First Intl. Workshop on Space Radiation Research and 11th NASA Space Radiation Health Investigators' Meeting, Arona, Italy, 5/28-31,2000.

BNL-67119

BNL Accelerator-Based Radiobiology Facilities.*

Derek I. Lowenstein
Collider-Accelerator Department
Brookhaven National Laboratory
Upton, New York 11973, USA

Abstract

For the past several years, the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory (USA) has provided ions of iron, silicon and gold, at energies from 600 MeV/nucleon to 10 GeV/nucleon, for the US National Aeronautics and Space Administration (NASA) radiobiology research program. NASA has recently funded the construction of a new dedicated ion facility, the Booster Applications Facility (BAF). The Booster synchrotron will supply ion beams ranging from protons to gold, in an energy range from 40-3000 MeV/nucleon with maximum beam intensities of 10^{10} to 10^{11} ions per pulse. The BAF Project will be described and the future AGS and BAF operation plans will be presented.

Key Words: (4) Radiobiology; Booster Applications Facility (BAF); Alternating Gradient Synchrotron (AGS); National Aeronautics and Space Administration (NASA).

*Work performed under the auspices of the U.S. National Aeronautics and Space Administration and the U.S. Department of Energy.

Introduction

Brookhaven National Laboratory (BNL), a US Department of Energy (DOE) national laboratory, is the principal source of ion beams for the US National Aeronautics and Space Administration (NASA) accelerator-based radiobiology program. BNL is a multi-disciplinary laboratory consisting of approximately 3000 employees and over 4000 investigators from around the world. The research areas cover both the physical sciences and the life sciences. The available facilities range from 23 different accelerators to accredited animal care facilities and cell and tissue laboratories. The accelerator complex consists of machines that accelerate electrons, protons and ions. The major accelerator facility is within the Collider-Accelerator Department complex (see Figure 1) which is composed of two Tandem van de Graaffs (1-10 MeV / nucleon), a 750 keV RFQ linac, a 200 MeV proton linac, a Booster synchrotron (40 - 3000 MeV / nucleon), the Alternating Gradient Synchrotron (600 - 30000 MeV / nucleon) and the Relativistic Heavy Ion Collider ($\leq$40,000,000 MeV cm. energy). The second major facility, the National Synchrotron Light Source consists of two electron storage rings, a 750 MeV UV ring and a 2500 MeV x-ray ring.

The accelerator-based NASA radiobiology program has, over the past five years focused its efforts at the Alternating Gradient Synchrotron (AGS). Additional NASA sponsored electronics and materials research is accomplished with the Tandem van de Graaff. Since 1995, the AGS has yearly delivered a limited set of ion species and energies for a community of approximately 70 investigators from 15-20 institutions. Over this period of time the focus has been on 600 and 1000 MeV iron, 1000 MeV silicon and 10,000 MeV gold ions. Operating time for radiobiology at the AGS is at a premium, as the major running time is dedicated to nuclear physics and high energy physics research. The NASA program has typically had 1 to 2 running periods of 150 hours duration during a given year. Each 150 hour running period consists of continuous beam operations of 24 hours per day until all the approved experiments for the period are completed. The running experience over the past 5 years is that all approved experiments in a running cycle receive their allotted beam time, with an accelerator operating efficiency of 95%.

Figure 1. Collider-Accelerator Department Accelerator Complex.

During a typical running period, such as in the Spring 1999 cycle, the AGS delivered iron beams on target at 1060 MeV/ nucleon (LET: 148 keV/μm) and 561 MeV/nucleon (LET: 177keV/μm). The dose rates ranged from 45 cGy/min to 10 Gy/min, with a spill length of 500 milliseconds and a repetition rate of 30 spills/min. The typical spill fluence (particles/spill) ranged from 6.5×10^6 to 1.7×10^8 with intensities (particles/cm^2/sec on target) 2.6 x 10^4 to 6.3 x 10^5 over a 7.5cm diameter beam spot. More than 1000 biological samples were irradiated at the AGS A3 beam line (Figure 2), including human, mouse, rat, hamster and canine cell lines, human-hamster hybrid cell lines and rodents. In addition physics experiments to establish beam characterization and dosimetry data were conducted.

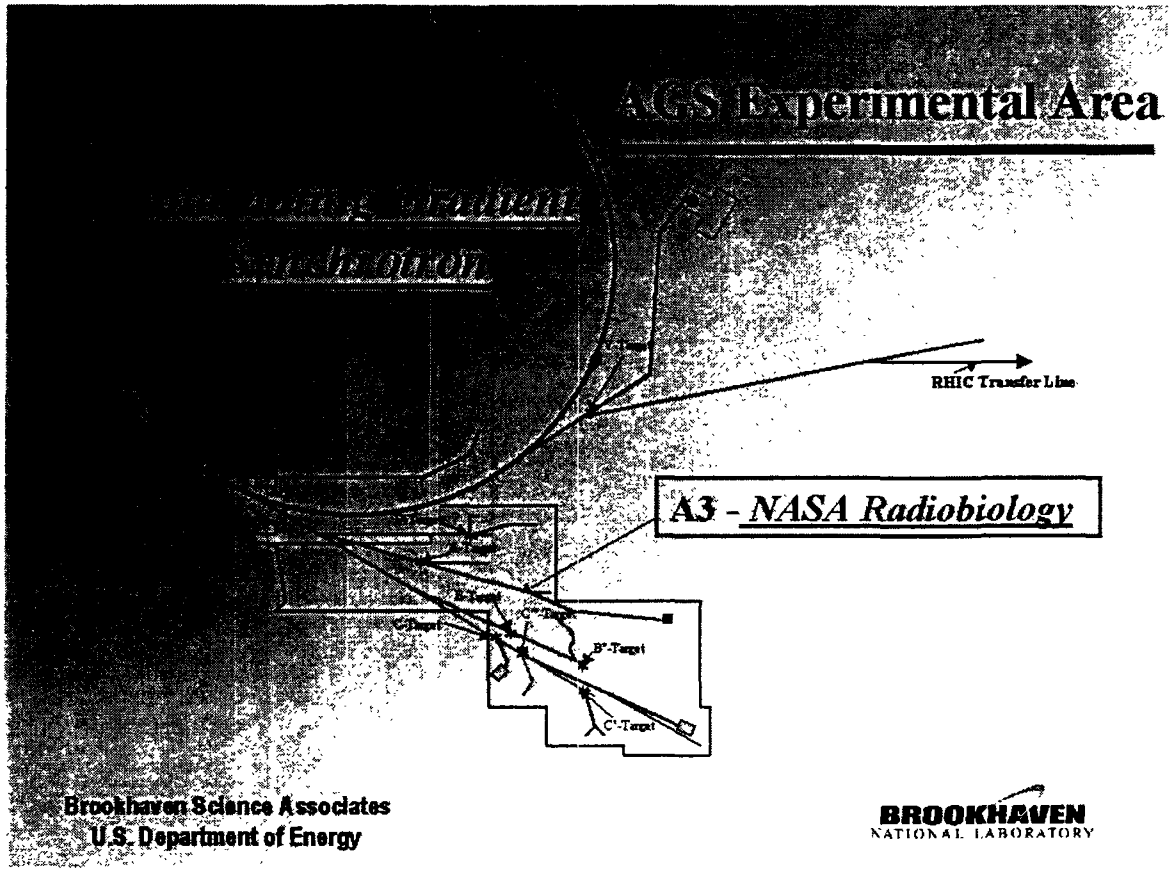

Figure 2. AGS Experimental Area Beam Lines.

The AGS is not capable of reaching the low end of the energy range for ions of interest to the radiobiology research community. This limitation will be eliminated with the start of operation of the Booster Applications Facility (BAF). BAF will be a dedicated NASA particle beam source that will provide for all ions from protons to gold, in an energy range from 40-3000 MeV/nucleon, with beam intensities ranging over 6 orders of magnitude. It consists of a beam transport from the Booster synchrotron to a dedicated experimental area and support facility (Figure 3). A list of a sample of available ions, the kinetic energy range and estimated maximum intensities is provided (Table 1). The range of species is expected to be expanded to uranium in the next several years. The BAF will operate in a slow-extracted mode. The beam spill can be varied from the Booster synchrotron uniformly over a 0.5 -1.0 second spill every 1.5 – 3.0 seconds. At the target station the beam size can be varied from 1 cm to 20 cm in diameter, for 95% beam intensity and maximum emittance. Beams with lower emittance and / or reduced momentum spread $dp/p<0.05\%$ will generate smaller beam sizes on target. Beam profiles will be flattened with octupole magnets with no beam collimation beyond the last dipole magnet.

Table I

Operating Parameters for Slow Extraction Beam for Some Typical Ion Species

Species	**Charge State In Booster**	**Kinetic Energy Range** (GeV/Nucleon)	**Estimated Max. Intensity** (10^9 Ions/Pulse)
H^1	1	0.10-3.07	100
Si^{28}	14	0.09-1.23	4
Fe^{56}	21	0.10-1.10	0.4
Cu^{63}	22	0.10-1.04	1
Au^{197}	32	0.04-0.30	2

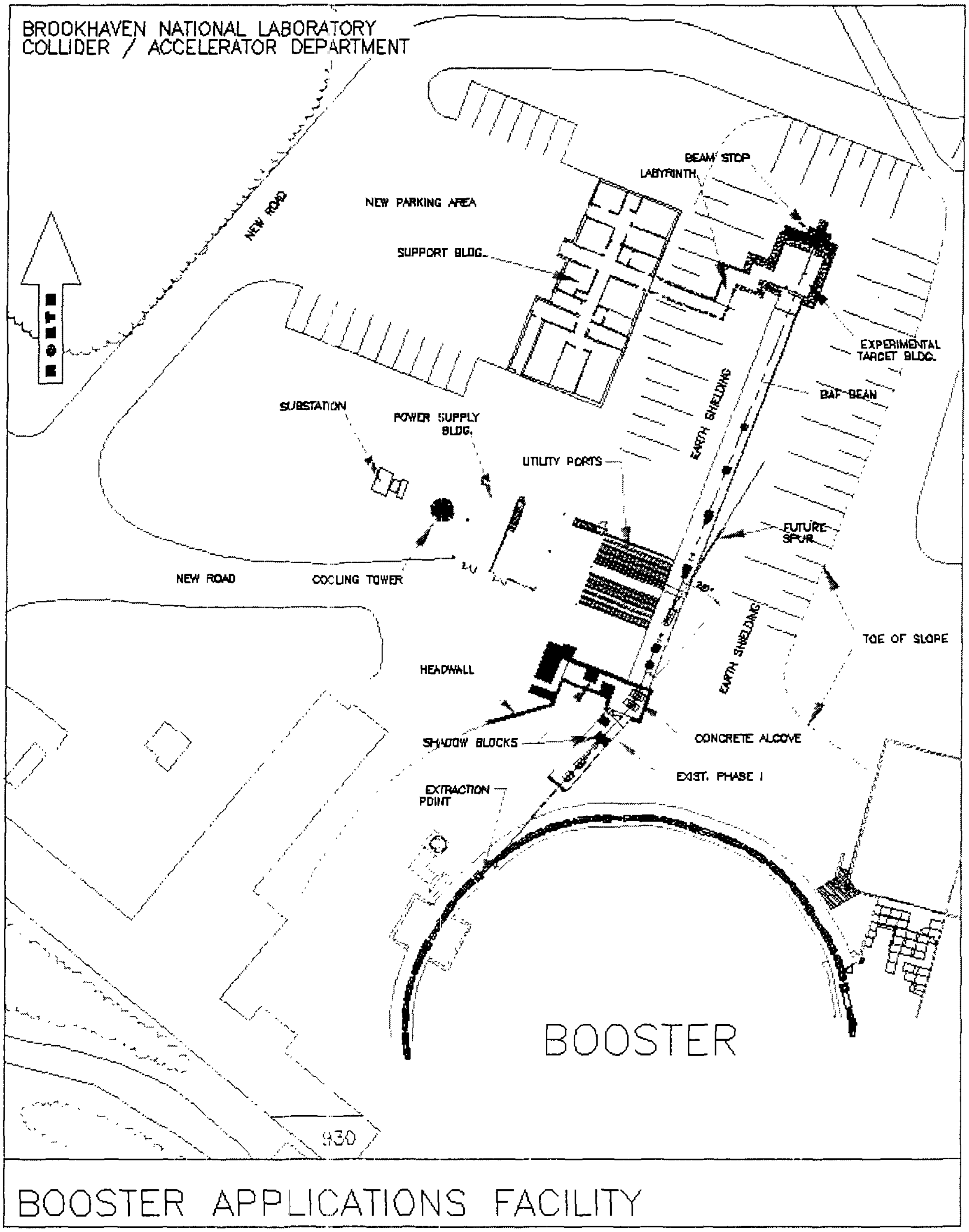

Figure 3. Booster Applications Beam, Experimental Area and Support Building.

The experimental area consists of a 40 m^2 target room and an experimental support area of 400 m^2. The target area will have a recessed and well-shielded beam dump at the end of the target room to prevent fragment products and back-scattered particles from reaching the target. The entrance to the target room is through a connecting maze from the experimental support area. Therefore, entrance to the room after the completion of an irradiation requires only opening of the interlocked safety gate and not a heavy shielded door, thus providing a safe and quick entrance. The target holder will be positioned by computer controlled stepping motors and additionally monitored by a video camera.

The experimental support area will provide space for a physics laboratory. Beam characterization and dosimetry will be provided by BNL for all experiments. The radiobiology area will consist of cell culture and animal laboratories. The areas are designed to be isolated from each other to facilitate the necessary clean operating conditions. A conference area and other amenities will also be provided for the experimental teams.

The cell culture facility will contain two experimental rooms (36 and 34 m^2) for short-term cell culture, each containing a HEPA filtered biological cabinet, CO2 incubators and dry incubator, a dosimetry computer, and work space. A common use laboratory will contain equipment used by multiple groups during a run, e.g., water purification system, refrigerator, etc. The laboratories in this facility have scrubbable walls and poured epoxy seamless floors to maximize cleanliness. A separate entrance and service corridor to the facility is provided.

The animal facility is designed for holding animals before and immediately after beam exposure, totaling less than 24 hours. Two experimental rooms (17 and 24 m^2) are provided, with racks for cages, experimental tables, dosimetry computer, etc. A wash room for sanitizing racks is provided. All rooms in the facility have scrubbable walls and poured epoxy seamless floors to allow sanitizing of the area. A separate entrance and service corridor is provided; the animal facility is separated by double doors in a corridor from the rest of the facility.

The experimental support area at BAF is not a long-term occupancy area, but is intended to be available to an experimental team during the period of time around an actual beam exposure. The Medical Department will provide space for both cell culture work and animal studies. The area of the long-term animal facility is ~1400 m^2 of which ~700 m^2 are used for housing animals. Most animal rooms are on a clean/dirt corridor system. There are also 4 large rooms (40m^2) with separate entry facilities and supplied by once-through, HEPA-filtered air, that can be used in as semi-barrier suites for long-term housing of post-exposure animals. There is also a complete barrier room and a laminar flow room available. These all include quarantine, surgery, necroscopy, radiology, and clinical pathology laboratories. The tissue-culture facilities consist of 240 m^2 of 3 dedicated and 3 shared tissue culture laboratories and a general use laboratory. The core facility equipment consists of such items as epifluorescence microscopes, spectrophotometer, liquid scintillation counters, x-ray source etc.

The BAF construction is scheduled for completion in 2002, whereupon beam commissioning will commence. The present NASA planning guidance is for yearly operations of 15 weeks of weekly 5 shift operations. In addition, some running is also expected with AGS beams at higher energies. The Booster, besides being the source of BAF beams, is also the beam injector to the AGS and for RHIC. We expect to run the Booster for BAF in a context-switching mode (supercycle) during AGS operations. During the beam injection mode for RHIC, twice daily for up to a total of 4 hours, BAF operations would be in standby. The impact on BAF operations will be minimized by judicious scheduling of operations.