AUTOMATING CONTROL OF THE BEAMS FOR THE NASA SPACE RADIATION LABORATORY *

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Abstract

The NASA Space Radiation Laboratory (NSRL) at BNL uses many different beams to do experiments associated with evaluating the possible risks to astronauts in space environments. This facility became operational in 2003 and operates from the AGS Booster synchrotron. In order to simulate the space radiation environment some of these experiments need to make use of beams of various energies. To simulate solar flare events, we implemented the Solar Particle Simulator in 2005. This system put in modifications to the accelerator controls to allow beam energies to be changed automatically, enabling target samples to be irradiated with many energies of the same type of ion, without having to make use of degraders. To simulate Galactic Cosmic events, they need to also be able to automatically change the ions used to irradiate a single sample. This project aims to allow NSRL to change ions as well as beam energies within a very short period of time. To do this requires modifications to existing controls as well as building new controls for a Laser Ion Source. In this paper we describe NSRL, our plans to implement the Galactic Cosmic Event Simulator, and the status of the Laser Ion Source.

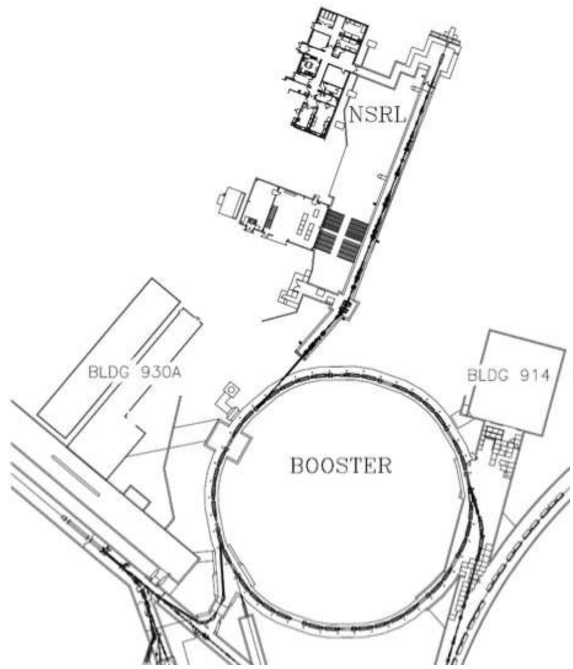

Figure 1: The AGS Booster and NSRL beamline.

INTRODUCTION

NSRL was designed to provide many types of beams at many different energies and intensities. Previous reports describe the facility, it's design and commisioning [1, 2, 3, 4, 5]. The facility has a target hall at the end of a beamline that was built extending from the AGS Booster Synchrotron. They make use of slow and fast extracted beams, from protons to many different heavy ion beams.

NSRL was built to provide a dedicated laboratory for NASA researchers to study radiation effects and to simulate the radiation conditions in space [6]. The two main sources of radiation in space are from the Sun and from high-energy particles originating from outside the solar system, Galactic Cosmic Rays (GCR). The most significant source of radiation from the Sun is from solar flares, or Coronal Mass Ejections (CME), usually designated by NASA as Solar Particle Events (SPE).

NASA researchers want to reproduce the environment in space, due to these two sources of radiation, as much as possible. This has led to two initiatives. First is the development of the NSRL Solar Particle Event Simulator, built and commissioned in 2005 [7]. This system made use of sequencing tools developed for RHIC operations, modified applications for controlling the AGS Booster systems, and new tools for managing energy changes [8, 9]. The main innovation of the Solar Particle Event Simulator was to automate the process of changing beam energy for NSRL. This system was designed to change the extraction system settings while not impacting the injection and RF capture processes.

The other initiative is to build a GCR simulator. The main difference between the GCR simulator and the SPE simulator is that CMEs are primarily composed of high-energy protons while GCRs are composed of many ions, from protons up to very heavy ions [10, 11]. The energies of the ions range from a few MeV/nucleon to well above 1 TeV/nucleon. But the peak of the distributions tend to be around the range from 100 MeV/nucleon to 1 GeV/nucleon, exactly the range of energies for which NSRL was designed.

The GCR simulator project has been started and is composed of three primary parts. First, an ion source is needed that will allow fast selection from many different ions. For this purpose the Laser Ion Source is being constructed and will be added as another source to the existing Electron Beam Ion Source (EBIS) system [12]. The second part of

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the project is to perform beam studies to better understand how to automate the Booster injection and RF capture processes, to allow switching ions to be done without retuning those systems by hand. The third part of the project is to integrate these new systems into the SPE simulator so that NSRL researchers can easily define a program of ions and energies and expose targets following that program without having to remove the targets during an ion or energy change.

GCR AND SPE SIMULATORS

Overview of SPE Simulator

With the SPE simulator being the basis for the GCR simulator, it is worth reviewing how that system is designed and works. It is important to note that no new hardware systems were used to build the SPE simulator. The entire system was simply a process of modifying controls systems software. The main tools that went into the SPE simulator are sequencing systems originally built for RHIC operations, modifications to the Booster main magnet and optics controls systems, and a magnet systems manager for the NSRL beam line, to allow model based scaling of magnetic elements.

The most important component to the system is the sequencer. As shown in the functional block diagram in Figure 2, it coordinates all the actions taken for a requested change in energy. For the sequencer to work correctly there were a number of changes that needed to be made. The system needed to be able to scale elements and functions, by applying a scaling factor, send a scaling factor to specific applications and execute the new scaled functions to be live, such as with the Booster Main Magnet application. The system was designed around the idea that a system expert configures a good working beam setup to the NSRL targets and from that setup it would be possible to scale, using known transfer functions for currents to magnet strengths and in some cases using a well vetted model of the magnetic optics [13].

The other components to the system include developing the proper scalings of the beam line elements for a given energy, including energy loss and rigidity shift from a stripping foil at the entrance to the beamline, and avoiding errors in the scaled setup due to magnet hysteresis. This part of the controls could be improved, and will be for the GCR simulator.

GCR Simulator Requirements

What NASA would like to be able to do is to expose targets with a mixture of ions and energies that match the known spectra seen to occur in space. This includes compensating for spacecraft shielding configurations and formulating different GCR reference fields, such as an Earth to Mars transit field or a Mars surfaces representative field. From the accelerator point of view this means they need to be able to change the ion species from protons up to heavy elements, such as iron, as well as change the energies of

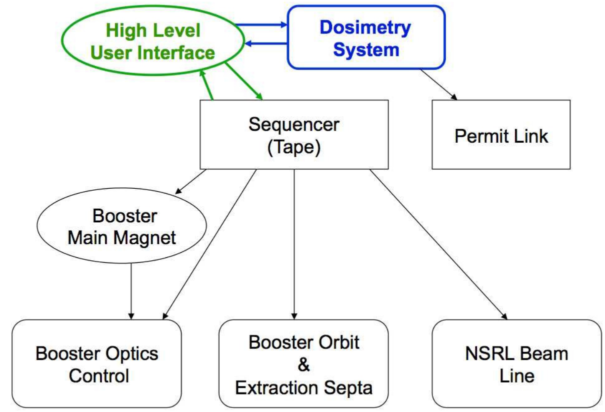

Figure 2: Block diagram of the controls for the SPE simulator. A sequence is defined for a set of requested beam energies. The dosimetry system, a part of the NSRL target monitoring systems, signals when the desired exposure has been achieved for a given energy and a new energy is selected in the sequence. Note, the lines between the Dosimetry system and the high level interface are not implemented for the SPE simulator, but will be for the GCR simulator.

each of the ion species over a large range. The main constraint is they need the quality of the beam to be unchanged for all ions and energies.

NSRL determines the quality of the beam mostly based on the uniformity of the beam profile on the beam targets, determined by the dosimetry system and imaging systems on the target table. Figure 3 shows an example of a uniform beam over a number of targets. Typically the uniformity of the beam over the targets is good to within a few percent.

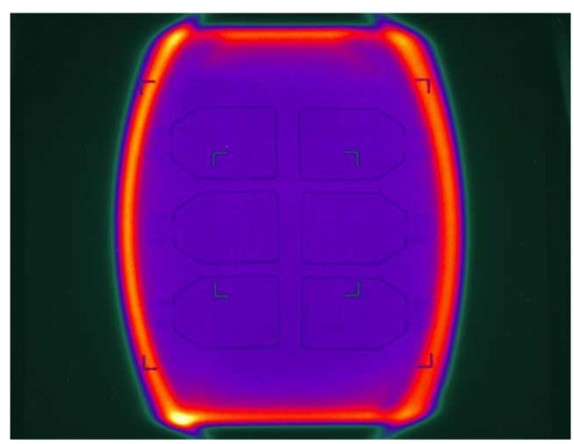

Figure 3: Example of a uniform beam over an NSRL set of targets.

The SPE simulator can keep the uniformity constant over many different energies, but it is not perfect. However, the system allows for new energies to be defined very quickly and with some very minor tuning the beam quality can be brought back to what is required. So the process of doing an SPE simulated exposure requires first setting up all the

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energies for a scan and then performing the scan by consecutively loading those saved conditions into the controls references. A goal of the GCR simulator is to learn how to improve on this and possibly eliminate the tuning.

Another aspect to beam quality is the intensity of the beam delivered to the target samples. Since the size of the beam is a function of energy, the physics of the extraction process limits how efficiently the beams can be extracted. So, as the energy decreases, the efficiency also decreases. Part of the tune up process, after an energy change, is to optimize the efficiency, but typically no improvement is found. However, what is important to the experiments is delivered dose. The dosimetry system is preset for delivered dose, not time of exposure. So it is acceptable if it takes slightly longer to do a given exposure than would be predicted if the intensity didn't change. Ways of improving the extraction efficiency are being investigated, but they are not a part of the project and not considered relevant to the success of the project.

Although not critical for the SPE simulator, EBIS is a critical part of the GCR simulator. EBIS consists of a set ion sources that inject ions into a solenoid with an electrostatic trap [14]. The beam of ions remains trapped in the solenoid, while an electron beam is injected along the solenoid axis. The electron beam strips electrons from the ions. To obtain a given charge state beam from EBIS the ion beam needs to remain confined inside the solenoid for a period of time. This confinement time changes depending on the desired ion and charge state. Figure 5 shows the layout of the EBIS facility.

One significant problem is in learning what it takes to change the ion species and scale the injection and RF system for the new ion correctly. Since some of these processes are very complex, some beam studies are needed to learn what methods work best. One thing that makes it difficult is ensuring the beams inject into the correct field at the correct time. For example, a change in ion species may change the timing for injection, since the EBIS operation requires different confinement times in the EBIS solenoid trap to create the right charge states for a given beam. In principle, this is predictable, but will require some studies to show the predictions can work well.

One important part of this project is an upgrade to the Booster RF with a new RHIC style LLRF system that is all digital [15]. This will enable much greater control over the RF configuration and also allow fast switching between configurations.

A particular challenge that needs beam studies will be in keeping the Booster orbit well controlled as ion species are changed. For the SPE simulator it was assumed that the orbits are corrected and that those systems would scale properly. But with the greater number of changes that will take place for an ion change, the beam orbits may need to be corrected explicitly, particularly to keep the same reference orbit during injection and at extraction. The detail here is the EBIS beams always arrive at the Booster with the same velocity, but with different rigidities. The injection field may be higher or lower as a new ion is selected. The orbit harmonics that orginate from the errors in the magnets and magnet placements very well could be different.

Another particular challenge will be in the measurement of dose in the target room. As ion species are changed the system needs to keep track of what ion is being delivered at any moment and needs to use the correct calibrations. However, much of this is not automated, and so needs to get interfaced to the Booster configuration databases.

GCR Simulator Plans

The most important component to the GCR simulator will be the new EBIS Laser Ion source. The Laser Ion Source uses a high power laser focused on a solid target to produce an ablation plasma. The plasma properties, such as the charge state distributions, beam currents, and ion energies, all depend on just the laser power density. From the plasma, 1+ charged ions are selected, accelerated, and then transported to be injected into the EBIS solenoid trap. Once in the EBIS solenoid, the electron beam will ionize the ions to the desired charge state and release them to the RFQ and Linac to be accelerated and transported for Booster injection. A basic layout of the Laser Ion Source is shown in Figure 4.

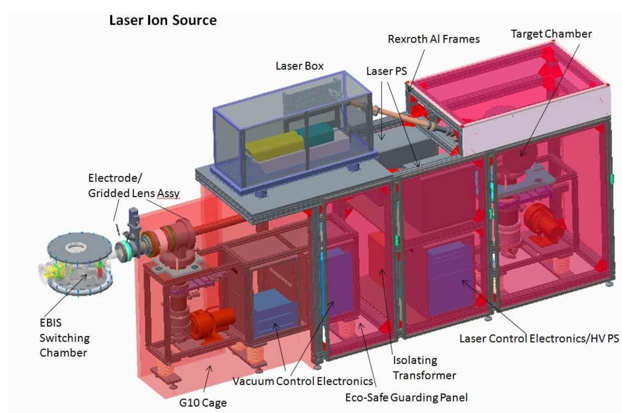

Figure 4: Layout of the Laser Ion Source. The laser, sitting above the beamline in the diagram, sends a laser pulse down into a chamber with a target holder that contains many different solid targets.

This system is being installed into EBIS at this time and plans are to commission the new ion source in November 2013. During the upcoming RHIC operations period studies will be performed to address the various beam physics questions outlined above. At the same time the software systems needed for the GCR simulator will be specified and built. These include the ability to automate much of the EBIS operations and allow scaling EBIS systems for ion changes, including development of an EBIS systems manager to allow model based modifications to be used in the scaling's, as well as building sequences to test ion changes.

Two existing software systems will make the GCR simulator possible and easier to manage. First, of course, is the

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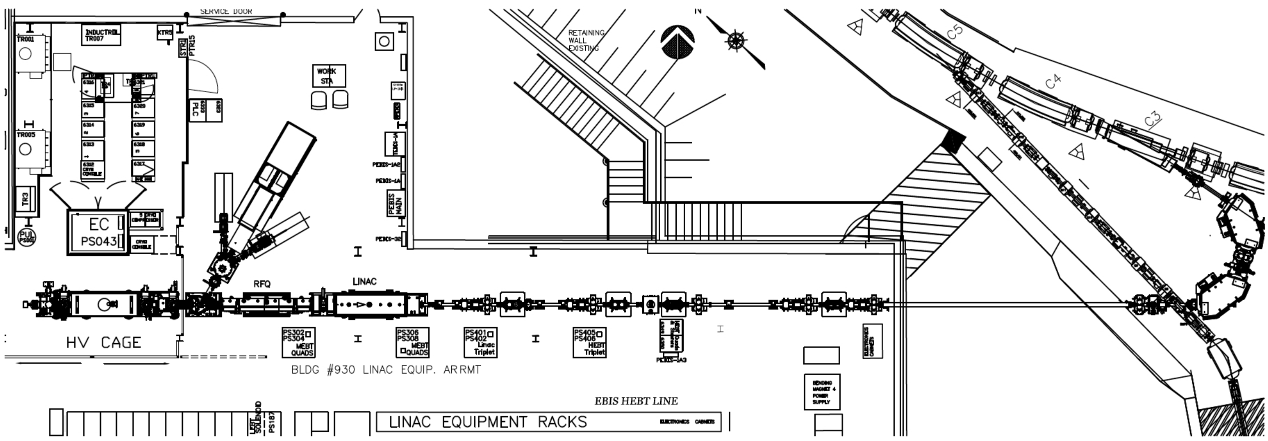

Figure 5: Layout of EBIS, from ion sources (the planned Laser Ion source is shown between the two ion sources) to booster injection.

existing sequencer system, which is already a key component to the SPE simulator and has had many enhancements and improvements put into it over the years [16]. The other is the existing Supercycle manager, which manages all the global timing links for the injector systems and for RHIC injection. An ion change may involve loading a new Supercycle, or may involve modifying an existing Supercycle and loading it to be live. Further investigation is ongoing to analyze the best ways to manage the timing requirements.

The sequencer software already has all the tools needed to implement the GCR simulator. But this does not provide an interface that will allow easily managing ion changes, so we imagine an application will need to be built to perform this function. Many systems will have to be analyzed and systems put in place to improve reproducibility. This includes hysteresis compensation, reproducibility in magnet settings (e.g., is power supply regulator calibration drifting or stable?), automatically adjusting instrumentation calibration for ion changes, and possibly implementing feedback systems to improve on reproducibility.

SUMMARY

NSRL is able to reproduce many of the conditions that will be encountered by space probes as well as astronauts in future NASA missions. The ability to realistically reproduce SPEs was added to NSRLs capabilities in 2005 and the ability to reproduce GCRs is being added now. To implement such capabilities requires many aspects to the accelerator controls be automated in reproducible and reliably ways. This has largely been successfully done for the SPE simulator system. We fully expect to be able to perform automated GCR simultion exposures starting in 2015.

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