RESULTS OF THE NASA SPACE RADIATION LABORATORY BEAM STUDIES PROGRAM AT BNL [*]

K.A.Brown[†], L.Ahrens, R.H.Beuttenmuller, I.Chiang, D.C.Elliott, D.Gassner, Z.Li, I.Marneris,
J.A.Mead, J.Morris, D.Phillips, V.Radeka, A.Rusek, N.Tsoupas, B.Yu, K.Zeno,
C-AD Dept., BNL, Upton, NY

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 NSRL makes use of heavy ions in the range of 0.05 to 3 GeV/n slow extracted from BNL's AGS Booster. The purpose of the NSRL Beam Studies Program is to develop a clear understanding of the beams delivered to the facility, to fully characterize those beams, and to develop new capabilities in the interest of understanding the radiation environment in space. In this report we will describe the first results from this program.

INTRODUCTION

The NSRL provides a high quality source of high energy, high charge state (HZE) particles within the high linear energy transfer (LET) ranges of most interest to scientists who want to study the kinds of radiation a spacecraft would be exposed to outside the earths protective envelope. Since the radiation environment beyond the earth/moon system is so varied and dynamic the NASA users need to reproduce in the laboratory many different conditions. To this end the NSRL was designed to accept a large range of ions over a large range of beam energies [1]. Nevertheless the full capabilities of this facility have not been explored, and the NASA users are interested in expanding their experiments to be more and more sophisticated. There are three primary capabilities which the users have requested. The first and foremost is an interest in fully characterizing the beams currently being provided. Secondly, the users would like to be able to rapidly expose samples to more than just a single type of ion or at a single energy. This requires significant configuration change to do multiple beam energies (without using an energy absorber, which have the potential of creating fragments or other types of ionizing radiation) or to change ion species. The final area of interest in the production of high energy micro-probe beams. For more details on the NSRL facility see [1, 2, 3, 4].

To support the development of these capabilities NASA has funded, as part of the regular scientific program, a program of beam development studies. The following is a list of topics that have been studied under this program. The time allocation for these studies was four hours per week.

- Spill control and structure studies
- Ion chamber response studies
- Reproducing the energy spectrum in space
- Beam emittance characterization
- Collimation effects
- Microprobe detector studies
- Characterization of dosimetry system
- Method of measuring uniformity in beams
- Multiple ion species irradiation

DISCUSSION

Instrumentation

Studies of the beam line ion chambers focused on finding a configuration that works for all ion species, beam sizes, and beam energies. Figure 1 shows an ion chamber response for three different beam conditions when using $ArCO_2$ at atmospheric pressure in the chamber. This figure shows data for a single ion chamber in the beam line, normalized to a downstream ion chamber held at a fixed high voltage. The beam conditions on the second ion chamber were very similar to the one being measured. The design of the ion chambers allows flowing into the chamber different gases. Gases that we have studied are $ArCO_2$, Nitrogen, and Helium. We found Nitrogen worked best for the normal operating ranges for most experiments. For lower beam intensities there are scintillator counters that can be plunged into the beam.

Beam Optics

The focus of the beam optics studies were on understanding emittance and twiss parameter measurements. In addition significant effort has gone into studies of generating uniform beams. More details can be found on the beam line, beam measurements, and non-linear optics in [1, 3].

In our models we have assumed that the beam parameters of the extracted beam at the beginning of the NSRL beam transport line are identical to the beam parameters of the circulating beam at the same location apart from the effect of the D3 thin septum magnet which provides a kick to the circulating beam to send it into the aperture of the D6 septum magnet. Table 1 shows the assumed horizontal and vertical beam parameters at the beginning of the NSRL beam transport line in the top row and the parameters from measurements in the bottom row. The measured data was taken using 1 GeV/n Ti and the 0.05 mm Cu stripping foil.

---

[*] Work performed under Contract Number DE-AC02-98CH10886 with the auspices of the US Department of Energy.

[†] kbrown@bnl.gov

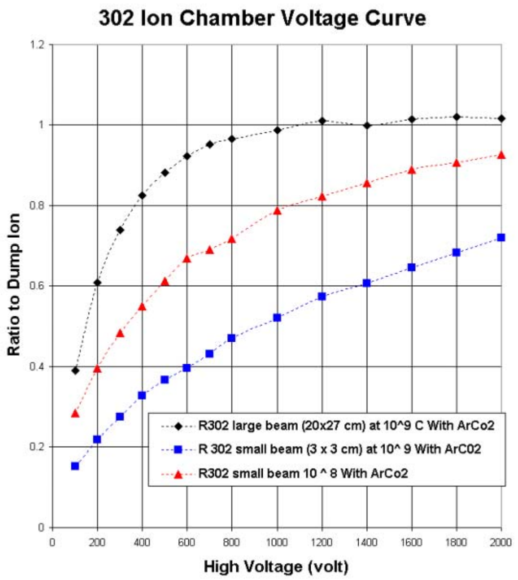

Figure 1: Normalized Ion Chamber response measurement.

η and η' are 0 in both planes.

Table 1: NSRL Beam parameters.

	α_x	β_x (m)	α_y	β_y (m)
Model	1.87	10.0	0.63	4.39
Measured	1.1	10.0	0.45	7.0

In order to ensure that the slow extracted beam acquires a more normal distribution we scatter the beam through a thin foil or wire at the entrance of NSRL (which also acts to strip off any electrons, since ions are typically not fully stripped in the Booster). The electron stripping reduces the rigidity of the transported beam. In the models we use a 10 π[mm.mrad] 95% normalized beam emittance for both the horizontal and vertical planes. Measured emittances are consistent with this, although data is still being analyzed. The magnitude of the measured beam emittances and the beam parameters, for the various extracted beams depends on the thickness of the foils used at the entrance of NSRL. Analysis of measurements has not yet incorporated the effect of the foils.

Spill Control

As is always the case with slow extraction systems the time dependent spill structure is a major concern. Figure 2 shows a 1 GeV/n Titanium beam spill with just an active filter in use to smooth the main magnet current ripple [7]. We studied a number of methods to reduce spill ripple.

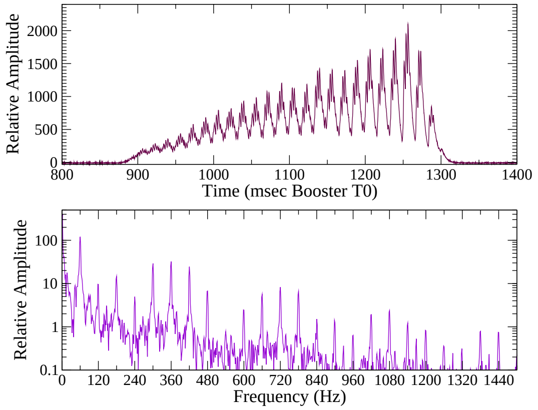

Figure 2: Normal slow extracted beam spill and associated frequency harmonics for 1 GeV/n Ti with no harmonic corrections and without any rf phase displacement.

As a first step to understanding the spill structure we measured the response to the beam from the Booster tune quadrupoles by injecting specific frequencies into the tune quadrupole power supplies. For the measurement we used frequencies which were not harmonics of the main AC line voltage of the power supplies (60 Hz in the U.S.). Figure 3 shows the normalized response of the beam spill and also as seen on a coil in the field of a reference quadrupole. Clearly, from the beam spill signal, the lowest frequencies around 60 Hz have the most significant effect. A fitting to the curves shows the response is very close to that of a two pole filter with a breakpoint around 100 Hz.

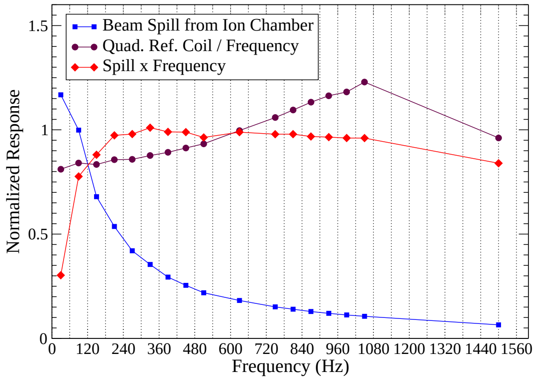

Figure 3: Measured frequency response of Booster main magnet power supply ripple on beam spill and as seen on a reference quadrupole pickup coil.

The most successful method of reducing the power supply harmonics from the spill has been the use of rf phase displacement. In this method the main RF is brought back on after the beam has been debunched, at a non-beam-synchronous frequency that corresponds to the revolution frequency for a particle in resonance. This causes the particles to be accelerated through the resonance between empty RF buckets. This method is a completely open loop operation.

Other methods of spill correction have to do with modulation of the tune quadrupoles power supply. This works very well when we use the spill itself in a closed loop configuration. In one study we learned the correction and fed it back in an open loop configuration. This worked well, but not as well as other methods. A technique which worked very well was to modulate the tune quadrupoles power supply just on a 60 Hz line frequency with the gain and phase adjusted to minimize spill ripple. Figure 4 shows the spill corrected using rf phase displacement (top) and by using a 60 Hz line frequency fed into the tune quadrupole power supply. The 60 Hz reference signal was not as clean as it should be, so it fed in higher frequency noise components, which is evident in the signal.

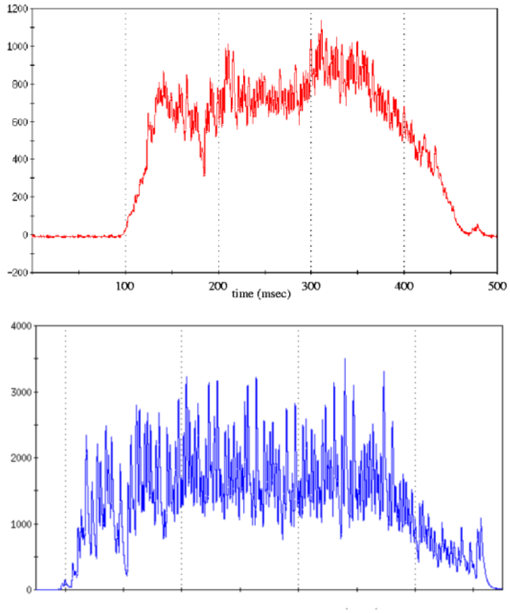

Figure 4: Top shows a spill corrected using rf phase displacement. The bottom shows a spill corrected using tune quadrupole modulation.

Energy Spectrum in Space

The end goal of this effort is to be able to have a user program in a dose versus energy request and then step the accelerator and beam line through the program, to produce the desired spectrum. This is very challenging, since a requirement is that the beam size and intensity not vary too greatly over the exposure. Our plan is to take advantage of the sequencing infrastructure built into the controls system for the purpose of RHIC operations. We would then use the Booster main magnet program as a scaling reference and scale elements from some well established known state (or set of states). An important part of the system is for the dosimetry system to provide an asynchronous event that would key the change to the next energy. For the studies performed so far we have built into the Booster main magnet software the infrastructure to allow the sequencer to automatically load a new state. This was successfully tested and has been used in operations. The next step is to do studies using the main magnet as a scaling reference.

Microbeams

The ability to produce clean microprobe beams at NSRL energies is being explored [6]. To this end a micron resolution detector has been designed and built by the BNL Instrumentation division [5]. The first beam tests of this detector were done in March/April run and more beam tests were performed in June. The concept behind these detectors is based on interleaved pixel electrodes arranged in a projective $x-y$ readout, which makes possible position encoding with a moderate number of readout electronic channels. A fine position resolution in the sub-micron range is achieved by determining the centroid of the charge collected on pixel electrodes with a granularity in the range of 5-6 microns. This electrode granularity does not pose difficult demands on the lithography and the fabrication technology. Results from the beam tests are still being analyzed, but so far the agree very well with predictions.

SUMMARY

As a result of the NSRL Beam Studies Program, NASA users have been able to perform new experiments and NSRL has been given new capabilities. We have begun to build the infrastructure for even more sophisticated experiments.

REFERENCES

[1] K.A.Brown, et al, “Results of the First Run of the NASA Space Radiation Laboratory at BNL”, These Proceedings

[2] K.A.Brown, et al, “Commissioning Results of Slow Extraction of Heavy Ions from the AGS Booster“, Proceedings of the 2003 Particle Accelerator Conference, Portland, OR, 2003

[3] N.Tsoupas, et al, “Results from the Commissioning of the NSRL Beam Transfer Line at BNL”, These Proceedings

[4] K.A.Brown, et al, “Design of a Resonant Extraction System for the AGS Booster“, p. 1270, Proceedings of the 1999 Particle Accelerator Conference, New York, 1999.

[5] Z. Li, ”Novel Silicon Stripixel Detector: Concept, Simulation, Design and Fabrication”, Nuclear Instruments and Methods A, vol. 518 (2004), p738-753.

[6] K.A.Brown, et al, “A Heavy Ion Microbeam Facility Using Micron Resolution Detectors for 3 GeV/Nucleon Beams“, Proceedings of the 2002 European Particle Accelerator Conference, Paris, 2002.

[7] I.Marneris, et al, “Booster Main Magnet Power Supply Improvements for NASA Space Radiation Laboratory at BNL”, Proceedings of the 2003 Particle Accelerator Conference, Portland, OR, 2003

[8] K.A.Brown, et al, “A High Precision Model of AGS Booster Tune Control”, Proceedings of the 2002 European Particle Accelerator Conference, Paris, 2002, p.548