.6.2. Identification of Worker Safety Conditions

3.7.6.2.1. Radiation Hazards

Radiation hazards are caused by prompt radiation from the accelerated beam as well as X-rays from the ATLAS ion sources and resonators. Exposure to prompt radiation at ATLAS is controlled by (a) shielding, (b) the ATLAS Radiation Interlock System (ARIS) and (c) administrative controls.

The shielding in place at ATLAS is analyzed in the document Radiation Shielding Considerations at ATLAS (Ref 3.)

The ATLAS Radiation Interlock System (ARIS) is discussed in Section 3.7.6.4 below. It is designed to:

- limit exposure to radiation,
- prevent access to locked areas,
- shut down the accelerator in the event of security breaks to locked accelerator beam-line areas,
- stop the beam in the event of radiation levels above acceptable levels.

ATLAS has procedures and administrative controls in place designed to minimize radiation exposure of personnel. These procedures and controls adhere to the ANL-E ESH Manual and to the Physics Division Radiation Safety Manual, which details personnel responsibilities, radiation protection standards, work practices, training requirements as well as the storage, labeling and handling of radioactive materials and waste. In addition, the maximum possible radiation dose rates are posted at the entrance to all radiation areas within ATLAS. Radiological Work Permits are utilized at ATLAS as required by the ANL-E ESH Manual, Section 5.24, Radiological Work Permits.

3.7.6.2.2. Electrical Hazards

Electrical hazards are present in the electrical equipment and power supplies at ATLAS. This equipment is operated and maintained by ATLAS personnel. The equipment is controlled by interlocked gates, protective enclosures, posting and labeling and working hot and lockout / tagout procedures as required in the Physics Division Electrical Safety Manual and the ANL-E ESH Manual.

3.7.6.2.3. Confined Space Hazards

One confined space exists at ATLAS, the pressure vessel of the Tandem which has to be entered periodically for maintenance or repairs. Work in this tank is controlled by an approved procedure that lists the requirements for such work. A completed Confined Space Entry Permit is utilized for each entry into this space.

3.7.6.2.4. Cryogenic Hazards

Cryogenic hazards are present in the extensive cryogenic system at ATLAS. These hazards are controlled by policies and procedures described in the Physics Division Cryogenic Safety Manual.

3.7.6.3. Shielding and Distance

Shielding and distance provide protection from radiation to workers and the public. Dose reduction is accomplished with (a) distance (b) physical barriers (c) shielding and (d) limiting the duration of exposure. On the outside of these barriers, the radiation level does not exceed the minimum level that would require the area to be controlled. Access to the experimental areas, as well as the ECR ion source areas, is monitored by ARIS to ensure that radiation doses to individuals are maintained below the levels allowed by DOE, and the lower levels of the ALARA goals of Argonne and the Physics Division. When access to such areas is essential and requires bypass of the ARIS control system, this must be done using procedures approved by the Physics Division Radiation Safety Committee and described by an ATLAS Operating Procedure.

3.7.6.4. ATLAS Radiation Interlock System (ARIS)

Because of the usually low radiation levels and the nature of the experimental equipment at ATLAS, it is highly desirable to permit users to enter areas where an ion beam is present under controlled conditions. Such access is permitted at ATLAS when the radiation levels are sufficiently low, and other conditions are satisfied, by mitigating the risk through the ARIS system as described in this section.

In order to provide the needed access to beam areas while maintaining the standards of radiation protection consistent with ALARA goals, the safety system at ATLAS has a number of redundant engineered capabilities. In general terms, these hardware features are as follows:

- Low-level radiation monitors near work areas.
- Interlocked access gates for beam areas.
- Continuously measured integrated dose limits during access over an 8-hour period.
- Locked access gates under specified conditions.

- A uniquely defined beam path.
- High-level radiation monitors along the entire beam path.
- A beam-current interlock system that is independent of the radiation interlock system.
- Beam-current attenuators that limit the beam from the ion source.
- The inherent limit on beam power.

3.7.6.4.1. General Design Features

The radiation produced by the ATLAS facility can be from the accelerated beams hitting components along the beam path, or from X-rays generated in the ECR source or in superconducting resonators. The ECR source is shielded and access to it is controlled by a fence that is also needed for electrical protection because the source operates at a high-voltage (see Section 4.4). The resonators are also shielded and, except for the positive ion injector, are contained within an ARIS-controlled region.

The areas where beam-induced radiation needs to be controlled at ATLAS are divided into a number of interlockable and monitored areas, as shown in Figure 3-1. These areas are separately shielded, and each area in which beam is present must be monitored by ARIS and satisfy other requirements. Access to all beam areas is controlled by a radiation interlock system that has four functions:

- to define the areas that the beam can enter,
- to monitor and limit the physical access of personnel into these beam areas,
- to measure radiation levels, and
- to use this information to limit radiation exposures.

A description of the radiation interlock system is given in Ref. 13.

Because of the complexity of the radiation interlock system it is impractical to control the system entirely with hard-wired circuitry. ARIS is controlled by a pair of programmed computers, one of which is specifically designed for the control of complex industrial processes. The much simpler Beam Current Interlock System (Section 3.7.6.5), an independent method of radiation protection, consists entirely of hardware.

The principal elements of the interlock system are:

- Beam Valves whose "open" or "closed" status is part of the interlock system and determines the beam path. The interlock system requires that the Beam Valves be open along only one beam path. When the Beam Valve to an area is opened, this area is treated as an active beam area, with respect to radiation safety, whether or not a beam is actually present.

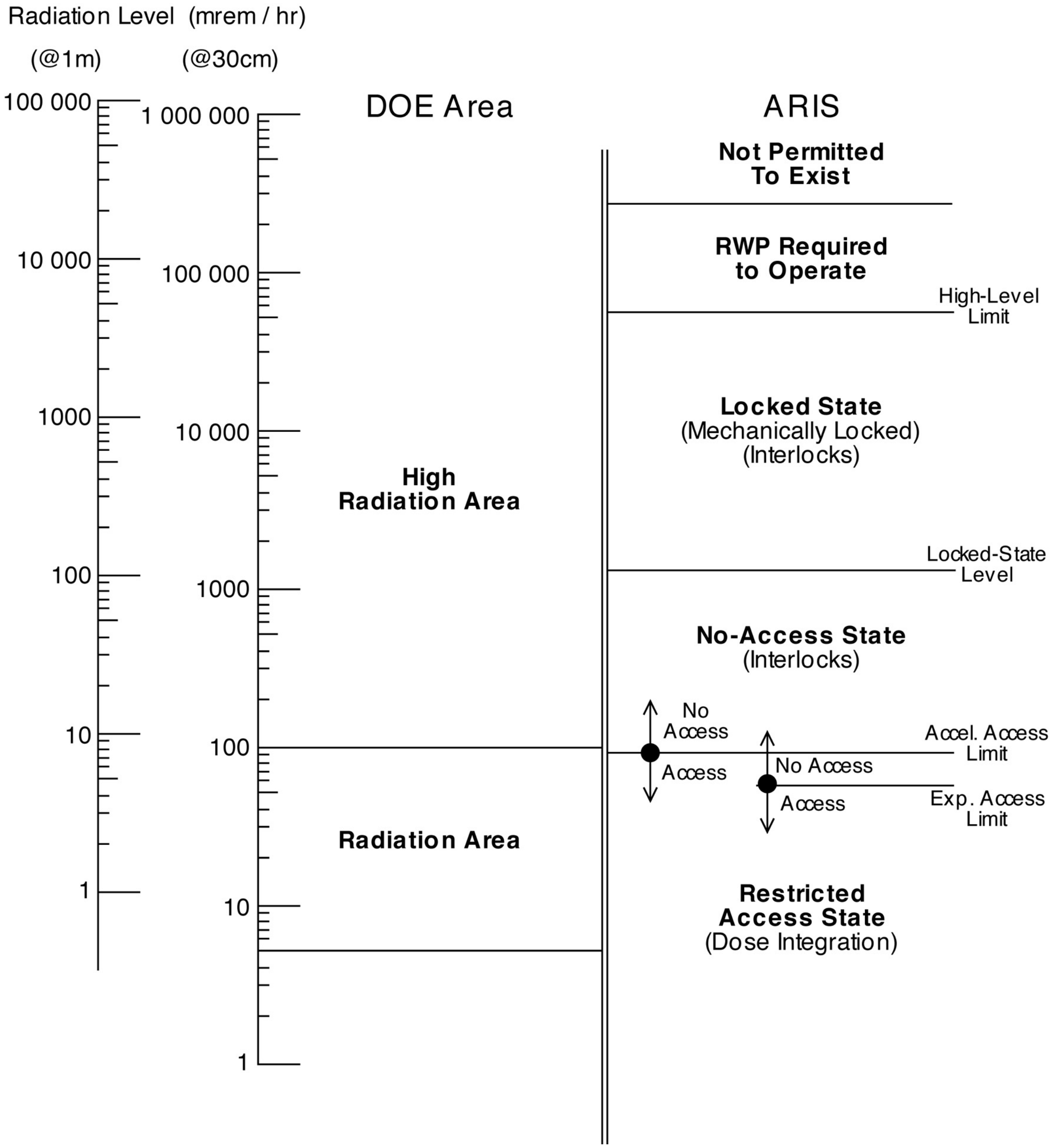

Figure 3-4

Chart Comparing DOE Radiation Area Definitions to Area Status Definitions Used in the ATLAS Radiation Interlock System

- Access Gates (and doors) that limit personnel access to beam areas and whose status is part of the interlock system. When the Estimated Radiation Level (ERL) for an approved experimental run (see Section 4.2.2.1) is greater than the "locked state level" of 100 mrem/h at one meter, as defined in Ref 10, the interlocked Access Gates are mechanically locked by the accelerator operator following a prescribed procedure. Only one gate for an active beam area is the "Access Gate"; all other gates for that area are locked and interlocked. The interlock system will inhibit the beam by inserting a Faraday cup into the beamline upstream of the accessed area if any gate other than the 'Access Gate' to an active beam area is opened. Radiation monitors that measure radiation levels along the beam path and in the area where the beam is used. Both photon (γ-ray and X-ray) and neutron-radiation detectors are used, and the location of these detectors has been selected to provide reliable measurements of both the low radiation levels encountered in normal operation of the facility and also for the high levels that could be generated accidentally by the accelerator. The raw data from all detectors are in the form of individual counts.

- A computer-based interlock control system that processes all information from the beam valves, access gates, and radiation detectors and, from these data, determines whether or not to inhibit passage of the beam into any potential beam area. By processing individual counts from the detectors, the control computer checks continuously that each detector is working, measures radiation levels over the full range involved at ATLAS and, for each beam area, determines the radiation dose that has been accumulated by a pair of γ-ray and neutron detectors while a monitored beam area is occupied during a running 8-hour interval.

Because the integrity of ARIS depends on the programming of the computer control system and the proper functioning of the associated hardware, tests are performed twice yearly to confirm that ARIS is functioning correctly. These tests simulate every potential fault that the program monitors, to ensure that ARIS responds with the appropriate actions. From time to time, the computer code is modified. A complete test of the entire system is conducted before ATLAS is allowed to run with the new ARIS code.

ARIS recognizes four action levels and inhibits the beam if any of these radiation levels are exceeded under specified conditions:

- "high level limit", above which the beam is always inhibited unless an RWP allows operation.

- "locked state level", above which access is not allowed, and the monitored area must be mechanically locked,

- "access level limit", above which the beam is inhibited if an interlocked access gate is opened,

- "integrated dose limit", the maximum integrated dose permitted during any 8 hour period while the interlocked access gate has been opened and not reset.

The relationships of the above action levels to the radiation level categories defined by the ANL-E ES&H Manual, Ch. 5 are shown schematically in Figure 3-4.

When the measured radiation in a monitored beam area is in the range between the "access level" and the "locked state level", the area is defined as being in the "no access" state. In this state, if an interlocked access gate is opened without the beam being stopped manually, the beam will immediately be inhibited by the interlock control system.

An inhibit action of this kind inserts a beam stop that can be reset only with the accelerator operator's involvement.

The numerical values for the trip levels defined above are given in an ATLAS Operating Procedure, and the current (2002) values are given in this document. These values may be modified after an appropriate safety review (see Section 3.7.5), if operating experience shows that the present choice of values becomes no longer appropriate.

3.7.6.4.2. Operational Characteristics

The following statements summarize the main features of how ARIS operates.

3.7.6.4.2.1. The set of interlocked Beam Valves defines a single beam path based on the information given in the "Authorization to Operate" document (see Section 3.7.5.1). When the Beam Valve for any beam area is opened, ARIS inserts a low energy beam stop and prevents it from being removed until the accelerator operator inspects the area to determine that no one is present, sets its access gate interlock, and mechanically locks the gate with a controlled key. The interlock control prevents the beam stop from being removed until the key has been returned by the operator to its normal captured location in the control room. The ARIS Operating Procedure specifies that the operator may unlock the gate only after it has been determined that:

- the required radiation monitors are connected and functioning (as indicated by ARIS),
- the Estimated Radiation Level for that measurement is lower than the "locked state level", and
- the beam has been initially tuned into the area.

If ARIS does not sense that the requirements of a unique beam path and functioning radiation monitors are satisfied, or if any measured radiation level exceeds its prescribed trip level, then ARIS will inhibit the beam by inserting a low energy beam stop. A beam area becomes a "monitored access area" when its monitors are functioning and its beam valve is open.

3.7.6.4.2.2. During Standard Operations (see Section 5.3.1), the accelerator operator is required to mechanically lock shut all active beam areas beyond the booster linac if the ERL value for the beam is above the "locked state level" of 100 mrem/h at one meter, as defined in Ref 10. Under this locked state, ARIS will cause a "trip" condition and inhibit the beam if:

- any Beam Valve that is inconsistent with the approved beam path is opened,
- any required radiation monitor fails to function,
- the radiation level read by any monitor exceeds the high level limits shown in Table 3-2,
- the interlock control system fails
- any interlocked gate to an active beam area is opened, or
- the “Emergency Stop” button in any beam area is pushed.

3.7.6.4.2.3. During Standard Operations, when the Estimated Radiation Level is less than the "locked state level", the access gate into a monitored beam area is monitored by ARIS, but does not need to be mechanically locked. Thus, a monitored beam area may be occupied under specified conditions. During such low radiation operation, ARIS will inhibit the beam if any of the incidents listed above under Section 3.7.6.4.2.2 occur and in addition if:

- any access gate is opened when the measured radiation level is greater than the specified "access limit" for the area (see Ref. 10F and Table 3-3), or
- the integral of the dose rate measured in any area exceeds the "integrated dose limit" (10 mrem at 1 m while the area is occupied) during the preceding 8-hour period. If this occurs, ARIS inhibits the beam. The operator must reset the interlock, and the administrative procedures require that the operator lock the Access Gate before the beam can be re-injected into that area.

During operations involving a beam of mass less than 12 or one with otherwise high Estimated Radiation Level (see Sections 5.3.2 through 5.3.4), all beam areas are locked, and the conditions specified above in Section 3.7.6.4.2.2 are valid except for the limit imposed on a high-level trip. The "high-level trip" may be changed from the present value of 5 rem/h at one meter only after a special ad hoc committee review and with the approval of the Division Director as specified in Section 5.3.3.

3.7.6.5. Beam Current Interlock System

Protection against radiation hazards caused by accidentally large beam currents that could result from equipment failure or operator error is provided by a beam current interlock system. The function of the beam current interlock system is to provide protection against hazards that can be generated by intense high energy beams of light ions (particularly beams with atomic number A lower than 23) from an ECR source. This system is based on a self checking (fail-safe), redundant pair of RF pickup probes mounted on the beamline entering the booster linac. At this location, the beam current injected into the booster is sensed independently of whether PII or the tandem is the source of ions. The hard-wired interlock system associated with the beam current detectors independently controls the state of three different beam-stopping devices:

- the platform high-voltage power supply of the ion source in use (the power supply is deenergized when a fault is sensed),
- magnetic beam deflectors located just downstream of the sources, and
- one of two faraday cups, located either at the entrance to PII or the entrance to the Tandem accelerator is inserted in the beam path.

If either beam current monitor detects a current in excess of its trip point the beam is shut off in less than 20 ms and an alarm is sounded. The beam current monitors are always set at a level to ensure that the radiation limits specified in the safety and operations envelopes (Sections 5.1 and 5.2) are satisfied and the approved maximum beam current will not be exceeded.

Technical details about the beam current monitor are given in Ref. 8, Sect. 8.

3.7.6.6. Beam Current Attenuator

For most light ion beams (e.g. with A less than 23), the maximum beam current that the source can produce is much greater than can be used for research. In such cases it is necessary to reduce the beam current, which can be done either by adjusting the source or by attenuating the beam after it leaves the source. When the beam intensity needs to be reduced from the maximum capability of the source by more than a factor of 10, this reduction is achieved by means of a special Beam Current Attenuator in the beamline near the ion sources.

In order to satisfy the requirements for access into beam areas, the beam current of ions such as ^{16}O may need to be reduced by as much as a factor of 1000. Clearly the Beam Current Attenuator can be an effective means of preventing the accidental acceleration of large beam currents, and thus it is important that it operate reliably. This is achieved:

- by means of a device that can position one of its several screens across the beam path,

- by an interlock system that requires a low energy beam stop to be in place before the screen can be changed, and by formal operating procedures.

Table 3-2
High Level Limits on Estimated Radiation Level

Tandem, 40^{o} Bend and Booster	ATLAS linac Tunnel	Experimental areas
2 rem/h	5 rem/h	5 rem/h

Table 3-3
ARIS Radiation Dose Rates
and Integrated Doses for Access

Maximum permitted under ARIS	ECR deck	Tandem, 40^{o} Bend, Booster	ATLAS linac tunnel	Experimental area
Dose Rate (mrem/h) @ 1 meter	9	9	9	5
Integrated Dose (mrem for previous 8 h)	10	10		10

3.7.6.7. Limits on Beam Power

The highest level of radiation that can be produced at ATLAS is limited somewhat by the maximum beam power capability of the accelerator system. Two kinds of limits apply. For very short times (a few seconds), the upper limit is set by the RF power available to each accelerating structure. If the beam loading in any resonator exceeds the available RF power, that resonator goes out of lock; acceleration by the remainder of the linac stops, and the beam is lost. It is estimated that this kind of limit on beam power is ~1.5 kW, much less than the total installed RF power because most of the power is required to maintain phase control. The short-term RF power limit implies that the maximum beam current that the main linac can accelerate is ~50/A particle microamperes, e.g. ~10 pμA for ^{16}O. This limit is smaller than the currents that the ECR ion sources of PII can provide for ions with A less than 12 and about the same as the source limit for A between 12 and 40.

The second kind of beam power limit is set by the components in the beamlines (none of which are actively cooled) and occasionally by the limited cooling (~12 W) of each accelerating structure. During tuning the beam always strikes beamline components. During most steady state operation a large part (more than 50%) of the beam is stopped by beamline components such as slits and diaphragms used to tailor the beam to user requirements, and for most experiments the beam is stopped by a Faraday cup mounted behind the target used in the experiment. Consequently, the lack of cooling of low mass beam-line components limits steady-state operation to beam power less than ~ 300 W, which implies a maximum beam current of 50/A particle microamperes for the typical ATLAS experiment. This limit on beam current is smaller than the capability of the ECR ion sources for a large variety of ions.

Overall, the limits on beam power are not expected to mitigate radiation incidents that occur on very short time scales, but would terminate longer incidents in the ways indicated above.

3.7.6.8. Radiation Status and Alarms

Every interlockable area, whether an active beam area or not, has at its access gate a display of the current status of that area, as determined by ARIS.

3.7.6.9. Controlled Entry

Entry into the controlled areas when the beam is on is allowed only when ARIS determines that conditions are safe to do so, or when a bypass and specific procedures have been authorized by the Physics Division Radiation Safety Committee. The review process is described by an ATLAS Operating Procedure or by an ad-hoc committee appointed by the Division Director.

3.7.6.10. Worker Safety Controls

3.7.6.10.1. Area Dosimeter Program

The facility implements a personnel and area radiological dosimeter program within the controlled areas of the facility. Radiation dosimeters are placed at strategic positions within the facility for the long-term monitoring of radiation levels, as recommended by the responsible Health Physicist. These dosimeters are analyzed by the Laboratory’s dosimetry group.

3.7.6.10.2. Personnel Dosimeter Program

Per 10 CFR 835, Occupational Radiation Protection, any area to which access is managed in order to protect individuals from exposure to radiation and/or radioactive material is defined as a controlled area. ATLAS Management has designated the entire facility as a Controlled Area.

TLD dosimeters are worn by all individuals in ATLAS, or by their designated escort in the case of visitors and others not assigned dosimeters. These devices are issued, processed, and analyzed by the Laboratory's Dosimetry Group. In compliance with ANL-E procedures, assigned dosimeters are exchanged on a set schedule and the exposed dosimeters are analyzed. The Physics Division ESH/QA Engineer keeps records of all individuals who were issued dosimeters on file for a period of at least one year. In addition, the Laboratory maintains the same records for 75 years, as required by DOE.

3.7.6.10.3. Radiation Protection Program

ATLAS complies with the ANL-E radiation protection program. This program, implemented with the assistance of the PBCS Health Physicist and the Laboratory's Health physics experts to keep radiation doses ALARA, complies with specific requirements of the ANL-E ESH Manual, Chapter 5.

Health physics personnel provide or assist in arranging for the following services to the facility:

- Surveillance and inspection of radiological facilities.
- Calculations of certain potential radiological hazards.
- Radiation monitoring and survey activities.
- Calibration of area radiation detectors.
- Maintenance and calibration of fixed radiation detectors and portable survey equipment.

3.7.6.10.4. Worker Training

All personnel who work at ATLAS are required to receive safety training based on the nature of their work, including ATLAS Site Specific Safety Training. For ANL employees, the content of the training depends on the nature of the individual's work as determined by the ANL Job Hazard Questionnaire, a document that complies with Federal and DOE requirements and ANL policy. The ANL Job Hazard Questionnaire is reviewed by the employees' immediate supervisor and the Physics Division's ESH/QA Engineer, who is the Division's Training Management System representative. A training profile is developed by the Training Management System that indicates the training courses employees are required or recommended to attend for specific job requirements. Attendance at training courses is documented. The Argonne Training Management System brings training requirements and the need for refresher courses to the workers' attention on a regular basis.

The ATLAS User Liaison Physicist is responsible for the safety training of outside users of ATLAS. This training consists of instructions concerning ANL and ATLAS safety requirements and procedures and detailed information about the safety aspects of the experimental equipment and the radiation safety system at ATLAS. The effectiveness of this training is documented by means of a written exam given to every user. This training is constructed so as to meet the Laboratory's training requirements for working in a radiation area.

4. Safety Analysis

4.1. Hazard Analysis Method

The hazard analysis process at ATLAS includes the identification and study of the potential hazards in all areas of the facility, including the ion sources, the linear accelerator sections and the experimental areas. Prior to 1991, the Director of ATLAS conducted an extensive hazard analysis. The Director was intimately knowledgeable with the entire facility and its operation, having been at that position since the inception of the facility. In that analysis, all potential hazards were identified and the estimated effect of each was evaluated. The results of that analysis are shown in Table 4.1.

Changes made to the facility after the analysis was completed, as well as the equipment in it, including experimental equipment, have all been evaluated by independent review committees. The major changes have been reviewed by ad-hoc committees called by the Division Director, typically consisting of members from the Physics Division and from other operating Divisions at the Laboratory. It is the policy of the Physics Division to include Subject Matter Experts from EQO in such reviews.

Recently, the results of the original analysis were re-reviewed by a committee consisting of the Division's management team, including the Division Director, the Chiefs associated with the use and running of ATLAS, and the Chair of the Division's Radiation Safety Committee and senior scientists. In that analysis, the results were found to remain relevant at this time.

The hazards identified include radiation, electrical, cryogenic, asphyxiation, fire, explosion, rf and magnetic field and confined space hazards. The overall scope of this analysis and some results of this study are summarized by means of the matrix given in Table 4-1, which specifies the relative magnitudes of potential hazards. Several other types of hazards may be considered standard workplace hazards, and as such were not included in this process, since they are not specific to accelerator facilities. Such are mechanical hazards of various sorts, the presence of compressed air, the use of ladders, portable and bench power tools, overhead cranes, occasional limited use of chemicals, etc. are included in this category. These hazards, and those similar to them, are covered in the ANL-E ESH Manual, as they are for all areas at the Laboratory. The potential hazards which were analyzed at the facility are discussed below. The worst-case scenarios and the means used to mitigate the hazards they represent, are given.

ATLAS generates almost no hazard to persons outside the facility and has virtually no impact on the environment. No toxic chemicals are emitted in the operation of ATLAS and radiation levels at any point outside the controlled area of the facility are strictly controlled to ensure potential doses are well below DOE and Argonne limits. The possibility does exist for neutron sky shine to give a dose of about 1 mrem/y to a person working within 50 meters outside the facility. See section 4.2.1.4.2.

4.2. Radiological Hazards and Protection

4.2.1. Radiological Hazards

4.2.1.1. Radiation

The ATLAS facility accelerates primarily heavy ions that, under normal operating conditions, are not a major source of radiation because the ion velocity and beam intensity are relatively low. The acceleration of light ions is limited both by an engineered safety system (Section 3.7.6.4) and by administrative controls designed to keep radiation exposure from beam-induced radiation as low as reasonably achievable and well within DOE, ANL and Physics Division dose limits. The principal form of radiation hazard induced by heavy-ion beams is neutrons, which are emitted in all directions and have a broad energy spectrum with a mean energy of roughly 5 MeV. Examples of such spectra are given in Ref. 3. The ATLAS building was designed to provide shielding against the hazard from these neutrons. Reference 3 details the calculations and considerations involved in the shielding of the various areas within the facility. An additional potential radiation hazard is from the X-rays generated in the ECR sources during their operation and from the X-rays generated in the ATLAS resonators.

4.2.1.2. Calculation of Neutron Radiation

The greatest neutron intensity is generated by beams of light ions, for which both the maximum possible beam current and energy per nucleon are large relative to heavier ions. The radiation levels generated by beams of many of these lighter ions impinging on thick targets may be estimated reliably from the data reported in Ref. 7, as summarized by Figure 4-1. Radiation from beams of the heavy isotopes of hydrogen: deuterium and tritium, warrant special attention due to the fact that they can produce much larger neutron fluxes than other beams. The energy to which beams of deuterons or tritons may be accelerated is limited in section 5.1.1.2 to 0.4 MeV, an energy at which they will produce only very modest neutron fluxes. This energy is chosen to permit acceleration from the ion source platform and the first resonator of the Positive Ion Injector.

A set of nuclear-model calculations (Ref. 8) provides estimates of upper limits of radiation intensities and reliable results for the angular distributions of neutrons generated by all ion beams in the energy range of interest at ATLAS. These results are consistent with published experimental data with respect to dependence on ion species, beam energy, and emission angle, but the absolute values are roughly twice as large as those for the available data. Since a difference of this kind is within the accuracy of the models used, it is concluded that the model treatment gives a reasonable description of the neutron hazard for heavy-ion projectiles if the calculations are normalized to the experimental data. An example of the dependence of dose rate on beam energy and ion mass is given in Fig. 4-2, where one sees that over the parameter space of primary interest for ATLAS the dose rate depends strongly on the energy per nucleon of the beam, but is relatively insensitive to ion mass. Also (not shown in Fig. 4-2) the dose rate is not very sensitive to target materials as long as they are heavier than iron.

4.2.1.3. Probability Distribution of Radiation Levels

To obtain the best results from experiments carried out at ATLAS, the research program depends on users and operating personnel having access to beam areas when radiation levels are low. The ARIS system allows such access while providing protection from radiation accidents and satisfying the Division's ALARA goals.

Operating experience has produced a realistic understanding of the beam characteristics that ATLAS users are likely to require most of the time, and thus it is possible to estimate the radiation levels that beam users will encounter. Figure 4-3 summarizes the results of the experience between 1995 and 2000, and these data are likely to be representative of future operations. More than 50% of the time the dose rate is less than 1 mrem/h at 1 m and it is greater than 500 mrem/h only 1% of the time. Thus, the hazard from neutron radiation is relatively small during normal operation, and the principal concern is the much greater potential hazard that might be generated by equipment failure and/or operator error. The magnitude of this potential hazard and the means that are used to mitigate it are outlined below.

4.2.1.4. Other Risks from Radiation

4.2.1.4.1. Neutron Radiation within the Facility

The radiation hazards for normal operation of ATLAS are discussed here in terms of the work-area categories defined in Section 4.2.2.2. Except in the beam areas, ion-induced neutrons are the only significant radiation hazard.

All areas through which the beam passes are interlocked, with two exceptions: (a) the short section of beam pipe at the entrance to the booster linac and (b) the room containing PII. These areas are treated the same as if they were "non-lockable areas adjacent to beam areas" since, in both cases, the physically possible radiation fields are limited to low levels by local shielding and by the low energies of beam projectiles at these locations. In particular, for PII the maximum beam energy per nucleon at the input to the injector linac is less than 0.15 MeV/u for all projectiles; and at its output the maximum energy is less than 2.5 MeV/u for the lightest ions and ~ 1.2 MeV/u for the heaviest ions.

As may be judged from the trends in Fig. 4.3, at these low energies the beam-induced radiation is negligible at the input to the PII linac and is less than 0.1 mrem/h per pnA at the output. Radiation shielding at the high-energy end of the injector limits the beam-induced radiation level in accessible areas to less than 2 mrem/h for all "Standard Operations", as defined in Section 5.3.1.

When the beam currents exceed those permitted for Standard Operation (the experiments requiring special consideration, as defined in Sections 5.3.2 through 5.3.4) it might be necessary to prevent access to areas close to the output of the injector linac.

Steel shielding along both sides of the PII linac protects against the X-rays generated by the accelerating structures of the linac. As a result, the radiation levels from this source are less than 1.0 mrem/h in accessible areas, including the work area above the linac.

	Other Electrical	High Voltage	Neutrons	Photons	Sky Shine	Other Radioactivity	SF_6	Liquid N_2	Liquid Helium	Noxious Gasses
ECR Ion Sources	4	5		2			1			2
Injector Beamline	3						1			1
Injector Linac	3	1		1			1	1	1	1
PII Output Line			1	1			3	1	2	
Control Room	3						1			
Tandem Ion Source	4	5					3			
Tandem Vault	3						4	1	2	
Service Area	1	1			1		3		2	
Booster Input	1	1	2	1			3	1	2	
Booster Linac	1	1	2	2			1	1	2	
Booster Work Area	2		1				1	2	2	
40° Bend Area	3		3	1		1	1	1	2	
ATLAS Linac	2	1	3	2		1	1	1	1	
ATLAS Output	3		5	1		1	1	1	1	
RF Corridor	1		1		1		1		3	
Target Area II	3		3	1	1	1	1		1	1
Hallway at Area II			1		1		1			
Target Area III	3		5	2	1	1			1	1
Target Area IV	3	5	5	2	1	1			1	1
Data Room III/IV	1									
Utility Room	3		2		1				1	
Storage Area			2		1					

Berm			2		1				1	
Roof			3		3					
Cryogen Storage								1		
Offices, labs and storage cages	1	1								
Nearby Parking, etc.										

Table 4-1

Summary of relative magnitudes of safety hazards at ATLAS.

Each entry gives the relative magnitude of the indicated hazard in a particular area, with 1 being a minor, almost negligible hazard, 3 being a moderate hazard and 5 being the worst hazard

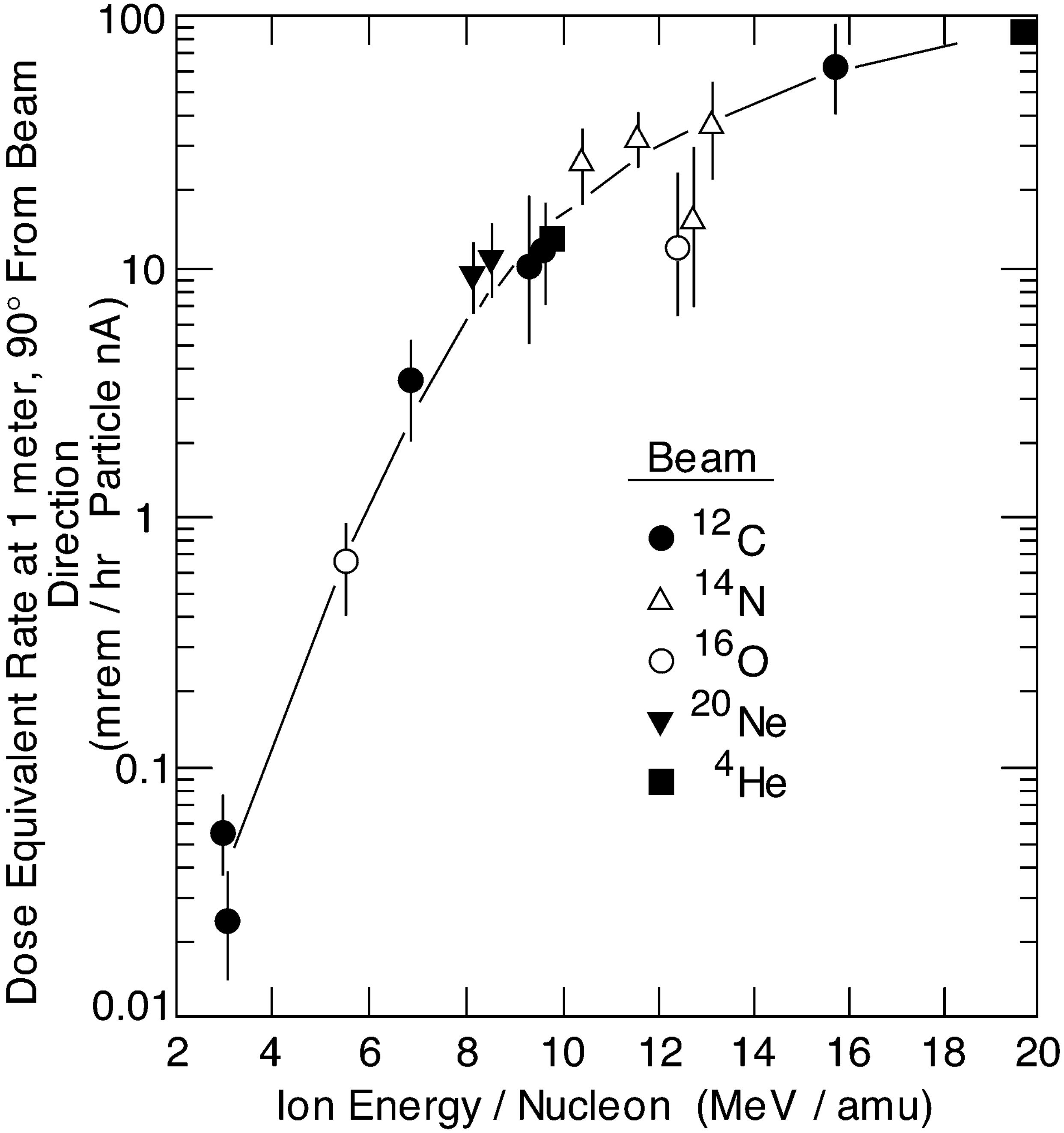

Figure 4-1

Measured values of the neutron dose equivalent rate one meter from a thick target of iron, nickel, or copper at 90° relative to the beam direction. One particle nanoampre = 6.25 x 10^9 ions / second

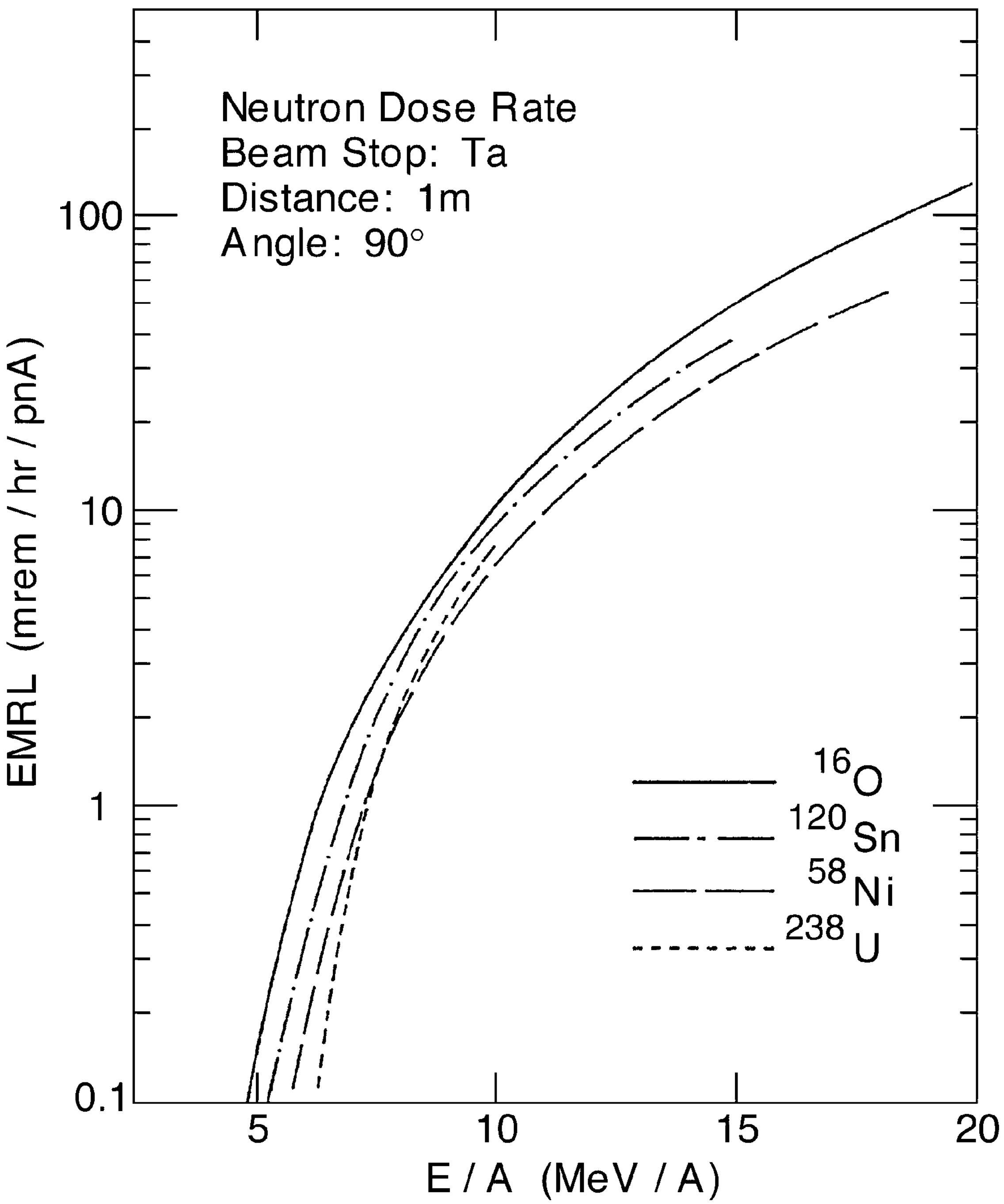

Figure 4-2

Calculation of neutron dose rates one meter from a thick tantalum target and at 90^{o} relative to the beam direction for several representative projectiles in the energy range relevant for ATLAS.

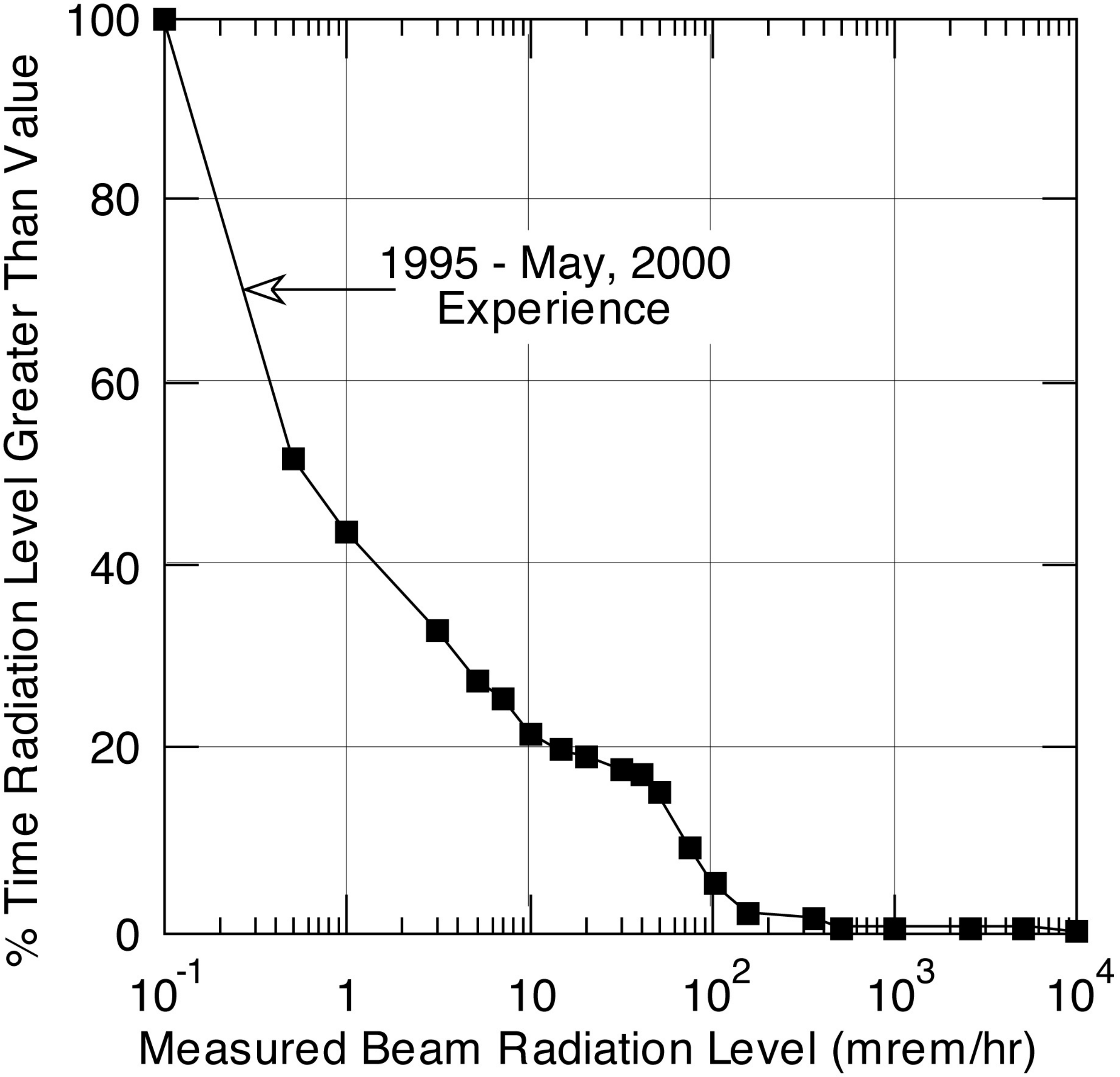

Figure 4-3

Integral probability that the radiation field generated by the ion beam used in research at ATLAS is greater than the specified value (abscissa). Here the radiation field is given in terms of the neutron equivalent dose rate 1 meter from a thick unshielded tantalum target and at 90° relative to the beam direction

For interlocked beam areas, radiation doses are controlled by ARIS. ARIS limits the maximum dose which could be acquired in a single beam area to 10 mrem per 8-hr day. Because of the nature of the research and the way in which beam time is allocated, it is extremely unlikely that any user would acquire more than 100 mrem in a year. Experience has shown that no user has acquired a detectable dose (10 mrem is the detectable threshold) during any recording period in the past decade due to radiation from ATLAS.

For each area adjacent to a beam area (lockable or interlockable,) radiation doses are limited by permitting access only if the radiation level anywhere in that area is lower than 2 mrem/h with the full beam intensity and at the maximum energy authorized for that run. Under such conditions, the radiation level in work areas is likely to be under 1 mrem/h, since the work areas are farther from the radiation source. Consequently, taking into account occupancy rate and beam scheduling, the estimated maximum dose rate that can be acquired by anyone is below 200 mrem / yr. Again, experience shows this estimate to be conservative.

For non-lockable areas adjacent to beam areas, radiation levels are kept low enough that no one can receive a dose greater than 200 mrem annually. This is achieved by (1) limiting the Radiation Level generated by the beam, as specified in Section 5, (2) limiting the annual average neutron generation of the beam, and (3) limiting access to such areas when necessary (see Appendix 2).

During Normal Operation of ATLAS, radiation dose rates in the controlled areas outside the building are negligible. A fence with warning signs limits access to the controlled areas immediately outside the ATLAS building. The access gates to these fenced areas are locked at all times except when the radiation levels are low, as confirmed by surveys, and there is a specific need to enter an area.

On the rare occasions when radiation levels outside the facility are significant, access to these areas is not allowed.

4.2.1.4.2. Neutron Sky Shine

Sky shine is the phenomenon of scattering of neutrons by the atmosphere, and is significant when there is little or no overhead shielding. Since the mean scattering distance is ~ 100 m, this effect (which can cause neutrons to scatter over many hundreds of meters) can become comparable to the direct, unshielded neutron flux at distances greater than 200-300 meters.

Calculations given in Refs. 3 and 9 show that a few individuals working in uncontrolled areas either within the facility or in nearby G-wing of Building 203 could receive doses from skyshine of about 1 mrem annually. This is far below DOE and ANL limits.

4.2.1.4.3. Beam-Induced Ionizing Photons

ATLAS beams can generate large numbers of photons: γ rays (and X-rays), most of low energy when the beam is intercepted by a target or slits and collimators. In comparison to neutrons, this hazard can be controlled easily because the attenuation length of γ rays in concrete is only ~ 1/3 that for neutrons, and in steel it is only 1/9. Thus, the risk from beam-induced photons is negligible for areas separated from the beam by shielding walls.

Personnel in areas where the beam is present are protected from excessive exposure to such radiation by the same safety system outlined above for neutrons. Experience from radiation surveys over a period of years indicates that the dose rate is primarily from neutrons.

4.2.1.4.4. X-rays from Accelerating Structures

Parasitic electrons in the superconducting resonators of the ATLAS linac can be accelerated by the RF field within a particular resonator, and generate X-rays (bremsstrahlung) when they strike the walls of the structure. The total power dissipated in this way is strictly limited by the cooling capacity (~12 W) of a resonator. Thus, the hazard from X-rays has an inherent limit. For the main ATLAS linac, the X-radiation level at a distance ~ 1 meter from the surface of the beamline cryostats is in the range 1 to 100 mrem/h, depending on operating conditions. For the PII linac, the X-ray levels are much smaller. Work areas near both the injector and the main linac are protected from this radiation by concrete or steel shielding walls.

ATLAS operations personnel need to enter the radiation area inside these shielding walls occasionally, and briefly, to monitor or adjust equipment. The X-radiation dose acquired from such entry is controlled in the same way as is beam-induced radiation in the experimental area. That is, the maximum dose that could be acquired during entry is limited to 10 mrem per 8-hr day by ARIS. Experience shows that such a limit has not been reached since ARIS began operation. In addition, entry is only permitted by ARIS if the instantaneous dose rate is less than 9 mrem/h at 1 m. For the purposes of the integrated dose limit, the dose in the three accelerator areas controlled by ARIS are summed for the 8-hour period while they are occupied, thus preventing cumulative exposures for accelerator personnel who may enter different areas during their shifts.

4.2.1.4.5. X-rays from Ion Sources

The ECR ion sources are prolific sources of low-energy X-rays. The hazard from this radiation is controlled by shielding and ARIS. With these safety systems in place the radiation level in any occupied area is also limited to less than 9 mrem/h at 1 m, and the integrated dose allowed for any 8-hour period is again 10 mrem. A single dose integral is applied to both ECR source areas under the assumption that exposure in these areas will be to the same person.

The radiation produced by the ion source of the tandem is too weak to be detected with conventional radiation monitors.

4.2.1.4.6 Soil and Water Activation

Evaluation of the potential for activation of soil around installations that involve radiation or radioactivity is important for those living near the installations and for those who consume foodstuffs produced on the land surrounding such facilities. Radioactivity in the soil can be leached out by water and in that way contaminate the water supply, or it can be extracted from the soil by plants which are consumed by man or by milk – and/or meat-producing animals. The activity may be produced directly in the soil by radiation or deposited by air activated in the facility and released afterwards.

From experience with other such facilities, it may be expected that localized radiation hazards will arise in various beam-line elements and in experimental targets. Although this localized area of radioactivity is expected, none of the items are in direct contact with soil or groundwater and thus soil and water activation as a result of radiation produced at ATLAS is expected to be negligible.

4.2.2. Radiation Safety System

As stated above, under normal operating conditions, the radiation hazard at ATLAS is small, but for some ions the accelerator is capable of generating and using intense beams. Consequently, the safety system must be flexible enough to permit the research program to be carried out effectively, but must also provide protection against the hazards that could result from equipment failure or operator error. The safety system is designed to satisfy both programmatic and ALARA requirements.

The maximum radiation that a beam from ATLAS can generate increases steadily with decreasing ion mass. Thus, both the engineered safety system and administrative safety controls must focus on providing radiation safety during operation with the lightest ions.

Overall, the ATLAS Radiation System satisfies all relevant DOE requirements, and radiation doses to personnel are consistent with the ALARA goals of the ANL Physics Division.

4.2.2.1. The Estimated Radiation Level, ERL

This estimate is made before each experimental proposal is scheduled and is part of the approval process. Using the beams (species of ions, energies, and beam currents) requested by the experimenter, the neutron flux at 90 degrees, 1 meter from an unshielded beam stop is calculated (Ref. 8) for the maximum energy and beam current, at the time of the safety review of the experiment. This value, called the ERL is then also verified by measuring the neutron flux with a reduced beam and scaling it up to the full intensity, at a point where the beam has reached its full energy: the ATLAS high-energy cup, or the output of the booster linac.

The 90 degree value is chosen because for most beams (including the most hazardous ones) the radiation flux perpendicular to the beam is close to the average flux. In most cases, this direction is also the most accessible one and is readily measured and monitored. For a heavy beam hitting a substantially lighter target (e.g. a Kr beam hitting stainless steel) the neutron radiation emitted in the forward direction can be higher. This can result in a narrow cone of neutrons in a space that is usually difficult to access or measure. When the conditions are such that this forward enhancement is significant and the radiation level is expected to be high, the beam stop is usually shielded. The value of the forward radiation has to be calculated (presently with the NEUGAM program), and this is used in the safety review of the experiment -- forming the basis of the "100 rem limit in any direction" in the Safety Envelope. While such peaking is expected, the peaking is dependent on the assumptions made about reaction mechanisms. The quantitative predictions by NEUGAM will be confirmed by measurements before intense heavy beams are accelerated.

The effects of various radiation flux levels in and around the facility were analyzed using Reference 3 as a basis and this is summarized in Ref 4. In the experimental areas III and IV, where the beams have their highest energies, the beam lines are well shielded at 0 deg where the radiation levels are highest, and adequately in other directions. Even at the limiting case of 100 rem/h in the ATLAS tunnel, the radiation levels in uncontrolled areas are not expected to exceed 2 mrem/h.

The ATLAS shielding in some other places, however, is not sufficient to maintain such a low level in uncontrolled areas at the highest radiation levels permitted in those places. Temporary fences ropes and postings are necessary to exclude personnel from these normally uncontrolled areas under those conditions.

4.2.2.2. Categories of Controlled Areas

All parts of the ATLAS facility are Controlled Areas‑except for the service area above the tandem vault and the cryogen-storage area outside the building. Because the time allocated for each experiment is only a few days and beam properties can change significantly both during an experiment as well as between experiments, the radiation level and the designated function of an area at ATLAS (e.g. whether it is a beam area or not) may change as often as several times per week. The radiation limits that are required for each sub-area satisfy Federal and DOE requirements, as specified in 10 CFR 835 and DOE 420.2A, Safety of Accelerator Facilities.

All parts of the facility and nearby areas outside the facility that could experience significant radiation levels are categorized below; areas where the radiation hazard is negligible (such as the control room) are not included in any of these categories.

- Category I. Interlocked and monitored beam areas. These areas include the ion sources, the tandem vault and all areas along the beam path beyond the input to the booster linac. The present interlockable areas are shown in Figure 3-1. This configuration may vary depending on the needs of the program. Since the radiation level at each location depends sensitively on beam parameters, radiation levels may vary greatly from one beam area to another. Users and operating personnel have access to beam areas when allowed by the ATLAS Radiation Interlock System (see Section 3.7.6.4) and when no special conditions are identified in the experimental safety review process.

- Category II. Interlockable, but not monitored, areas adjacent to beam areas ("Interlockable adjacent areas".) These areas are sometimes beam areas. For Standard Operations (see Section 5.3.1), access to an interlockable adjacent area is permitted if the radiation level in that area is below 2 mrem/h for the anticipated full beam energy and intensity. This condition is initially based on the Estimated Radiation Level (ERL). If access is requested to an area locked because of the ERL, then access can be granted after a full radiation survey, performed by a health physics technician under actual beam conditions, shows the area to have a radiation level below 2 mrem/h. If the survey condition does not correspond to the maximum allowed beam current, the survey results will be used to instruct the ATLAS operators on the maximum current which can be delivered with the area open.

- Category III. Lockable (but not interlockable) areas adjacent to beam areas ("lockable adjacent areas".) These areas, which consist of the ATLAS utility room, a small assembly room and the 'triangle room' that is used for the Penning Trap experiments, adjoin the ATLAS tunnel. For Standard Operations (see Section 5.3.1), access to lockable adjacent areas is permitted under the same conditions as those for Category II areas.

- Category IV. Non-lockable, frequently occupied areas adjacent to beam areas ("non-lockable adjacent areas") such as certain hallways and the work areas in which the booster linac and PII are located, are characterized by having radiation levels which are low (under 0.5 mrem/h 1 m from the source). However, special administrative controls to some of these areas may have to be imposed when conditions identified in the safety review for a particular run, for example when beams of mass lighter than 12 are accelerated, or other conditions warrant it. (See Sections 5.3.2 through 5.3.4)

- Category V. ECR Source Areas. These areas can have X-ray radiation generated by the ECR source. The ECR sources, in general, are operated when the rest of the accelerator is in use, but can also be operated independently for tests and development. The ECR source areas are enclosed in a wire fence assembly that is interlocked independently for high voltage protection, and, through the ARIS system, for radiation protection. Access to the areas is monitored and controlled by the ARIS system in a manner very similar to the Category I areas.

- Category VI. Controlled areas outside the building. These areas are the earth berm within the radiation fence (Figure 1-3) and parts of the roof of the facility. Access to these areas is permitted only for specific need under low-radiation conditions. Access is controlled by means of locked gates.

- Category VII. Nearby uncontrolled areas outside the facility. This category consists of the lawn and cryogen storage area on the north side of the ATLAS linac, the service area above the tandem vault, the road and parking area between G-Wing of Bldg. 203 and ATLAS, and G-Wing itself. The annual dose limit for a member of the public is 100 mrem (Ref. 14.) To ensure that an individual entering one of these areas does not receive a dose approaching this limit, the annual radiation level that impinges on these areas is limited by controlling, if necessary, the parameters of the beams that are accelerated. Any deviation from this policy requires a review by the Physics Division Radiation Safety Committee that would determine the required compensatory measures needed to ensure that the above dose limit to the public is not exceeded (e.g. roping of the areas where, under exceptional circumstances, this limit may be exceeded).

4.2.3. Engineered Radiation Safety System

Since the radiation safety system for ATLAS depends heavily on active hardware elements, two independent interlock systems are used to provide protection against the worst case hazard: the most intense light ion beams at full energy, that are most likely to be the ones initially accelerated in PII. The primary protection is provided by the ATLAS Radiation Interlock System described above (Section 3.7.6.4) based on an array of strategically placed radiation monitors that, when tripped, stop any beam in less than 2 seconds. A second level of protection is provided by a Beam-Current Interlock System that stops an intense beam in 20 ms. These redundant systems are independent of each other.

4.2.4. Administrative Limits on Operation

The radiation and beam-current interlock systems outlined above are designed to limit the risk from beam-induced radiation to acceptable levels for all modes of operation covered by this SAD. The risk is reduced further by administrative limits on various parameters involved in the operation and use of ATLAS. These limits include, but are not limited to the beam current and energy, and restrictions on access to various areas within the facility. These limits are relevant mainly for light ions and for possible future experiments that might require beam parameters beyond the present norm, and are determined by the review committee required to meet for light ion experiments. Most limits on radiation levels are specified in terms of neutron radiation dose rates because other kinds of radiation are much weaker and neutrons will more readily penetrate the shielding around beam areas and be scattered by the atmosphere as "sky shine".

4.3. Radioactivity

Radioactivity at ATLAS can be induced by the beam, or it can be radioactive material produced elsewhere that will be used for acceleration, radioactive targets, or radioactive sources used for calibrating detectors. The quantity of radioactive material in the facility is below Hazard Category 3 threshold levels at all times. Thus, the facility does not qualify as a nuclear facility. Beam induced activation at ATLAS is the most serious hazard and can produce radiation fields from γ rays corresponding to a rate of ~100 mrem/h 1 meter from the source. An exposure rate of this magnitude would require the following improbable combination of circumstances:

- a worst-case beam with respect to type, energy and intensity is accelerated onto a tantalum beam stop, or a lower-Z thick target.

- the beam stop is irradiated long enough to come to decay equilibrium,

- the beam-stop system is disassembled within a short time from the time the beam is removed, and

- the activated part of the beam stop is placed in an exposed location when a person is in the immediate vicinity.

The conditions assumed above have never come close to being experienced in the research program at ATLAS. (The beam that could have caused the largest activation levels was accelerated in connection with radiation-safety measurements conducted by health physics personnel.) While the probability of the above circumstances occurring at ATLAS is small, to assure that a significant radiation exposure does not occur, standard operating procedures at ATLAS require that equipment used in the beamline downstream from the linac must be surveyed by health physics personnel before, during and after disassembly. (See the Physics Division Radiation Safety Manual.) Under these procedures, the level of hazard can be determined in advance and appropriate steps can be taken to mitigate the hazard and assure that such equipment is handled appropriately.

The removal and disassembly of experimental targets, detectors, and accelerator system equipment from a beamline are controlled by the following procedures:

- Targets made of an inherently radioactive material (such as Pu) may only be removed from a target chamber after being surveyed by a health physics technician. When such targets are in use, a survey by a health physics technician is also required before the removal of any other component in the target chamber can take place.

- Detectors, accelerator system equipment, and all other targets may only be removed by Physics Division personnel who have successfully completed the appropriate Radiation Worker training and the Physics Division's Open Source training. Such targets and detectors will remain in the Experimental Area until a health physics technician has surveyed them.

- Targets and detectors which have been irradiated by a beam with an intensity greater than 100 pnA (10 pnA for beams of protons), and those located in a chamber known to be radioactively contaminated, may only be removed from the beamline after they have been surveyed by a health physics technician.

- The disassembly of targets and detectors follows the same rules as their removal from a beamline.

The hazard associated with radioactive material brought in for acceleration is typically limited to shorter-lived beams. Radioactive materials with activity levels up to 1 Ci are now in use at the negative-ion source of the tandem injector and are planned for the ECR source. The lifetimes of these materials range from a few hours to years. The total mass of the material used in the source is generally kept to 100 mg or less (never more than 1 g) and the higher specific activity levels are associated with shorter-lived species. The hazards associated with such activity are: potential exposure to radiation during the loading of the material into the source and later during cleanup, possible spillage and the potential for spreadable contamination (especially near the ion source), and the possible contamination of beamline components during the acceleration process.

In order to mitigate the hazards involved, all source loading and cleanup activity with such radioactive materials is performed under a Radiological Work Permit, following guidelines spelled out by a detailed safety review which also considers limits on the amount of radioactivity allowed. Workers involved in this activity must be trained as Radiation Workers II and health physics technicians must be present to monitor all activities. Beamlines near the source are labeled with warning labels and health physics technicians must be present during any maintenance activities requiring opening of these beamlines.

The activity generated by depositing beams of radioactive nuclei on slits, targets, beam stops, etc. is very small and poses a smaller hazard than the activities induced by the more intense stable beams.

The hazard associated with deposition of particles at a beam stop from longest-lived radioactive nuclei such as ^{238}U is negligible. Assuming that a 5 eμA U^{30+} beam is accelerated for 2000 hours per year for 10 years, the accumulation of ^{238}U in the beam pipe will be only about 4 x 10^{19} nuclei, which decay at a rate of only ~ 195 decays/sec. This corresponds to a source strength of ~ 10 nCi.

The intensity of shorter-lived radioactive beams (e.g. ^{18}F, ^{44}Ti, ^{56}Co..) accelerated from the ion source to various target stations is usually very small. (e.g. 0.1 pnA for ^{44}Ti and 0.05 pnA for ^{56}Co have been extracted from the ion source)

Assuming that a beam of 0.1 pnA of ^{44}Ti ($t_{1/2}$ = 60y) running for 30 days/year over a period of 5 years is stopped always at the same location, one obtains an activity of 75 μCi. More realistically, this activity is distributed over several locations (slits, Faraday cups, etc.) with correspondingly lower activities.

The worst-case scenario is a beam of 0.05 pnA of ^{56}Co($t_{1/2}$ = 77d) running for 30 days per year. In this case the maximum activity for stopping the beam in one location would be 2.2 mCi.

These values are smaller than the activities produced by the interaction of more intense stable beams with the material in the slits and targets.

Radioactive sources, both open and sealed are routinely used at ATLAS for detector calibration. The source strengths are typically 1µCi for open sources and 10µCi for sealed sources. The procedures for their use are described in the Physics Division Radiation Safety Manual. The use of radioactive targets, and sources with strengths larger than routine, require approval by the Physics Division Radiation Safety Committee and must be handled according to the guidelines provided by the committee. In addition, Radiological Work Permits are used when required by Laboratory regulations. All open sources are kept in the H174 laboratory and sealed sources are kept in locked safes in the ATLAS experimental area when not in use.

4.4. Electrical Hazards and Protection

The most significant electrical hazards in the ATLAS facility are:

- the high-voltage hazards associated with the ATLAS ion-source systems,
- the high voltage supplies for the booster-linac pin-diode circuits, and
- the more conventional electrical circuits distributed around the ATLAS facility, which are similar to conventional industrial installations.

The electrical safety program at ATLAS is based on the ANL ESH Manual, chapter 9-1, which derives from Subpart S of 29CFR1910 and the National Electrical Code. All potentially hazardous circuits are clearly marked with hazard-warning notices. All employees working with electrical power sources are responsible for compliance with the prescribed procedures and are trained to handle their duties.

The high-voltage systems associated with the ion sources of PII and the tandem are the major electrical hazard. Each of these sources is mounted on a platform with a maximum voltage greater than 200 kV and, relative to the main voltage platform, several lesser voltages are also present. For each system, a metal cage having the safety features listed below encloses the whole voltage platform, and a cage mounted on the platform encloses the components associated with the lesser voltages. Dual interlock switches inhibit the platform voltage when the overhead crane is located over the cage.

Any one of the high voltages associated with the ion sources is potentially lethal and, without active control mechanisms, numerous kinds of human error could result in a fatal accident. This hazard is mitigated by:

- exclusion from hazardous areas by cages and their safety systems, described below under documented procedures,

- restrictions on those permitted to operate the source, and

- training of those permitted to operate the source.

The safety systems associated with the steel cage around a voltage platform provide five levels of protection:

- the cage itself,

- a redundant interlock system that inhibits the high-voltage supply when the cage-access gate is open,

- warning lights, signs, and horns,

- a mechanical grounding bar that automatically inhibits opening the access gate until the bar makes contact with the platform, and

- a manually operated grounding stick located on the entrance to the enclosing cage.

With the above controls in place, it is likely that the main risk from the high-voltage hazard is human error. Those allowed to operate the sources must first complete the ANL Training Management System's Electrical Safety Training and Lockout/Tagout Training. The probability of an accident is believed to be extremely small. A rough indication of the electrical risk is provided by the world wide experience with voltage platforms at tandems, for which there has never been a fatality in ~1,000 cumulative years of operation.

4.5. Asphyxiation Hazards and Protection

4.5.1. Liquid Nitrogen

The worst-case possibility for asphyxiation by nitrogen is that one of the main transfer lines from the 20,000 gallon LN2 tank outside the building could be severed at a location where they are approximately 10 to 15 feet above floor level. The three lines are located in the tandem vault, the booster-linac room and the Experimental Area. Because of their rigidity, these lines could each be severed only by a large force such as the overhead cranes used in the areas.

The crane near the line in the Tandem vault cannot reach the line and such an accident would be extremely improbable.

The crane near the line in the Booster-linac room is used regularly, and there is a finite probability for such an accident in this location. To determine the effects of such an accident, an experiment was conducted which simulated such an event. The results of the experiment showed that even under this worst case condition, the oxygen content 45 inches above the floor was never less than 18 - 19%.

Nevertheless, an oxygen deficiency monitoring system is in use in the accelerator operations area covering both the above areas. If the system would detect a low oxygen level, it would cause:

- Alarms to sound and warning lights to flash throughout the ATLAS facility. (Explanatory signs are posted near the flashing lights which direct all personnel to evacuate the facility).

- The Argonne Fire Department to be automatically notified.

The liquid nitrogen system in the Experimental Area presents a potential hazard only under certain specific circumstances. So far, it has been used only when Gammasphere was located at ATLAS. At all other times, the line has been inactive. When inactive, liquid nitrogen is prevented from entering the area by the closure of three upstream valves - two mechanical and one normally closed valve which is electronically controlled. The latter can only be opened when it receives power from the oxygen deficiency monitoring system in place in the area. Therefore, when the monitoring system is inactivated, the valve is automatically in a closed position. The crane in the Experimental Area is used regularly, and the possibility of an accident occurring is in this area is real when nitrogen is present in the system. To mitigate any possible hazard from this event, active oxygen deficiency monitoring is in use in the area when liquid nitrogen is present in the system. If a low oxygen level were to be detected by the system:

- An alarm would sound in the Experimental Area, the data rooms and in the ATLAS control room. Explanatory signs are posted near the flashing lights which direct all personnel to evacuate the facility.

- The main valve at the storage tank would automatically close. This valve is a normally closed valve, so in the case of a power failure, it will close. This prohibits an electrical power failure from compromising the system.

- The Argonne Fire Department would automatically be notified.

4.5.2. Liquid Helium

The worst case for asphyxiation by helium is the possibility that one of the three 1,000 liter LHe storage dewars attached to the ATLAS cryogenic system would rupture and release its contents suddenly. All three of these dewars were built commercially by Cryenco to their standard storage-dewar design, except for the neck, which is exceptionally large (6 inch dia.) in order to accommodate several helium-distribution lines (see flow diagram in A6.8 of Ref. 2). The dewars are in different areas.

The most probable scenario for a sudden release of the LHe stored in a dewar is that the vacuum wall of the dewar is ruptured and the in-rushing air generates a large heat load on the inner vessel. A rupture of the vacuum wall could be caused by a massive blow from power equipment such as an overhead crane. An accident of this kind is very improbable because the cranes are rarely used in the neighborhood of dewars.

Based on general experience, Ref. 12 gives a value of 10^{-6} per hour for the probability of rupture of dewars in general. This value is consistent with our experience, which is in excess of $8x10^{5}$ dewar-hours of operation without a dewar accident. The probability of our dewars rupturing is thought to be far less than those in general use because:

- they are not moved,
- they are protected from mechanical damage by their locations out of traffic lanes, as shown in Figure 1.3.
- they are on average only 25% full of LHe, and
- only a few trained persons are involved in their use and maintenance.

A dewar explosion caused by an ice blockage in its necks is extremely improbable because of the dewar's design and because operation of the accelerator requires the whole helium-distribution system to be maintained free of contamination. As has been proven during 22 years of operation, power failures and accidents to attached equipment (refrigerators, etc.) do not generate enough heat or pressure input to cause an explosive situation in the dewars, because relief valves provide protection to those systems and to the dewars.

The risk from asphyxiation caused by the scenario outlined above has been evaluated (Ref. 2, Sect. A6.8) by means of the procedure described in Refs. 12 and 5, which takes into account:

- the probability of a rapid release of helium,
- the resulting oxygen deficiency under the assumption of complete mixing of helium with air, and

- the probability of death from the oxygen deficiency.

This analysis shows that the fatality rate for any of the dewars is lower than 10^{-10} per hr. (By definition, the fatality rate here assumes a 100% occupancy rate.)

Thus, the areas are classified as Category 0 areas (under 10^{-7} per hour), and no special precautions are required by the standards given in Ref. 5. The small fatality rates for the dewars result mainly from the large volumes of the high bay areas in which they are located. The only possible exception to this rule is the area around the K dewar. That area is protected by the presence of an oxygen deficiency sensing head that is installed immediately above that dewar (Figure 1-3.)

4.5.3. Sulphur Hexafluoride (SF_6)

During operation, the 12 m^3 tank of the tandem electrostatic accelerator is filled with SF_6 insulation gas at a pressure of ~80 psi (absolute). When the interior of the tandem tank is opened for maintenance, the SF_6 is stored in liquid form in a high-pressure tank located in the service area above the tandem vault. Although SF_6 is not toxic, the large volume of inert gas associated with the tandem constitutes an asphyxiation hazard. At ATLAS, this hazard is present in three locations, the tandem tank, the tandem vault and the service area.

4.5.3.1. Tandem Tank

It is necessary to enter the tandem tank occasionally for maintenance. The hazard associated with this work could result from either of two possibilities:

- a failure to completely replace the SF_6 in the tank with air before entry, or
- an accidental opening of valves that would refill the tank while someone is inside.

These hazards are mitigated by the use of documented entry procedures and restriction on the personnel who may work in the tank. The procedures include the following precautions:

- a Lockout/Tagout procedure is in place for this operation. The procedure follows the ANL ESH Manual requirements. The procedure details the lockout/tagout of the appropriate valves in the SF_6 system,
- continuous air circulation through the tank when it is occupied is assured by the use of an external fan,
- an oxygen deficiency monitor is always used by the personnel when entering the tank.

These procedures are reviewed regularly as required by the ANL ESH Manual chapter on Confined Spaces.

4.5.3.2. Tandem Vault

In the tandem vault, outside the tandem tank, the asphyxiation hazard stems mainly from the large density of SF_6 gas (~ 5 times greater than air), which would cause the SF_6 to stratify to the lower portion of the room. The most probable way that this hazard could be initiated is by the breaking of a pipe or port on the tandem tank. A breakage that could cause an SF_6 leak rate great enough to be potentially lethal would require a considerable force or impact, such as could be delivered by the overhead crane. An accident such as postulated here is very improbable because the crane, which is slow moving, is used rarely and then only for handling rather small objects such as beam-line components. Because of limited headroom, the crane cannot be used to transport large objects into the building from the truck door at the north end of the vault.

If all of the gas in the tandem tank were released suddenly, the tandem vault would be filled with SF_6 to a depth of 7 ft.

This hazard is mitigated by the following:

- The tandem tank and its piping are inherently safe against a sudden rupture, since the tank is a coded pressure vessel with a certified maximum working pressure of 300 psig. The system is operated at ~20% of this value. In over 1000 use-years of worldwide operation of tandems with pressure tanks, to our knowledge there has never been an incident in which a large volume of insulating gas was released rapidly.

- The oxygen deficiency monitoring system used in the ATLAS Operations area monitors conditions within the tandem vault. Any decrease in oxygen level in the vault would result in the same actions as mentioned above, in Section 4.5.1.

4.5.3.3. Service Area

The SF6 storage tank or its piping could rupture. The storage tank is a coded pressure vessel that usually operates at a pressure of ~400 psi and has pressure relief at 650 psi by means of 2 parallel burst disks that exhaust outside the building. Sudden rupture of the system is very unlikely because:

- there is no large source of energy such as a crane or a lift truck used in the area,
- there are few penetrations of the pressure vessel, and
- work activity in the area is infrequent.

Fire cannot easily rupture the tank because:

- it is insulated with non-flammable material

- there is little flammable material in the area, and
- the area is equipped with smoke sensors and sprinklers.

The storage tank has a large amount of SF_6 in it less than 5% of the time, and the occupancy rate of the area is less than 2%. These facts, combined with the inherent safety of the SF_6 storage system, as outlined in the preceding paragraph, ensure an extremely low risk of explosion from the system.

Also, the oxygen deficiency monitoring system described in Section 4.5.3.2 includes in its coverage the service area and provides the same protection as it does in the areas discussed above.

4.6. Explosive Rupture Hazards and Protection

4.6.1. Liquid Nitrogen

Analysis shows that the risk from explosion caused by LN2 in the ATLAS distribution system is minor. The principal controls and mitigating factors are:

- the volume of LN2 in individual vessels is small (less than 50 l),
- the maximum rate of heat transfer into LN_2 caused by a failure of the insulation vacuum is small because of the presence of superinsulation (Ref. 11) around all vessels and piping (except within beam-line cryostats),
- the heat of vaporization of LN_2 is relatively large, and
- all vessels have adequate pressure relief.

4.6.2. Liquid Helium

A cryogenic explosion can occur if a pipe or vessel containing a cryogen has inadequate pressure relief for the gas generated by a credible heat input. All vessels and cryostats and all parts of the LHe system of ATLAS have been analyzed for this hazard. Pressure relief valves and burst disks have been installed throughout the system to provide protection against this hazard, wherever necessary.

The greatest explosion hazard at ATLAS is that associated with the three 1,000 l storage dewars discussed above in Section 4.5.2. As indicated there, the probability of such an explosion is estimated to be 10^{-6} per hour per dewar. The hazard from explosion of the dewars is mitigated by the protection provided by walls, radiation shielding, and nearby equipment and by the low occupancy rate in hazardous areas. Overall, the average occupancy rate in the general area near each dewar is estimated to be 3%. Also, shrapnel from an explosion would cover only a small fraction of the solid angle. Taking all these factors into account, the risk of injury is less than 3 x 10^{-9} hr-1 per dewar, or 10^{-8} hr-1 for all dewars. Only a small fraction of these potential injuries would result in death.

In addition to the explosion hazard associated with dewars, two other potential hazards need to be considered:

- trapped LHe in distribution lines, and
- accident-induced pressure in beam-line cryostats.

With respect to trapped LHe, all parts of the LHe-distribution system have adequate pressure relief, with one exception. Through a design error, there is one tube in a distribution line that does not have pressure relief between three valves. It would be possible to close all of these valves while LHe is in the line, creating a trapped volume. The hazard potential is minimal because:

- the amount of potentially trapped LHe is small (~0.5 kg.)
- the tube in question is surrounded by 4 concentric layers of stainless-steel piping.

However, this potential hazard has been further mitigated by the following:

- only a limited number of highly trained people access this system.
- the valves all have tags attached stating they must be kept in the "open" position.

The potential explosion hazard for the beam-line cryostats needs to be examined mainly because of the relatively high probability of vacuum incidents (such as the accidental opening of a beam-line valve) which flood the insulation-vacuum region of the cryostat with air. An experimental test described in Appendix 7 of Ref. 1 showed that vacuum failures of this kind are not a safety hazard for the cryostats used in the main ATLAS linac, and the results of several substantial vacuum accidents have confirmed this conclusion. However, it is physically possible to have a more rapid inrush of air because of a major mechanical accident in which a large opening is created in the vacuum wall of the cryostat itself. This scenario is highly improbable, and no such accident has been experienced at ATLAS in more than 20 years of operation or in any other beam-line cryostat.

The safety implications of a catastrophic rupture of the vacuum wall of a beam-line cryostat have been analyzed. Two volumes in the cryostat contain significant amounts of helium:

- the LHe entrance manifold which holds about 6 kg of helium, and
- the LHe exit manifold, which holds about 3.5 kg of helium.

The rate of heat input into this helium is limited by the heat-transfer coefficient (Ref. 11) of the helium-vacuum interface when the rate of inflow of air is very large. As a result, even for an instantaneous loss of vacuum, the rate of pressure increase is small enough that the pressure relief capability of the input manifold is adequate. Pressure relief for the exit manifold itself is also adequate. However, several bellows attached to this manifold might not have the required large factor of safety for a worst case vacuum accident, although we know that these bellows have not in fact ruptured in several substantial vacuum accidents. In any case, a rupture of a bellows would not pose a safety hazard because:

- the manifold is enclosed within a secondary barrier, a large-volume thick-walled stainless steel cryostat with excellent pressure relief, and

- the amount of helium in the manifold is small. It would occupy less than 2% of the vacuum space at atmospheric pressure. The cryostat design used for the injector linac is quite different than that of the main ATLAS linac. In particular, it is a gravity flow system in which LHe is stored in a 200 liter internal dewar. Analysis shows that the pressure-relief capability provided for this dewar is adequate under the worst case accident, a sudden inrush of air into the vacuum space.

4.7. Flammable Liquids

The hazard of fire and explosion due to the ignition of vaporized flammable liquids is controlled at ATLAS by strict limits on the quantities of such liquids permitted in the area. Flammable liquids are stored and used in small quantities for incidental use only. The quantities of such liquids are controlled so as to conform to the requirements of the ANL ESH Manual (Chapter 11-3). Flammable-liquid storage cabinets are used for long term storage of these liquids.

4.8. Fire

The ATLAS facility is in compliance with NFPA 101, Life Safety Code. It is protected against fire by the following means:

- a smoke-detection system is installed throughout the facility and is connected to the ANL Fire Department and also sounds local alarms to alert the personnel in the facility,

- heat sensitive automatic sprinklers are installed throughout the facility,

- portable fire extinguishers are mounted at readily accessible locations throughout the facility and, in case of fire, egress is possible through exits along the perimeter of the building.

In the judgment of a fire-safety consultant (Ref. 6), the fire hazards at ATLAS range from light to ordinary. Combustibles consist of electrical and electronic cables and equipment, small quantities of combustible liquids and gasses, and small quantities of paper.

The greatest fire risk to the facility are cable fires. There are two potential causes for such fires:

- accidental insulation failures occurring in places where concentrated cable pathways (e.g. in cable trays) exist. Fires of this kind are improbable at ATLAS compared to other accelerators because of the low power levels of most equipment. There are few large magnets, the superconducting accelerating structures cannot be damaged by cooling failure, the 100 kW electric motors of the helium compressors are immersed in helium gas, and power conducting cables and signal cables are separated. The cabling used throughout ATLAS is rated for the power levels it is expected to carry.

- exposure to a fire already started from another source which has not been extinguished quickly. The potential for this occurring is minimal due to the fire protection features mentioned above.

If a fire were to start, the first level of protection is the initiation of an audible fire alarm by the smoke detector system, and the activation of the appropriate sprinklers (if the fire intensity is sufficiently large.) Should this occur, beam delivery is interrupted, operations cease and personnel are evacuated. During off-hours, the operators serve as wing monitors. Portable fire extinguishers are available for immediate action. The Fire Department serves as the second level of protection. The Department is automatically alerted at the activation of either the smoke detection or the sprinkler systems. The Fire Department is manned continuously, providing on-scene response within 3 minutes.

4.9. Flammable and Toxic Gases

Relatively small quantities of flammable isobutene gas are used as the ionization medium in various types of detectors for the experimental research program at ATLAS. The hazard of a gas explosion exists at several points, namely:

- leakage and local accumulation from the supply side of the gas handling system,

- accumulation of exhaust from the gas handling system,

- leakage and/or breakage of detector foils into the vacuum system, and

- accumulation of gas released during recycling of high vacuum cryo-pumps.

The safe handling of such gases is assured by the implementation of extensive safety precautions described in the Physics Division document titled "Procedures for the use of Isobutane and other Flammable Gases." (Ref. 17) The use of a toxic gas with a TLV less than 20ppm requires prior approval by the Physics Division ESH/QA Engineer. All source vacuum pumps are vented to the outside.

There are no natural gas lines terminating at or near the ATLAS facility.

4.10. Radio-frequency Fields

The radio frequency systems for ATLAS operate between 48.5 MHz and 97 MHz at power levels that do not exceed 250 watts in any individual rf amplifier driving beam-line resonators, and do not exceed 5 KW in the amplifier used at the test cryostat. The radio frequency power amplifier systems are heavily shielded to eliminate detectable leakage. No detectable leakage is observed from the RF resonators outside of their cryostats. The ECR sources utilize 10 Ghz., 2.5 kW and 14 Ghz., 2.5 kW transmitters. The sources are tested for leakage when first assembled, and are retested whenever work is done which might disrupt the shielding.

4.11. DC Magnetic Fields

Magnetic fringe fields originating from beamline elements and magnetic elements of several spectrometer systems in the ATLAS experimental area could pose significant localized hazards to persons with cardiac pacemakers. The American Conference of Governmental Industrial Hygienists' 2001 edition of the Threshold Limit Values and Biological Exposure Indices recommends that workers having implanted pacemakers not be exposed to magnetic fields in excess of 5 Gauss. Such fields may exist in close proximity to beamline and spectrometer magnets. Entrances to ATLAS areas where strong magnetic fields may exist are posted with OSHA-code warning signs stating that such magnetic field hazards may be present in the ATLAS area, and yellow warning lights are installed at beam-transport dipole magnets that are easily accessible.

5. ATLAS Envelopes

The Accelerator Safety Envelope for ATLAS defines the outer boundaries for the operation of the facility, within which the more restrictive Operations Envelope describes more specific limits.

The Accelerator Safety Envelope (ASE) for ATLAS is a set of technical and administrative requirements that establish and define the boundaries within which the accelerator and its experiments may be operated. These conditions are based upon the requirements documented in DOE Order 420.2a and its associated guidance document. The conditions are designed to constrain the operation of ATLAS such that the facility staff and users, ANL employees, public, and the environment will be protected. Operation of the facility is permitted as long as ATLAS operates within the set of technical and administrative requirements documented in the ASE. Exceeding the ASE would require an immediate shutdown and notification of DOE.

The Operations Envelope sets up a system of controls to minimize radiation exposure to personnel well below the DOE limits in accordance with ALARA principles and functions to ensure that the limits of the ASE will not be approached. Thus, the ASE tends to be more general and sets the outer limits, whereas the Operations Envelope fits within it and defines the rules and procedures in more detail. The Physics Division Director or Designee approves the operations envelope and any subsequent change(s).

The selection of limits defining the ASE are based on the hazard, MCI (Sec. 5.6), and shielding analysis documented in Chapter 4 of this SAD. Any revision to these limits resulting from changes in operating conditions or modifications to the ATLAS facility will require a revision or supplement to the SAD. The Physics Division Safety Committees, under the direction of the Division Director, are those normally responsible for reviewing modifications to the facility or any emergent issues that potentially could have implications affecting the ASE.

5.1 Accelerator Safety Envelope

The Accelerator Safety Envelope for ATLAS consists of the following:

5.1.1 Technical Requirements

5.1.1.1 Engineered Safety System

A validated, engineered radiation safety system, consisting of ARIS as well as other active control devices, shall be in place and operational to the extent defined and described by this SAD.

5.1.1.2 Beam Parameter Limits

- Beams of the hydrogen isotopes ^{2}H and ^{3}H will not be accelerated by ATLAS to an energy of more than 0.4 MeV, except as results from minor impurities in other source materials.
- The energy of all beams from ATLAS will be less than 25 MeV/u.
- No operation shall be authorized to proceed with an Estimated Radiation Level ERL of the beam greater than 30 rem/h nor with a radiation field 1 m from any source in excess of 100 rem/h. (See Note 1.)

5.1.1.3 Radiation Dose Limits (See Note 2.)

- Exposure of any person to radiation produced by ATLAS beams will not exceed 1 rem in one year.
- No person, whose workplace is outside the ATLAS facility, shall have an exposure from such radiation produced by ATLAS beams in excess of 100 mrem in one year.
- The dose generated by ATLAS beams to the general public, outside of the Argonne site limits, will be less than 10 mrem in one year.

5.1.2 Administrative Limits

5.1.2.1 Facility Access

No entry is allowed to any area with radiation levels greater than 5 rem/h. Entry with levels below this, but exceeding the Operations Envelope, will require specific Radiological Work Permits.

Note 1: The rationale for describing the ASE in terms of a radiation level (vs. a bounding current) is that the radiation level is dependent on the parameters of the ion species being accelerated. There are numerous ion species of varying mass that are accelerated with different energies, charges, and currents to fit the need of the experimenter. A limiting current or energy limit for a particular beam species that would be associated with a particular ERL may not be appropriate for another beam species. Specifying the envelope in terms of a radiation level will allow normalization of the radiation effect of the various ion species for comparison to a common evaluation guideline. The evaluation guideline has been shown to be a safe bounding value based on the analysis documented in Reference 3. Radiation levels of the ion species with various parameters are based on operational experience and extrapolation of empirical data.

The NEUGAM program has been written to allow an estimate of radiation levels to be made before experiments are carried out. It has been verified to be approximately correct at 90 degrees. Representative curves are shown in Figure 5-1 for ERL values corresponding to the Safety Envelope Limit of 30 rem/h. A beam stop of Fe was assumed as a worst case. The usual beam stops are tantalum, but sometimes the beam may be intercepted by lighter materials, such as iron, stainless steel, or titanium. Figure 5-2 is a similar plot corresponding to the 100 rem/h Safety Envelope limit for ANY radiation field. The prediction of NEUGAM is that for heavy beams the radiation field will be sharply forward peaked and this is therefore a more restrictive limit for the heaviest beams (and the lightest targets). While such peaking is expected, the peaking is dependent on the assumptions made about reaction mechanisms, and its quantitative aspects will be confirmed by measurement of representative beams before intense heavy beams are to be accelerated.

Note 2: Active radiation monitoring by detectors that are part of the ATLAS Radiation Interlock System and other additional monitors that may be required as a result of specific experiment safety reviews shall be used to insure that the maximum doses specified in 5.1.1.3 will not be exceeded.

5.2. Operations Envelope

This section defines the Operations Envelope of ATLAS. The Operations Envelope is defined in addition to the Safety Envelope, and consists of a set of administrative controls imposed on the operations at ATLAS. These controls are created by the Physics Division to ensure that the Safety Envelope is not approached. The section below describes the control elements in place at the time of publication of this SAD. These elements may be changed from time to time. However, any such change may only be made with the written approval of the Physics Division Director or the Director's designee.

Section 5.3 specifies additional requirements for two modes of operation requiring separate reviews. The primary control on radiation hazards at ATLAS is an engineered control, the ATLAS Radiation Interlock System, or ARIS (Section 3.7.6.4). This system continuously monitors the state of the accelerated beam and radiation conditions within ARIS-controlled areas. Based on these inputs, ARIS allows or prohibits access to these areas and presents real time displays of conditions within the areas.

Complementing the ARIS system are administrative controls on radiation hazards at ATLAS. These are described below.

5.2.1. Facility Access

Access to the potential radiation areas of the facility is controlled when the accelerator is in an operational mode. The "facility" includes the fenced-in earth berms and part of the roof of the building housing ATLAS.

5.2.2. Engineered Safety Systems

The engineered safety systems, ARIS and the ATLAS Beam-Current Monitor, must be functional for beam to be accelerated through the ATLAS facility. The ATLAS Beam-Current Monitor provides a level of redundancy to the ARIS system especially with respect to the high radiation conditions. These systems undergo periodic (at this point semiannual) tests to ensure proper operation of each system. All personnel working at ATLAS must be trained to properly understand the functioning and use of the ARIS system.

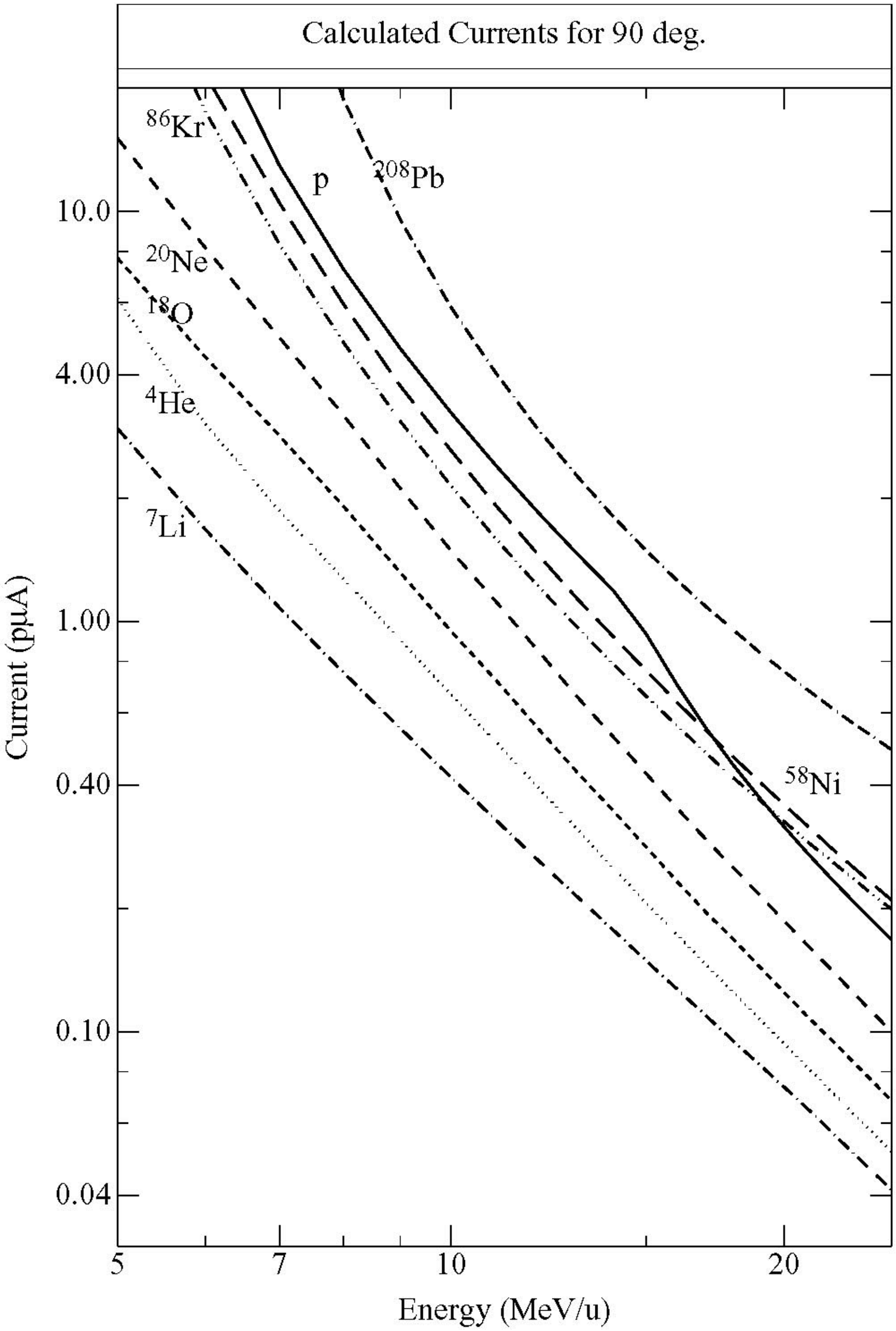

Figure 5-1

Beam currents calculated by the NEUGAM program for a representative set of beams that correspond to an Estimated Radiation Level (1 m from any possible beam stop, at 90 degrees to the beam) of 30 rem/h, the limit set in the Safety Envelope. The beam stop is assumed to be Fe – as typical of the lighter materials that may be along the beam path. Such calculations are used in planning a measurement, for an indication of probable radiation levels. The actual levels are established by measurements. The figure extends beyond the present limits of the accelerator in both beam current and energy for some of the beam species. The present limits are shown in figures 3-2 and 3-3.

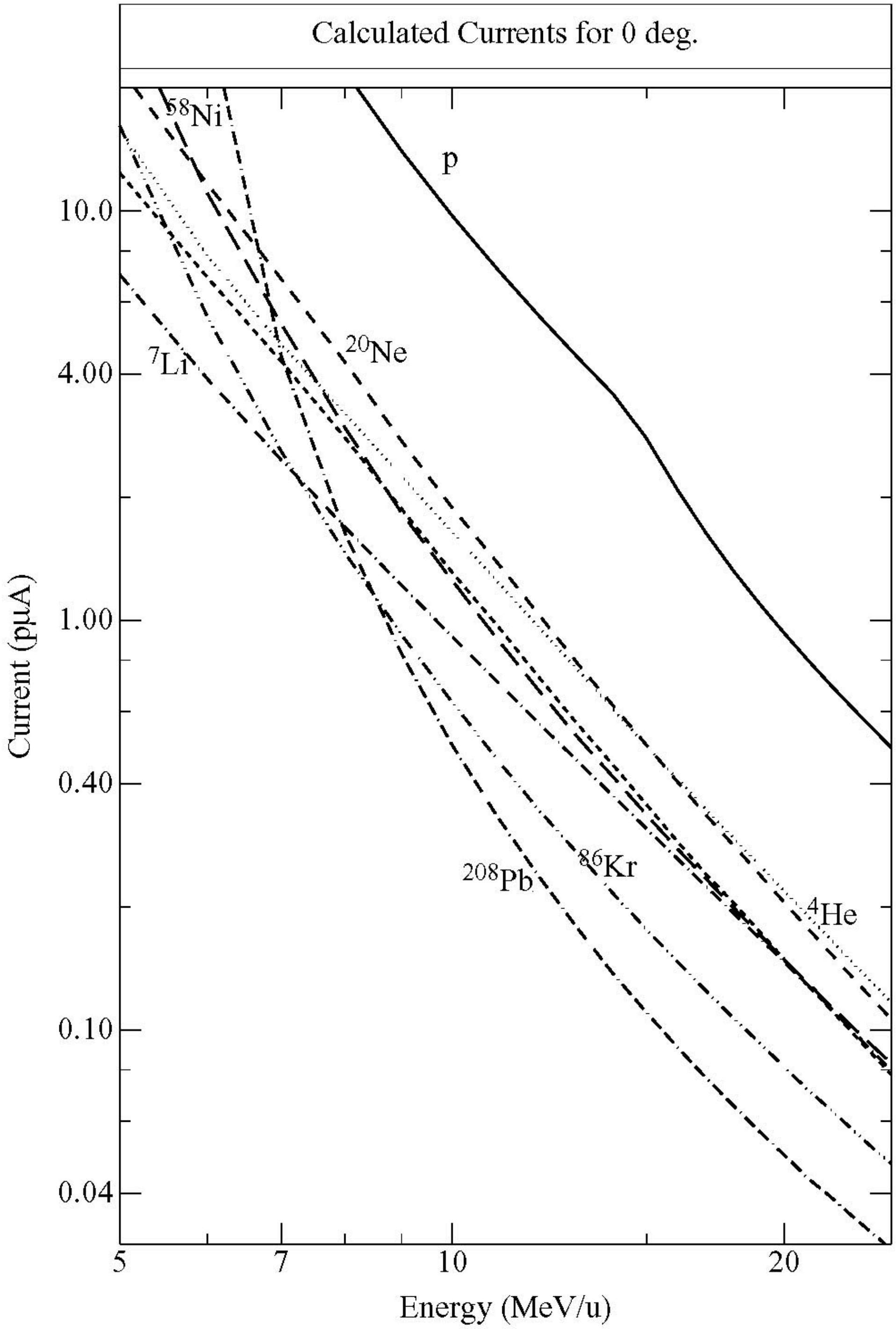

Figure 5-2

Beam currents calculated by the NEUGAM program for a representative set of beams that correspond to 100 rem/h at 1 m in the 0 degree forward direction from an Fe beam stop, as in Figure 5-1. The sharp angle dependence for the heaviest beams (Kr and Pb) will have to be confirmed by measurements.

5.2.3. Beam Limitations

5.2.3.1. When helium is used as a support gas, the accelerator will not be tuned to a charge-to-mass ratio of 1/2 or 1/4 without an experiment-by-experiment review by an ad-hoc committee appointed by the Division Director.

5.2.3.2. For any ion beam with mass below 23 that needs to be attenuated by a factor larger than 10, the attenuation must be achieved by means of a beam current attenuator.

5.2.3.3. The energy of all ATLAS beams will be lower than 20 MeV/u.

5.2.3.4. The energy of all beams accelerated by PII alone will be below 2.5 MeV/u.

5.2.3.5. The schedule of beam acceleration must be such that ATLAS will not cause anyone outside of the facility to receive a radiation dose of more than 50 mrem annually.

5.2.4. Accelerator Design

Except for the beam-target location and the region upstream from the Booster linac, the primary accelerated beam must not be able to strike any material lighter than steel unless such use is approved by the Physics Division Radiation Safety Committee or an ad-hoc committee appointed by the Division Director.

5.2.5. Access to Radiation Areas

Access to different parts of the facility are governed by the radiation levels listed in Table 3-3, and the categories of operation described in Section 5.3.

5.2.5.1. For primary beams with A lighter than 12 delivered to an ARIS-monitored area, access to that area is permitted only with a Radiological Work Permit, after appropriate review as described in Section 5.3.2.

5.2.5.2. For primary beams with mass between 11 and 23 delivered to an ARIS-monitored area, access to that area is permitted only for energies E/A under 10 MeV/u.

5.2.5.3. For all beams, access to any area adjacent to a beam area is permitted without a prior radiation survey only if the ERL of the beam is less than 100 mrem/h. For example, this includes lockable or interlockable areas that are not directly along the beam path but adjoining it, such as Target area III, as shown in Figure 1-3, at times when beams of high ERL are transported past the ATLAS high-energy cup. For any beam above this value of ERL all adjacent areas must be locked until a radiation survey has been performed and the health physicist has established access conditions, taking into account the beam current at the time of survey and the maximum approved value. For non-lockable adjacent areas, the Health Physicist assigned to the Physics Division will always establish access limitations on the basis of radiation surveys.

5.2.5.4. The Access Gate of a beam area downstream of the accelerator will be locked if the Estimated Radiation Level ERL of the beam is greater than the "locked-state level" of 100 mrem/h. Entry to such an area may be allowed if a survey has verified that the Radiation Level is no higher than 5 mrem/h at 1 m. at that beam energy and intensity. Entry may continue at increased intensities so long as the Radiation Level remains below 5 mrem/h at 1 m. as scaled from the previous survey. For other limitations, see also Sections 5.3.2 through 5.3.4.

5.2.5.5. Access to areas with radiation levels above those specified in 5.2.5.4 or bypass of any safety interlock, when conditions absolutely require it, is permitted only under the conditions specified in an approved procedure after a thorough review, and under a Radiological Work Permit.

5.3. Categories of Operation

Operations at ATLAS fall into the following categories:

- standard Operations, examples of which are given in Appendix 1,
- acceleration of ions with mass less than 12 (except deuterium and tritium beams below 0.4 MeV and beams with Estimated Radiation Levels greater than 5 rem/h,)
- acceleration of any beam that has an Estimated Radiation Level greater than 5 rem/h and deuterium and tritium beams.

Examples of these latter two categories are given in Appendix 2. In no case may the operating envelope limits be changed to exceed values that violate the ATLAS Safety Envelope or the requirements specified in 10 CFR 835.

5.3.1. Standard Operations

In general terms, "Standard Operations" includes all modes of operation with low-intensity beams having atomic weight greater than 11 and an expected value of ERL less than 5 rem/h, and are not expected to produce a radiation field exceeding 15 rem/h 1 m from any source in any direction. (The only exception to the above is the ERL value allowed in the 40° bend region and ATLAS tunnel. The allowed ERL in those areas is reduced to 2 rem/h due to shielding limitations.) Most, but not all, of the running time at ATLAS has been in this mode. The limiting ERL for Standard Operations are given in Table 3-2. All experiments that fall into this category are reviewed as detailed in Section 3.7.5.1.

5.3.2. Acceleration of low mass ion beams (except deuterium or tritium beams below 0.4 MeV)

All experiments involving the acceleration of beams with atomic mass less than 12 (except deuterium or tritium) which have an expected ERL less than 5 rem/h and are not expected to produce a radiation field exceeding 15 rem/h 1 m from any source in any direction will require a separate documented review by the Physics Division Radiation Safety Committee. The review for each such experiment will include: a) a consideration of possible worst-case incidents, b) a reexamination of requirements for reentry into beam areas where a secondary beam is present and areas adjacent to them, c) an examination of the potential for excessive radiation in non-interlockable areas, and d) the imposition of additional administrative constraints, if needed. The committee's report to the Division Director will include a recommendation for approval (along with any additional administrative constraints) or disapproval. The Division Director must authorize each such experiment separately.

5.3.3. Operation with Estimated Radiation Level ERL greater than 5 rem/h or with an anticipated radiation field exceeding 15 rem/h 1 m from any source.

All experiments using beams with an Estimated Radiation Level ERL above 5 rem/h or which are expected to produce a radiation field exceeding 15 rem/h 1 m from any source in any direction will require a separate documented review by an ad-hoc committee called by the Division Director. This committee will include at least one member from outside the Physics Division. The committee's review will include the items detailed in Section 5.3.2 above. The committee's report to the Division Director will include a recommendation for approval (along with any additional administrative constraints) or disapproval. Subject to this review, the health physics technician(s) will be available at all times and will check radiation levels at least once per 8 hour shift. For such experiments the entire ATLAS facility will be operated under a Radiological Work Permit and access to the facility will be limited to personnel essential for operating ATLAS or the experiment. The Division Director must authorize each such experiment separately.

5.3.4. Operation with Beams of Deuterium or Tritium below 0.4 MeV

All experiments using beams of deuterium or tritium will require a separate review as described in Section 5.3.3.

5.4. Administrative Controls

It is the responsibility of ATLAS management, supported by Physics Division management, to enforce administrative controls in the operation and use of ATLAS. As outlined in the "Conduct of Operations" the ATLAS Operations Manager, the ATLAS Operations Supervisor, the Chief Shift Operator, and the Health Physicist assigned to ATLAS play key roles in the implementation of administrative requirements. For each scheduled experiment, the approved operating parameters are specified in a formal "Authorization to Operate" document that limits the range over which the parameters may be varied. The Operations Supervisor has the responsibility for enforcing these limits and the Chief Shift Operator is responsible for configuring the accelerator so that these limits are not exceeded. The accelerator operators will also implement all limits on access into monitored beam areas.

When the Estimated Radiation Level ERL of the beam in the area is less than the "locked state level", the operator may grant access to the experimental areas. For these low hazard beams the experiment spokesperson is responsible for monitoring the area status. Trained users are authorized to execute "low level" area sweeps (to search for and remove personnel). Completing such a sweep will place the experimental area in a "Restricted Access - Not Occupied" state. The user is responsible for monitoring the 8-hour integrated dose level and preventing it from reaching the Dose Limit.

5.5. Radiation Shielding

Ref. 3 gives an analysis of the shielding presently in place at ATLAS. The Physics Division has developed a policy which governs the configuration of shielding at ATLAS. The policy requires that shielding be used as necessary to limit the radiation exposure of the general public as well as facility employees and users. Procedures which verify the proper configuration of existing shielding are under development and will be implemented beginning with the testing of the Radiation Interlock System in the winter, 2002. (Ref. 16)

5.6. Maximum Credible Incident

5.6.1. The Incident

The maximum credible incident (MCI) would occur with ATLAS beams from the Positive Ion Injector. The ECR ion source of this Injector can produce much higher beam intensities than the Tandem. The highest radiation levels are produced by the lighter beams (e.g. oxygen) in the upper range of energies that can be reached by ATLAS.

The incident is in the course of an experiment that requires a high intensity and relatively high energy ^{16}O beam, where no access can be allowed. However, during the setup and testing process, it is necessary for the experimenters to enter the target area with weak pilot beams in order to optimize the alignment and detector arrangement.

The requested full beam is 2 pμA of ^{16}O at 10 MeV/u. The ion source is tuned for 3 pμA (allowing for an operating margin). In order to keep the beam-induced radiation level low, the intensity of the pilot beam is reduced to 0.00025 pμA by the use of several attenuators. At this beam current, the radiation levels are below 5 mrem per hour and the Operations Envelope permits access.

Through a failure to follow procedures and poor communication between the experimenter and the operator, the operator removes one of the beam-limiting attenuators. This is a fairly slow process requiring approximately 30 seconds. The beam current increases by a factor of 1000, the largest single attenuation factor available, to 250 pnA. The experimenter is now in a radiation field of ~5 rem/h that would subject him or her to a dose of 5 rem in one hour, were it not for the protective features of the ATLAS safety system.

5.6.2 Mitigation of the MCI

There are several redundant systems that will mitigate the consequences of such an accident:

- The ARIS high-level area neutron monitors will exceed their programmed limits for neutrons and the beam will be inhibited in approximately one second.
- A completely redundant system, The ATLAS beam-current monitor will also sense the increase in beam current above the approved limit and the beam will be stopped in less than 0.1 sec.

Thus the total dose to the experimenter is expected to be below 2 mrem.

Two further factors will also tend to limit the exposure:

- The ARIS low-level radiation monitors will respond and inhibit the beam within 30 seconds.
- Additional mitigation is in the characteristics of ATLAS. For such high beams, the sudden added load of the high beam current requires careful tuning and adjusting of the accelerator parameters. If the high beam is suddenly injected, without further tuning and attention, this will likely cause quenching of some of the superconducting solenoids, and result in beam loss within the accelerator enclosure at lower energies and before the full intensity has been reached.

6. Quality Assurance

In order to ensure safe operations of the ATLAS facility, the Quality Assurance Plan of the Physics Division is followed.

7. Decommissioning and Decontamination (D&D)

Decommissioning and Decontamination will be similar to that of other accelerators. Radioactive material involved in the decommissioning and decontamination plan of ATLAS will be primarily activated beamline components. The majority of material to be disposed of will consist of beamline components and related hardware.

At the time of decommissioning, the equipment inventory that is currently maintained will be reviewed to assess which equipment can become available after the facility's closure.

Hardware and other equipment which is installed outside radiological areas will be excessed using standard ANL procedures for disposition of government property.

Hardware and other equipment from radiological areas will be decontaminated if necessary, re-used by similar facilities or disposed of as radiological waste.

Decommissioning will comply with DOE Order 5820.2A, Radioactive Waste Management.

8. Waste Handling and Disposal

Conventional solid waste, primarily waste paper and packing material, is disposed of similarly to waste from other laboratories and office buildings on the ANL-E site, with the exception that all waste in radiation areas is surveyed prior to leaving those areas to ensure that no radioactive material is released.

During the operation of the ATLAS accelerator facility there is no release of hazardous material. The only by-products are the release of cooling water from ATLAS support systems to the sanitary system, nitrogen gas and SF_6 to the atmosphere during the transfer to and from storage and the accelerator.

Minimal amounts of radioactive or hazardous waste are generated as a result of activities at ATLAS. Such waste, when it is generated, is disposed of following the requirements found in the ANL-E Waste Handling Procedures manual.

References

1. 1985 Safety Analysis Review of ATLAS (October 21, 1985).

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4. ATLAS Report RA-7, "Maximum Radiation Dose Rates from the ATLAS Facility", R. Pardo, 8/7/2002.

5. Physics Division Cryogenic Safety Manual (Physics Division Document).

6. Building 203 - ATLAS, Means of Egress Survey Report, W. L. Futrell, Fire Protection Consultant (February 5, 1991).

7. Heavy-Ion Target Area Fast Neutron Dose Equivalent Rates, W. F. Ohnesorge, *et al.*, Health Physics, Vol. 39, p. 633 (1980).

8. Radiation Safety at Low Energy Heavy Ion Accelerators, B. Back (1993); NIM B74, 527-541 (1993).

9. Analysis of Radiation Hazards at ATLAS, a Physics Division Document, L. M. Bollinger, (July 1991).

10. A Proposed Scheme for ATLAS Radiation Interlock System, a Physics Division Document, J. P. Schiffer (March 12, 1991).

11. Technology of Liquid Helium, ed. R. H. Kropschot *et al.*, National Bureau of Standards Monograph 111 (Oct 1968).

12. Cryogenic Safety Document No. 5064 for Fermi National Accelerator Laboratory.

13. ATLAS Radiation Interlock System, B. B. Back *et al.*, (March 10, 1992).

14. Department of Energy, 10CFR part 835, Occupational Radiation Protection, Final Rule (November 4, 1998).

15. Physics Division ALARA goals, set yearly

16. Physics Division Shielding Verification Procedure

17. Procedures for the use of Isobutane and other Flammable Gases, a Physics Division Document, B. G. Glagola and J. R. Specht (March 11, 1991)

Appendix 1

Several examples are given of the types of experiments that fall in the Standard Operation category, along with procedures and limits that are required for each.

Mode N1: Primary Beam into Experimental Area III/IV.

Radiation: all measured values of radiation, and the value of ERL must be less than the "high-level limit" of 2 rem/h for all areas along the beam path up to and including the 40° -bend region and 5 rem/h for all areas after the 40° -bend region.

Mode N2: Primary Beam into Experimental Area II.

Radiation: all measured levels of radiation along the beam path, measured at 1 m, must be less than the "high-level limit" of 2 rem/h.

Hallway: whenever ARIS measures a radiation value greater than 100 mrem/h at
1 m in Area II (see Figure 1-4), the areas and hallways adjacent to Area II, including the Triangle Room (Ion Trap Area), will be surveyed and, if necessary, controlled by health physics personnel.

Mode N3: Primary beam hits target in ATLAS linac tunnel, and secondary beam may be going into Experimental Areas III or IV.

Radiation: Same as for mode N1, but if ERL exceeds 1 rem/h and access is needed to the secondary beam areas or adjacent areas, a review of the Radiation Safety Committee must approve this. The review should consider additional monitoring (with either audible alarms or interlocks outside ARIS) to be installed in the areas to be occupied, to guard against personnel exposure to accidental leakage of the primary beam and other worst-case scenarios

Appendix 2

Examples are given of the types of experiments that require special consideration.

Mode X1: primary beam with ERL greater than is permitted for Standard Operations where the beam hits a target in the ATLAS linac tunnel and secondary beam may be going into Area III or IV.

- Radiation levels must be less than 30 rem/h at 1 m everywhere along the beam path.

- The ATLAS facility must operate under a Radiological Work Permit.

- No access to monitored beam areas is permitted.

- Access to adjacent areas (accessible areas adjacent to primary beam areas) is strictly limited and controlled by health physics personnel, with details spelled out in the Radiological Work Permit applicable to the particular experiment. Health physics personnel monitor radiation levels at least once per shift. The nearby areas outside the facility are also surveyed and monitored by health physics personnel.

- All beams going into Areas III/IV must satisfy the same radiation limits as Mode N1.

Mode X2: primary beam with A lighter than 12 and ERL less than 5 rem/h

- Access to beam areas is permitted, as for other beams, after a review and only under a Radiological Work Permit.

- Access to adjacent areas is governed similarly to Standard Operations as described in 5.2.5.3.