CONF-821123--38

SOME SPECIALIZED RADIOLOGICAL-SAFETY CONSIDERATIONS AT ARGONNE NATIONAL LABORATORY'S HEAVY ION RESEARCH FACILITY
(SAR, Shielding Design, Q.F.'s, HIRC)

R. H. Cooke and R. A. Wynveen
Occupational Health & Safety Division
Argonne National Laboratory, Argonne, Illinois

CONF-821123--38

DE83 008645

Introduction

An existing accelerator system at Argonne National Laboratory (ANL) has been upgraded and is being extended to provide heavy ions with energies well above the nuclear binding energies (5-25 MeV/A). The final configuration of the system, called the Argonne Tandem-LINAC Accelerator System (ATLAS), is to become a user-oriented national facility for nuclear physics research. ATLAS will produce some specialized radiological safety considerations unique to this facility in addition to the safety considerations normally addressed at accelerators.

The ATLAS Facility shares the Physics Building with six other smaller accelerators, offices, and general purpose laboratories, some of which are used for low-level counting of radioactivity. The portions of ATLAS that currently exist and those portions that are under construction are shown in Figure 1. The FN-Tandem has been operational since the mid 60's. Currently, two ion source injection systems are housed within the Tandem vault. Target Area I has been in use for many years and continues to be used for beams from the Tandem.

The booster LINAC exists now and currently delivers beam into target area II. The booster LINAC consists of 24 independently-phased superconducting split-ring resonators housed in four cryostats. Each superconducting split-ring resonator can have up to 1.5 MV potential between the drift tubes.

As shown in Figure 1, a new beam enclosure, to house an additional 18 resonators in 3 cryostats, and a new target area III are under construction. From the distribution of charge states created by the strippers located before the 40° bend, it is anticipated that beams will be delivered to target areas II and III simultaneously. The maximum projectile energy for each of the three target areas is shown in Figure 2 as a function of projectile mass.

Known Radiation Hazards

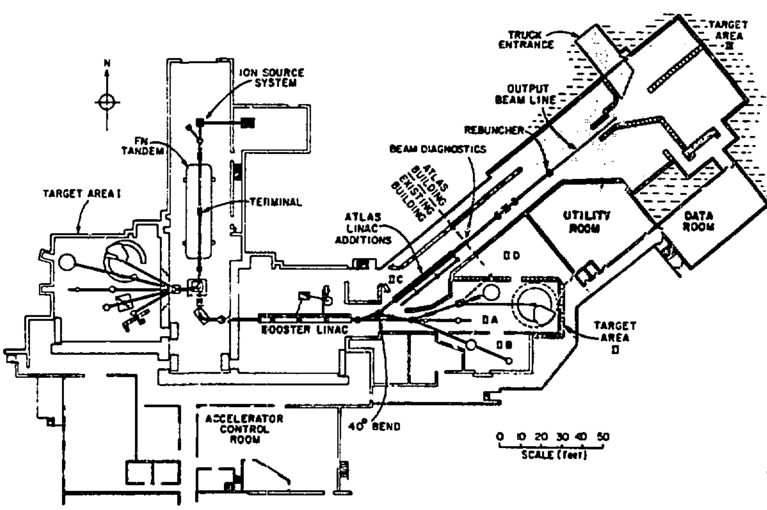
Argonne National Laboratory is committed to keeping personnel radiation exposures As Low As Reasonably Achievable (ALARA). In the ALARA context, any radiation exposure may be considered to present an unacceptable risk (hazard) if it is unnecessary or without benefit. Hazard is, therefore, not viewed in a purely legal or biological context.

Radiation areas have been identified that require positive protective actions to maintain low personnel exposures and eliminate unnecessary ones.

For heavy ion acceleration, the main radiation hazard in the Tandem vault is at the low energy end near the ion source. As expected, there are numerous negatively charged particles accelerated out of the ion source that are rejected by the magnet that turns the beam into the Tandem. These produce significant x-rays in the magnet area.

The primary source of radiation near the booster LINAC cryostats is the x-rays that are generated by parasitically accelerated electrons interacting with cryostat components. These x-ray fields are produced whenever a resonator is energized. The fields are independent of whether other components are operating or whether beam is present. The x-ray fields associated with each resonator's operation vary dramatically. These largely nonreproducible variations depend on numerous parameters including the type of beam particles, tuning parameters, and resonator status. Although the ion beam can interact with cryostat components, experience has not shown this source of radiation to be significant.

Gamma and neutron fields have been detected and measured downstream of the booster LINAC when the projectile energy is above the coulomb barrier energies for beam transport materials, beam stops, or targets. The exact location and intensity of these fields is difficult to correlate with operating parameters because of the many variables involved. The tuning and beam steering processes produce different fields at different locations than is generally the case for a normally running experiment. The neutrons produced are either evaporation neutrons that are generally isotropic in the center of mass system or higher energy neutrons that are emitted



MASTER

Figure 1. The ATLAS Facility showing the existing building and the facilities that are under construction (shaded area and darkened outlines of equipment).

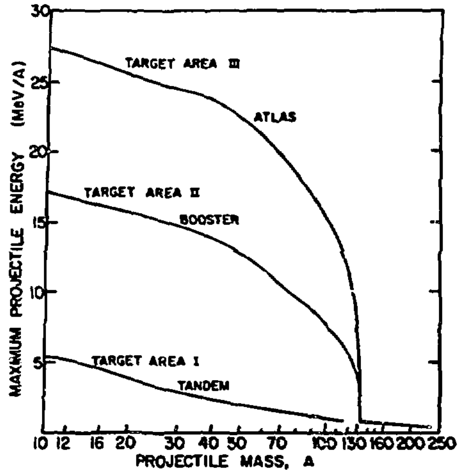


Figure 2. The maximum projectile energy available to each target area.

preferentially in the forward direction. These fast neutrons are thermalized in the materials of the facility.

Projected Hazards

Additional hazards are expected when the new ATLAS addition is completed (see Figure 1). Significant neutron fluxes and gamma fields may exist near the new cryostats. This new source of radiation will be in addition to the cryostat x-rays because of the higher energy beams entering the new cryostats.

The potential radiation hazard in target area III is expected to be similar to that in target area II except that higher neutron fluxes and gamma fields are expected due to the higher energy beams. In addition, the forward-directed fast neutrons must be stopped locally to insure that neutron fields outside the facility are minimized and to protect personnel that may be working in downstream areas of Target Area III.

A new and largely unpredictable potential radiation hazard will exist in the area of the 40° bending system. In the formation of the two simultaneous beams, the unused charged states will be stopped in the bending system producing a potential for significant neutron fluxes and gamma fields.

Health Physics Concerns and Hazard Control

Several operational aspects of the ATLAS Facility impact on the Laboratory's ALARA program and generate concerns about potential personnel exposures. These concerns have been addressed by various types of controls. The objective of these controls is to allow the maximum access possible to all areas of the facility while providing reasonable assurance that personnel exposures will be minimized. The Health Physics Section of ANL provides radiation protection expertise and advice to ANL operating divisions and assists the operating divisions in carrying out a radiation safety program. A Health Physics Technician is available on request to perform radiation surveys in the ATLAS Facility sixteen hours a day.

a. General - The fact that the ATLAS Facility is operating yet still evolving is of general concern. Many people with varied backgrounds are working in the facility and the facility is becoming larger and more complex. Under these conditions, safety hardware becomes quickly outdated and expensive to change. Although hardware is preferred, administrative controls to supplement the existing hardware have been adopted. The operating division carries out the administrative control. The ANL Health Physics philosophy is that although Health Physics may provide the operating division with calibrated instruments to use, all radiation surveys must be made or confirmed by a person whose only vested interest is safety (a Health Physics Technician).

The operating division designates a "shift radiation safety officer", with clearly outlined responsibilities, anytime radiation is present. A Health Physicist reviews all experiments in advance of their scheduling and is, therefore, alerted to any potential hazards. A routine radiation survey of the entire facility is made daily by a Health Physics Technician and any measured fields are posted on a prominently displayed map of the area. A safety committee, appointed by the operating division, reviews all procedures, identifies training needs, and investigates unanticipated exposures.

There is also a requirement that personnel radiation monitors be worn by all personnel in the facility because brief, random, and non-reproducible fields can occur for various reasons at a variety of locations. These fields can be difficult to find and measure and, very likely, would go unnoticed unless personnel monitoring revealed their presence. Scientist control increases the possibility of such unnoticed fields since he may have the needs of his experiment foremost in his mind, and not be mindful of the additional hazards created by changes in the accelerator's parameters. For this reason, some constraints on operating parameters may ultimately be programmed into the controlling computer. Tuning of the LINAC, which can last several hours, and the setting up of the steering of the beam, is another cause of such fields.

b. Ion Source - Access to the operating ion source is sometimes required. With the maximum injection voltage (150 kV) and current, x-ray fields as high as 1 R/h with energies ranging to 150 keV can be produced near the bending magnet. Since some ion source adjustments can require extended amounts of time for troublesome or new sources, significant personnel exposures are possible. These can be whole body or localized eye or skin exposures.

A requirement that the Tandem operator reduce the injection voltage, if possible, when giving out the only key to a non-interlocked gate at the low energy end of the vault, reduces the potential for exposures. Radiation surveys upon entry are required and the Health Physics Technician on duty is to be called for area surveys if work for extended periods of time (beyond a few minutes) is required. Many of the adjustments will eventually be placed outside the vault where no radiation hazard exists.

c. LINAC - The booster LINAC has evolved to its present state from an experimental-type apparatus. Consequently, many of the cryogenic, electrical, and gross tuning controls are in areas near the cryostats where x-ray fields, ranging up to 200 mR/h (no neutrons), are consistently present. The booster LINAC cryostats are shielded on two sides to about seven feet high to allow maintenance and testing work in the surrounding area without exposure. The cryostat area is open at the low energy end and pedestrian access is limited by use of a radiation warning sign and rope strung between the two shielding walls. Thus, there is always the possibility of unauthorized personnel intentionally or inadvertantly entering the cryostat area. There is also the temptation to enter the area to perform work other than adjustments "just for a few minutes" rather than disrupt an experiment by shutting down the booster LINAC. The new shielded beam tunnel is being built so that many, if not all, of the cryostat/resonator adjustments for the new cryostats will be remotely performed on the "RF corridor" side of a shielding wall.

There is an x-ray radiation monitor mounted above each of the four cryostats which, at approximately 1 mR/h, will activate a centrally located red rotating light. Entry into the cryostat area is allowed only for emergency adjustments necessary to keep the system operating. The resonators are to be turned off or power reduced substantially during entry into the area if full power is not necessary during the entry.

d. Target Areas - Several experimental groups may need access to any one of the target areas to prepare for future experiments while beam is present. Thus, there is always the possibility that personnel may be working in neutron flux densities and gamma fields that can produce significant personnel exposures in relatively short times (a few hours). Assessing the hazard potential in the various areas is difficult. The control over access must be refined for Target Area III, since exposure potential will be increased due to the higher energy beams.

There are interlocks on the entrances to Target Areas I & II that will close beam stops at the high energy end of the Tandem. There is a key lock system on both areas that insures the appropriate area is vacated and secure before beam can be delivered. Although not all access to Target Area II is protected by gates and interlocks during the construction process, it is expected that this will be the case when ATLAS is operational.

All of the interlocks and key activated systems for Target Areas I and II may be bypassed by the Tandem operator with a key when the "Heavy Ion Radiation Criteria" (HIRC) is low enough to permit personnel access. The bypass must be requested by an experimenter and the experimenter must calculate the HIRC value. The HIRC was developed by the operating division and has been used as a method of determining when the radiation safety features may be bypassed. The HIRC value is an index of the maximum possible radiation levels for the planned operating conditions. The HIRC is expressed as:

$$HIRC = \left(\frac{I}{Q}\right)\left(\frac{X^3}{Z^2{}_p}\right)\ (1 + 0.5A_p - Z_p)$$

where: $X = (E-3.7Z_p)$ when $E-3.7Z_p > 1$

and $X = 1$ when $E-3.7Z_p \leq 1$ and

I = shutter current in electrical nanoamps
Q = charge state of the beam
Z_p = atomic number of the beam particles (integer amu)
A_p = atomic weight of the beam particles (integer amu)
E = bombarding energy in MeV

Bypasses of radiation safety features may be activated by the Tandem operator without a prior Health Physics survey of the area, when the HIRC value is less than 21,100. For HIRC values greater than 21,100, for light ion beams, and for lithium beams, Health Physics must survey the area and approve activation of bypasses. The value 21,100 and bypass approval are based on fields being less than 10 mrem/h (η and γ) at 2 m with no accessible area greater than 200 mrem/h (η and γ).

The HIRC value system has, so far, been effective since no significant exposures have been incurred by personnel working in the target areas while experiments were in progress. The HIRC does, however, have some practical and theoretical limitations. The HIRC is based on the worst case conditions but in practice these conditions are rarely present. Therefore, the radiation levels from experiment to experiment do not correlate well with the HIRC values. This leads experimenters to discount or lose confidence in the HIRC value system. Personnel are often excluded from an area until the Health Physics Technician can survey the area when no significant radiation is present. In addition, because the tuning and steering process takes time, often Health Physics staff will survey the area when the system is still being tuned and the parameters used for the HIRC calculation have not been reached. Finally, as new ion sources are developed and the booster LINAC capabilities are increased, the 10 MeV/A assumption used in developing the HIRC is not valid for many experimental runs.

Target Area I is adequately shielded for neutrons and neutron shielding is being added to Target Area II. It is not known how effective the Target Area II shielding is for the neutrons that may be produced from high HIRC value experiments. Therefore, the occupants of surrounding areas are limited to a quarterly dose of 250 mRem.

e. Formal Safety Review - ANL is a Department of Energy (DOE) contractor and as outlined by DOE Order 5481.1A, ANL management has required that the operating division prepare a safety analysis report (SAR) for the ATLAS Facility for formal review before full operation begins. Such reports and formal review systems have been used for nuclear reactors for some time but their use for an accelerator is new and unfamiliar to the operating division. This report is to address safety aspects of the facility including radiation hazards and how they are to be minimized. Final preparation of this document is being delayed by the operating division until the new portion of the facility is completed in order to maximize their flexibility. It is difficult to be quantitative in areas where data is lacking; however, the draft SAR has permitted Health Physics to make a relatively detailed shielding analysis. Even though the final SAR is far from complete, the draft SAR and the formal review process has led to several productive discussions between the operating division and the safety groups at ANL. Several changes were made in the ATLAS design as a result. The benefits of a safety review by personnel outside the operating division have clearly been demonstrated.

f. Shielding - Several assumptions were necessary to evaluate the shielding provided in the new ATLAS addition. It was assumed that the dominant neutron source will be evaporation neutrons with an average energy of 2.7 MeV. The energy spectrum and flux density contribution at the shielding of moderated forward-directed neutrons and multiply-reflected neutrons is not reliably known. As recommended by the methodology of NCRP #51[1] used for the shielding analysis, only a gross increase in the assumed source of neutrons or final shield thickness was used to account for multiply-scattered neutrons. It was also assumed in estimating neutron transmission through penetrations, trenches and the pedestrian labryinth to the data room, that only thermal neutrons entered these areas.

Another critical assumption used in evaluating both the shielding and the radiation fields produced by "skyshine" is the intensity of the source. A source term of up to 150 mRem/h per particle nA at 1 meter is expected. One particle nA is 6.25×10^9 particles/second. The source term was estimated by extrapolation of data from W. F. Ohnesorge, et al[2] to 27 MeV/A. The operating division for ATLAS has estimated that the facility will operate approximately 1% of the time at parameters sufficient to produce source terms greater than 50 mRem/h per particle nA at 1 meter. Since the 50 mRem/h per particle nA at one meter is the design basis of the new addition the operating division intends to apply administrative controls during this 1% high radiation operation to insure that personnel are not unnecessarily or inadvertantly exposed. There are suspected inadequacies in the present shielding design of the new addition even with the design basis of 50 mRem/h per particle nA at one meter. These inadequacies will have to be evaluated and corrected before full operation begins.

The new cryostats will be contained in a tunnel with a shielded roof and there is an earth berm up to 10' high around the Target Area III; however, there is no overhead shielding in Target Area III. Therefore, local overhead shielding may be essential to reducing "skyshine" to the nearest occupied areas of the building.

Experimental Efforts

In order to develop and apply administrative controls effectively and efficiently, a means of predicting radiation levels must be developed. An accurate knowledge of the energy distribution of neutrons and how the environment of the facility affects the spectrum must also be available to establish correct Quality Factors and make meaningful calculations of dose equivalent commitment from absorbed dose or count rate measurements. For example, when using a portable instrument such as the Eberline PNC-4, one obtains direct readings of events per minute. Calibration techniques at ANL provide a conversion factor to convert to a flux with units of ncm^{-2} sec^{-1}. In order to convert to dose equivalent commitment one must know the energy distribution of the neutrons and assign a quality factor for the spectrum. The quality factor is a measure of the biological effect in rem per unit of absorbed energy in rad. When the quality factor for a spectrum is known, a standard reference such as NCRP 38[3] can be consulted to convert the flux density into dose equivalent rate in rem/h.

To better assess the adequacy of the shielding, to estimate source terms and to calculate dose equivalent commitment, data is being gathered on the radiation produced by various beams.

A Bonner Sphere Spectrometry System is currently being used to obtain information on the neutron radiation, the major radiation of concern in Target Area II and the new addition. Data is input to a computer program containing the response functions of the various detector systems. The computer program generates a neutron energy spectrum and determines Quality Factors and dose equivalent rates from the input of count rate data. The errors introduced by the program are apparently no larger than the statistical errors of the input data.[4]

Measurements are being made 1 meter from a thick target at both 0° and 90° to the incident beam. Comparisons are also being made between the dose equivalent rate calculated by the Bonner Sphere Spectrometry System and that obtained from a variety of hand-held portable neutron instruments in use at Argonne National Laboratory. Table I lists data from various beams impinging on Tantalum.

The data gathered to date is preliminary and a comprehensive error analysis has yet to be completed. It is expected that uncertainties in both the dose equivalent rate at one meter normalized to one particle nA and the energy per nucleon will be small. Small uncertainties are expected because of the range of energies covered by the Bonner detector system being used, the integration of electrical current at the target, and the control over the beam that insures that only projectiles within a fairly narrow band of energy produce the measured neutrons.

Tantalum is used extensively throughout the accelerator system in beam stops and shutters. Tantalum was initially investigated to determine neutron production at the locations where the beam is often stopped during tuning and the setup of experiments. Neutron production of various beams on stainless steel similar to that used in the beam tubes, is

	0 degrees		90 degrees	
Energy/amu (MeV/A)	Bonner System mrem/h	Eberline PNR-4[f] mrem/h	Bonner System mrem/h	Eberline PNR-4 mrem/h
5.4[a]	0.1	0.1	< 0.1	< 0.1
6.0[b]	0.7	0.7	0.5	2.0
7.0[c]	1.8	-	1.1	-
8.4[d]	6.3	7.8	3.3	4.7
8.9[e]	7.3	4.2	4.2	2.9

a. 150.0 MeV silicon
b. 96.0 MeV oxygen
c. 84.0 MeV carbon
d. 134.0 MeV oxygen
e. 106.4 MeV carbon
f. Typical Rem reading instrument calibrated with PuBe

Table I - Dose Equivalent Rate at One Meter from a Thick Tantalum Target Normalized to 1 particle nA

now being investigated. For example, a carbon beam on stainless steel with an energy of 7.0 MeV/A produces 6.3 mrem/h per particle nA at one meter at 0° and 1.8 mrem/h per particle nA at one meter at 90°. All of the data have been encouraging and suggest that a method of predicting an upper limit of dose equivalent rate by using the energy per nucleon of the beam projectile can be developed.

The data gathered to date also suggest that the majority of neutrons produced by the beams on thick targets have energies below 3 MeV. Thus, the assumptions used in the shielding calculations appear to be reasonable for the beam energies at or below 8.9 MeV/A.

Future Efforts

Efforts are being continued to press for the operating division to prepare a safety analysis report that is as detailed as possible. Radiation fields that are being produced in Target Area II continue to be delineated. As higher energies for existing beams and new beams become available, either cataloguing the radiation from all beam species or developing a reliable method of predicting dose equivalent rates from various beams will continue.

References

1. National Council on Radiation Protection and Measurements, NCRP Report No. 51, Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities (1977).

2. W. F. Ohnesorge, H. M. Butler, C. B. Fulmer and S. W. Hosko, Heavy Ion Target Area Fast Neutron Dose Equivalent Rates, Health Physics, 39, 633 (1980).

3. National Council on Radiation Protection and Measurements, NCRP Report No. 38, Protection Against Neutron Radiation (1971).

4. E. H. Dolecek, Argonne National Laboratory, personal communication. Information obtained at DOE Neutron Dosimetry/Technology Transfer Workshop, LASL, September 1982.