

*Results of the First Run of the NASA Space
Radiation Laboratory at BNL*

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Results of the First Run of the NASA Space Radiation Laboratory at BNL *

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Abstract

The NASA Space Radiation Laboratory (NSRL) was constructed in collaboration with NASA for the purpose of performing radiation effect studies for the NASA space program. The results of commissioning of this new facility were reported in [1]. In this report we will describe the results of the first run. The NSRL is capable of making use of heavy ions in the range of 0.05 to 3 GeV/n slow extracted from BNL's AGS Booster. Many modes of operation were explored during the first run, demonstrating all the capabilities designed into the system. Heavy ion intensities from 100 particles per pulse up to 12×10^9 particles per pulse were delivered to a large variety of experiments, providing a dose range up to 70 Gy/min over a $5 \times 5 \text{ cm}^2$ area. Results presented will include those related to the production of beams that are highly uniform in both the transverse and longitudinal planes of motion [2].

INTRODUCTION

The NSRL was designed to receive a wide range of ion species, over a large range of beam intensities and energies. The ions are supplied by two Tandem Van de Graaffs which are connected to the AGS Booster by the 840 m TTB (Tandem-To-Booster) transport line shown schematically in Figure 1. Delivery to experiments is accomplished by resonant extraction from Booster and transport to the NSRL target room. The AGS Booster has operated since

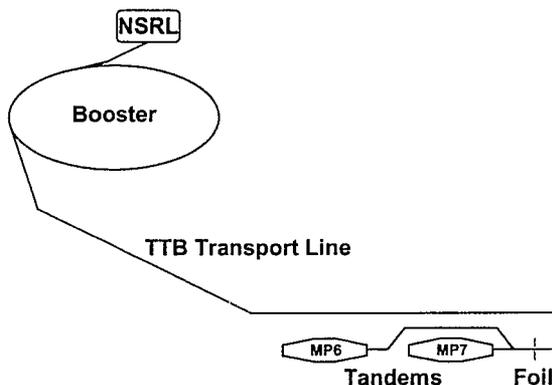


Figure 1: Layout of Accelerators for NSRL.

1991 as an injector of protons and heavy ions into the AGS.

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It is a 201.78 m circumference separated function alternating gradient synchrotron which can operate up to a maximum rigidity of 17 Tm. The lattice consists of 6 super-periods, 24 cells. It operates near the betatron tunes of $\nu_x = 4.82$ and $\nu_y = 4.83$. The acceleration rates are 8.9 T/s up to 7.5 Tm and 1 T/s for going up to 17 Tm. In this years first runs the NSRL has employed heavy ion species of Iron, Carbon, Titanium, Silicon and protons at beam energies ranging from 0.3 to 3.0 GeV/nucleon. Resonant extraction is employed in order to deliver a continuous stream of particles. In table 1 is listed the ion species, maximum beam intensities, beam sizes, and maximum dose rates delivered to the NSRL experiments in this first year of operations. The minimum intensities operated were on the order of $10^2/\text{cm}^2/\text{cycle}$. The maximum kinetic energy of the ex-

Table 1: Typical NSRL Beam Parameters

Ion	Intensity (ions/cycle)	Beam Size (cm^2)	Dose Rate (Gy/min)
Fe (1 GeV/n)	1×10^9	20x20 7x7	7 50
Ti (1 GeV/n)	0.8×10^9	20x20 10x10	4 20
Si (0.6 GeV/n)	3×10^9	20x20 5x5	5 25
C (0.3 GeV/n)	12×10^9	20x20 10x10	4 15
p (1 GeV/n)	34×10^9	20x20 7x7	0.2 1.5

tracted beams is limited by the maximum Booster rigidity of 17 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 thick septum magnet. Beam intensities are controlled through collimation at the entrance to the D6 septum magnet. To achieve extremely low intensities we employ wires for stripping, instead of foils. Due to the limited range of the Booster quadrupoles at high fields, the design of the resonant extraction system requires moving the operating point in tune space through $\nu_x = 4.5$ and extracting on the 13/3 resonance. This has been demonstrated to work very well without beam loss and without any evident emittance growth [1].

DISCUSSION

Concurrent Operation of NSRL and RHIC

The first run for experiments started in October 2003 and continued to the end of November. This was followed by another run in March and April 2004. An important consideration in the scheduling of the runs is the ability to operate NSRL and 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 the fill (typically 5 to 10 minutes). This procedure was used successfully during the latter part of March when gold ions were being delivered to RHIC and iron and titanium ions were being delivered to NSRL. Earlier in March, carbon and silicon ions were delivered to NSRL. 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.

Accelerator Performance

The AGS Booster RF system is undergoing an upgrade. The first new piece of equipment, a digital signal processor (DSP) controlled direct digital synthesizer, was commissioned during this run. This new system allows for real time calculation of the RF frequency as a function of magnetic field and a radial offset program. The new hardware and software is well integrated into the controls system and has proven to be very reliable. [5] An important part of this new system is that it allows the Booster to operate completely open loop (no radial or phase loop).

Slow Extraction Performance

The slow extraction system was described and reported on in [1, 3, 4]. The system has performed very well and operated with extraction efficiencies of greater than 70 %. The system was not designed with an electrostatic septum, so the maximum efficiency is limited to about 80 % by the thickness of the thin septum magnet.

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 [6]. The technique which has worked best, and is what we employ for operations, 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. The technique involves first turning off the main RF voltage, to allow the beam to debunch, and then bringing on the RF again, but at a frequency that corresponds to the revolution period at the radius of the resonance. In this mode of running no beam is captured inside the RF buckets, so all the beam gets filtered between the empty buckets during extraction. Figure 2 shows a normal uncorrected beam spill. Figure 3 shows how the structure is improved using the main RF as a filter. Another achievement, which again was made

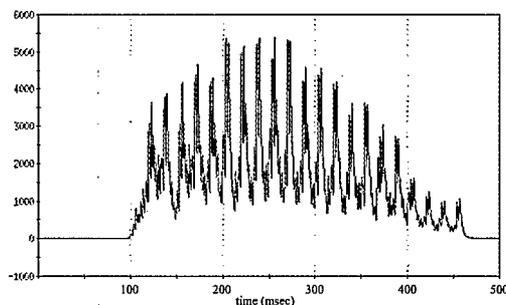


Figure 2: Normal beam spill without RF phase displacement.

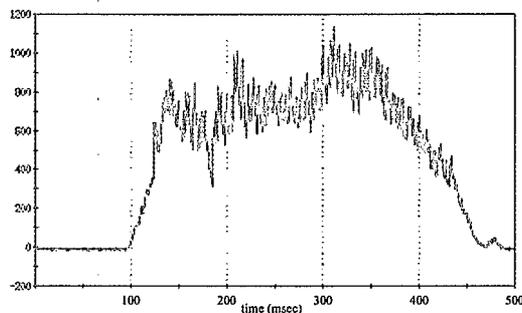


Figure 3: Normal beam spill with RF phase displacement.

possible with the new low level RF system, was to make very short spills. Figure 4 shows a 1 msec and a 3 msec spill as used by one experiment. This was done by keeping the tune quadrupole settings fixed such that the beam normally could not drift into resonance for the normal dB/dt , and would thus end up dumping in the accelerator. Then a "notch", or fast ramp down and then up again, was added to the tune quadrupole function, to get a small burst of extracted beam. With the RF on, we could then adjust the pulse length of the spill over a range from 1 up to over 3 msec by changing the frequency of the RF.

Transfer Line Performance

The design and performance of the beam line is described in ref. [2]. The performance of the beam line has been exceptional. The beam parameters have been measured and agree very well with predictions. The alignment

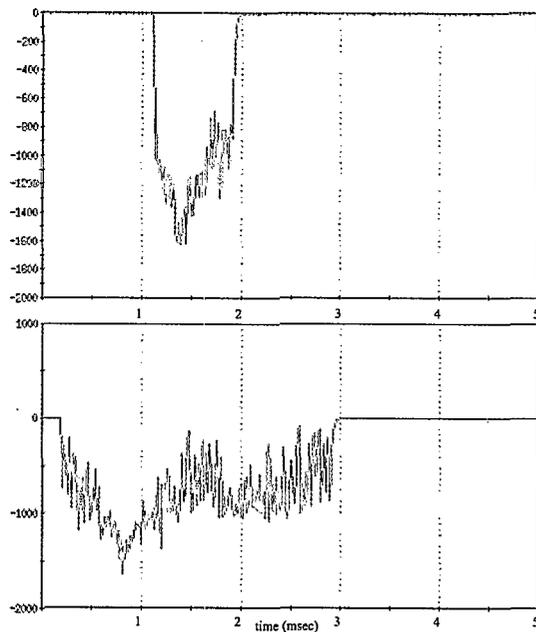


Figure 4: 1 and 3 msec spills measured using a scintillator in the beam.

of the elements have been checked and only one element required a correction. The octupoles have performed precisely as predicted. The performance of the octupoles, we found, greatly improves with the use of thicker stripping foils. This has been verified in models, in which the multiple scattering smoothes and makes the distribution more Gaussian. Any amount that the beam distribution deviates from a Gaussian will cause unwanted aberrations in the final distribution. Figure 5 shows a typical uniform beam distribution. Notice that the horizontal plane shows folded in wings that do not appear in the vertical. Since the beam distribution for a slow extraction system is highly non-Gaussian, it is not surprising that the horizontal is different from the vertical.

Dosimetry System

The dosimetry system consists of four ion chambers, one of which is a segmented ion chamber. The chambers are filled with N_2 gas. Each ion chamber has a 32-zone concentric-ring/quadrant foil, a high-voltage foil, and a 2-zone concentric-ringed foil. The fourth chamber is divided into 256 square elements, 1.5 cm to a side, arranged in a 16x16 array. Only one of the ion chambers is used for beam cut-off. To deliver a precise predetermined dose the system sends a request, through the Booster event link, to a beam permit system which 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.

A binary-filter absorber can be used to vary the range

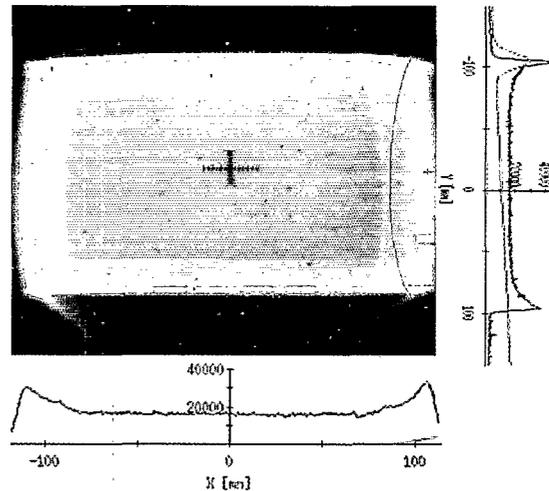


Figure 5: $20 \times 20 \text{ cm}^2$ uniform beam

(energy) of the ions delivered to targets by introducing a measured amount of polyethylene. It is primarily used to generate Bragg curves. The absorber consists of 9 sheets ranging in thickness from 0.05 cm to 12.8 cm. Total thickness is computer controlled and can vary from 0 to 25.55 cm in 0.05 cm steps.

SUMMARY

The new NSRL facility 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, expanding the range of experiments that can be performed.

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