PERFORMANCE AND CAPABILITIES OF THE NASA SPACE RADIATION LABORATORY AT BNL *

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Abstract

The NASA Space Radiation Laboratory (NSRL) at BNL was commissioned in October 2002 and the facility became operational in July 2003. NSRL was constructed in collaboration with NASA for the purpose of performing radiation effect studies for the NASA space program. NSRL can accept a wide variety of ions from BNL's AGS Booster; these are slow extracted with kinetic energies ranging from 0.3 to 3 GeV/n. Fast extraction from Booster to NSRL has also been developed and used. Many different beam conditions have been produced for experiments at NSRL, including very low intensity. In this report we will describe the facility and its performance over the eight experimental run periods that have taken place since it became operational. We will also describe the current and future capabilities of the NSRL.

INTRODUCTION

NSRL was designed to accept a wide variety of ion species, over a large range of beam intensities and energies. The ions are supplied by two Tandem Van de Graaffs that are connected to the AGS Booster by the 840 m TTB (Tandem-To-Booster) transport line shown schematically in Figure 1. More detailed descriptions of the design and commissioning of the facility can be found in [1, 2, 3, 4, 5]. Ions are delivered to NSRL via a single beam line that branches off from BNL's AGS Booster. The Booster was designed to accelerate protons and heavy ions. It is a 201.78 m circumference separated function alternating gradient synchrotron that can operate up to a maximum rigidity of 16 Tm. In its experiments, NRSL has used iron, titanium, chlorine, silicon, oxygen, and carbon ions, and protons delivered from Booster at kinetic energies ranging from 0.3 to 3.0 GeV/nucleon. Resonant extraction is used in order to deliver a continuous stream of particles. Fast extracted beam also has been developed and used for a small set of experiments. Table 1 lists the ion species, maximum beam intensities, beam sizes, and maximum dose rates delivered to the NSRL experiments. For experiments requiring low intensity, the minimum flux density operated on target is on the order of $10^2/\mathrm{cm}^2/\mathrm{cycle}$. The maximum kinetic energy of the extracted beams is limited by the maximum Booster rigidity of 16 Tm and by the maximum NSRL transport line rigidity of 13 Tm. Ions are fully stripped at a stripping foil located at the entrance of the final extraction septum magnet. Here collimators can be inserted to adjust the beam size and intensity. To achieve extremely low intensities we employ wires for stripping, instead of foils. Since the facility was designed to do experiments that evaluate the radiation exposure risk to astronauts in the NASA space program and to study materials for NASA space vehicles, a wide variety of experiments are performed requiring diverse sets of beam conditions.

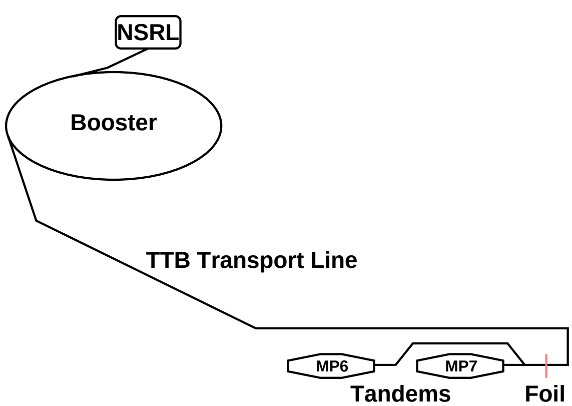

Figure 1: Layout of Accelerators for NSRL.

Table 1: Typical NSRL Beam Parameters

Ion MeV/n	**Intensity (ions/cycle)**	**Beam Size (cm^2)**	**Dose Rate (Gy/min)**
p 1000	34×10^9	20x20 7x7	0.2 1.5
C 290	12×10^9	20x20 10x10	4 15
O 600-1000	5×10^9	20x20 10x10	3.5 14
Si 300-1000	3×10^9	20x20 5x5	5 25
Cl 500	2×10^9	20x20	3.5
Ti 1100	0.8×10^9	20x20 10x10	4 20
Fe 300-1000	2×10^9	20x20 7x7	7 50

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As a result, we have developed a number of techniques for providing a wide variety of beams. To do this development an integral part of the NSRL program is the NSRL beam experiments program.

DISCUSSION

Concurrent Operation of NSRL and RHIC

An important consideration in the scheduling of the NSRL operation is the ability to operate NSRL and BNL's Relativistic Heavy Ion Collider (RHIC) concurrently. Both require ions that must be transported to Booster from the Tandems. If the ions for NSRL and RHIC need to have different magnetic rigidities in the TTB line, then the settings of the elements in the line will be different for the two cases. Since the elements cannot be switched on a pulse-to-pulse basis, delivery of ions to NSRL must be interrupted when RHIC needs to be filled. This involves a three-minute "mode switch" of the TTB line elements followed by whatever time is necessary for filling RHIC (typically 5 to 10 minutes). This procedure has been used successfully when gold ions and copper ions were being delivered to RHIC while iron and titanium ions were being delivered to NSRL. When carbon and silicon ions are delivered to NSRL this mode switch was not necessary. These ions can be transported in the TTB line at the same rigidity as gold ions for RHIC. In this case switching of the TTB line elements was not necessary and ions could be delivered to NSRL and RHIC on a pulse-to-pulse basis. In general the mix of ions delivered to RHIC and to NSRL must be evaluated carefully, since only under the right conditions can both programs be satisfied. In the future this problem will be rectified by the moving away from the Tandem as a source of ions with the construction of the Electron Beam Ion Source [9].

Accelerator Performance

Each NSRL run period lasts between 300 and 400 hours. Three runs are scheduled each year. To date the facility has run a total of 43 weeks. Experiments are typically done during the daytime period, although often they operate into the evening. Accelerator availability for NSRL has been very high, between 90 and 95 %. Since there are a large number of experiments, a significant amount of setup time is required. Typically 25 to 30 % of the run time is spent in setup and documentation. The beam experiments program usually takes between 5 and 10 % of the run time.

Slow Extraction Performance

The slow extraction system was described and reported on in [1, 2, 3, 4]. The system performs very well and operates with extraction efficiencies of greater than 70 %. The system was designed for reliability and ease of operation. The maximum efficiency is limited to about 80 % by the thickness of a thin septum magnet in the extraction system. The system operates very reliably requiring just a short time to configure.

Spill Structure

We have devised and tested a number of spill structure correction techniques for the NSRL. A more detailed discussion of these techniques can be found in [7]. The technique that has worked best is to use the main RF system for phase displacement filtering of the DC beam. This could only be accomplished with the new LLRF system for the Booster, which allows running completely open loop [6]. Figure 2 shows a normal uncorrected beam spill. Figure 3 shows how the structure is improved using the main RF as a filter. A variety of different beam time structures have been requested and delivered to NSRL experiments. These include very short slow extracted beams of 1 to 3 msec long, beams with large low frequency structure (20 Hz bursts), and fast extracted beams (600 μsec). Two different modes of fast extraction have been employed; bunched beam fast extraction and debunched beam fast extraction. For debunched beam fast extraction the beam is allowed to debunch and then the extraction kicker is pulsed.

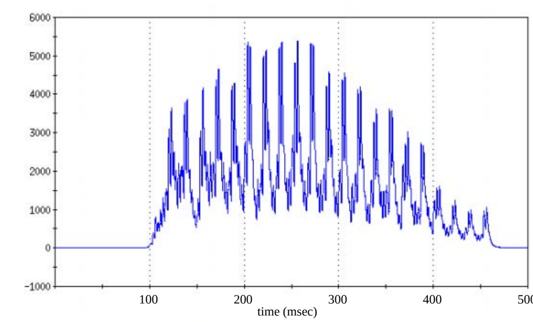

Figure 2: Normal beam spill without RF phase displacement.

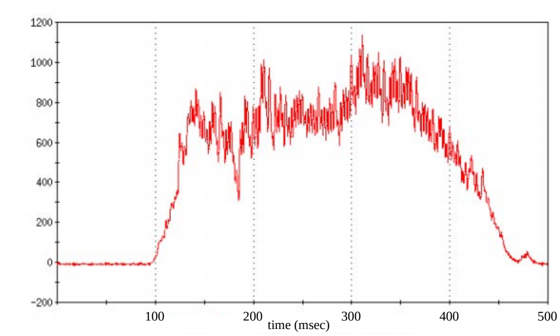

Figure 3: Normal beam spill with RF phase displacement.

Transfer Line Performance

The design and performance of the beam line is described in refs. [5, 4]. The performance of the beam line has been exceptional. The beam parameters have been measured and agree very well with predictions. The alignments of the elements have been measured and all are within specifications. The octupoles, used to produce a uniform transverse distribution, have performed precisely as predicted. Figure 4 shows a typical uniform beam distribution on the target flag.

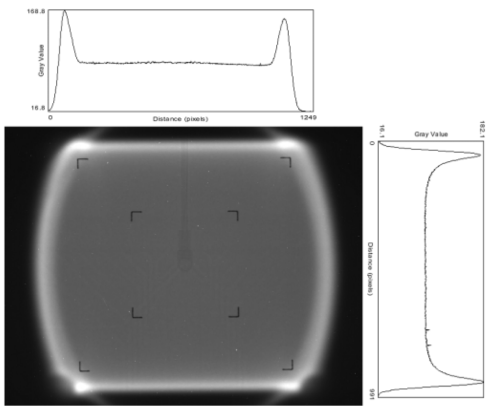

Figure 4: 20x20 cm^2 uniform beam

Dosimetry System

The dosimetry system has been described in ref. [4]. Since the experiments require this system to provide a dose measurement for every exposure, the system is required to be operational and calibrated for all experiments. It consists of four ion chambers, one of which is segmented. The chambers are filled with N_2 gas. Only one of the ion chambers is used for beam cut-off. To deliver a precise predetermined dose the system sends a request to a beam permit system that aborts the current spill and prevents more spills until reset. The response time of the total system is on the order of a few milliseconds. The system provides a precise dose to within 0.5 % or less, depending on the number of beam spills and the beam intensity.

Mixed Field Operation

A mode of operation that has become a routine part of every experimental run is the “mixed field” mode in which a single sample is exposed to two different ion species. Mixed fields of protons and iron ions have been routinely delivered to experiments. In principle any set of ions that could be produced at the Tandem could be used in the mixed field mode. This is possible because two Tandems (and LINAC, if necessary) are available and we can mode switch to different accelerator and beam line configurations in a very short time (2 minutes) to deliver the two different ion species.

Solar Particle Simulator

A new mode of operation currently being developed is the ability to expose a single sample to a large range of beam energies in a relatively short period of time. The purpose of this system is to simulate solar particle events. We have developed new techniques using the existing controls system and new software tools. The system is described in detail in ref. [8]. In beam tests we have changed the beam energy on demand from 1 GeV down to 90 MeV, keeping the beam size and quality on the target constant.

SUMMARY

The NSRL is performing extremely well. Beam quality and delivered dose rates have exceeded the facility design goals. We have demonstrated great versatility in operations and in the beams delivered, meeting the requirements of all the experiments and expanding the range of experiments that can be performed.

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