NASA Space Radiation Laboratory*

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From 1995 until 2002, NASA supported a limited set of radiobiology experiments using ion beams from the Brookhaven National Laboratory (BNL) Alternating Gradient Synchrotron (AGS) accelerator. This program was initiated after the termination of Bevalac operations at Lawrence Berkeley National Laboratory. The BNL experiments were sponsored and funded by NASA as part of the Space Radiation Health Program (SRHP). The SRHP is a peer-reviewed basic and applied research program relating to the effects on humans of space radiation, with the ultimate goal of providing a firm scientific basis for space radiation protection. These experiments address the particular problem of high energy heavy ion radiation exposures during future long-term deep space flights. Their principal objective is to improve our understanding of the biological effects of low fluences of densely ionizing charged particles on living cells and tissues. Humans themselves are not subjects for irradiation in these tests.

The NASA Space Radiation Laboratory (NSRL) was designed and built to provide particle beams for research in radiobiology, materials and electronics upset, in support of the humans-in-space initiative. BNL has the responsibility to provide the particle beams for experiments and to provide the life science support facilities for cells and animals that are required to accomplish the scientific mission. BNL also has the responsibility to provide the scientific, engineering, technical and administrative support for the experimental community to accomplish their research at NSRL. A detailed description of the facility and guide for experimental users is available at
http://www.bnl.gov/medical/NASA/CAD/NSRL_Beam_Information_Guide.asp

NSRL began research operations in July 2003, immediately after the completion of the NASA funded and DOE managed construction project (Figure 1.) Since the initial run, the operation has followed a pattern of 3 runs per year. NSRL currently provides ion beams for 1000-1200 hours per year to approximately 150 experimenters per run from 40 institutions. The research institutions include universities, national laboratories, and research institutes, including both US and international investigators.

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Photos are courtesy of Brookhaven National Laboratory.

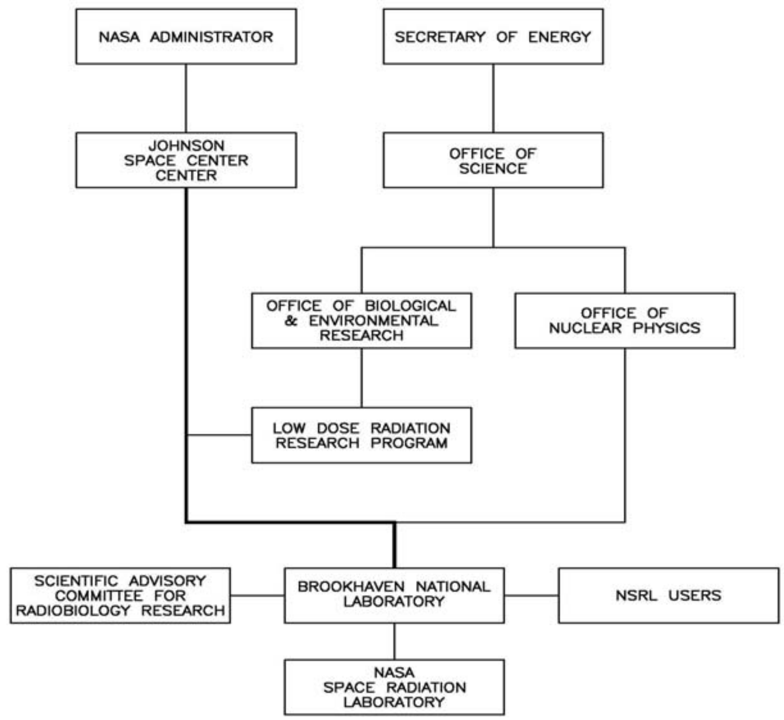

Figure 1. NASA and DOE NSRL Management Structure

Scientific Program

The humans-in space program Bioastronautics Critical Path Roadmap identifies the area of radiation risk and mitigation as one of the primary questions to be answered before humans can undertake extended stays beyond low Earth orbit. The roadmap identifies as some of the most pressing questions the areas of carcinogenesis, central nervous system, degenerative tissue, heredity, fertility, sterility as risks and acute radiation syndromes.

The particle radiation spectrum in outer space is comprised of two general components; galactic cosmic rays and solar flare protons. The chronic flux of galactic cosmic rays is the major radiation component. The cosmic rays consist mostly of particles in the mass range predominantly from protons to nickel, and are the result of supernova events. The cosmic rays will deliver significant doses to astronauts when integrated over extended stays of months to years on moon or Mars missions. The research mission is to understand the long-term health effects of radiation doses to astronauts and the short-term effects that could compromise the mission objectives.

The second radiation component is the occasional high intensity proton flux that results from solar flares. The solar flare protons can deliver life-threatening doses over a period of hours to days. A major question to be addressed is the shielding materials and topology for a temporary storm shelter to minimize the dose. For both sources of radiation, biological risk, radio-protectant effectiveness, space vehicle shielding, electronics and materials sensitivity to radiation are critical questions.

In addition, there are nuclear physics cross-section, angular and energy distribution data etc. that are needed as input to modeling codes. These modeling codes will allow evaluation of risk due to radiation fields and geometries that have not been directly measured.

Accelerator Operations

NSRL consists of a beam particle transport emanating from the Booster synchrotron to a dedicated experimental area and support building (Figure 2).

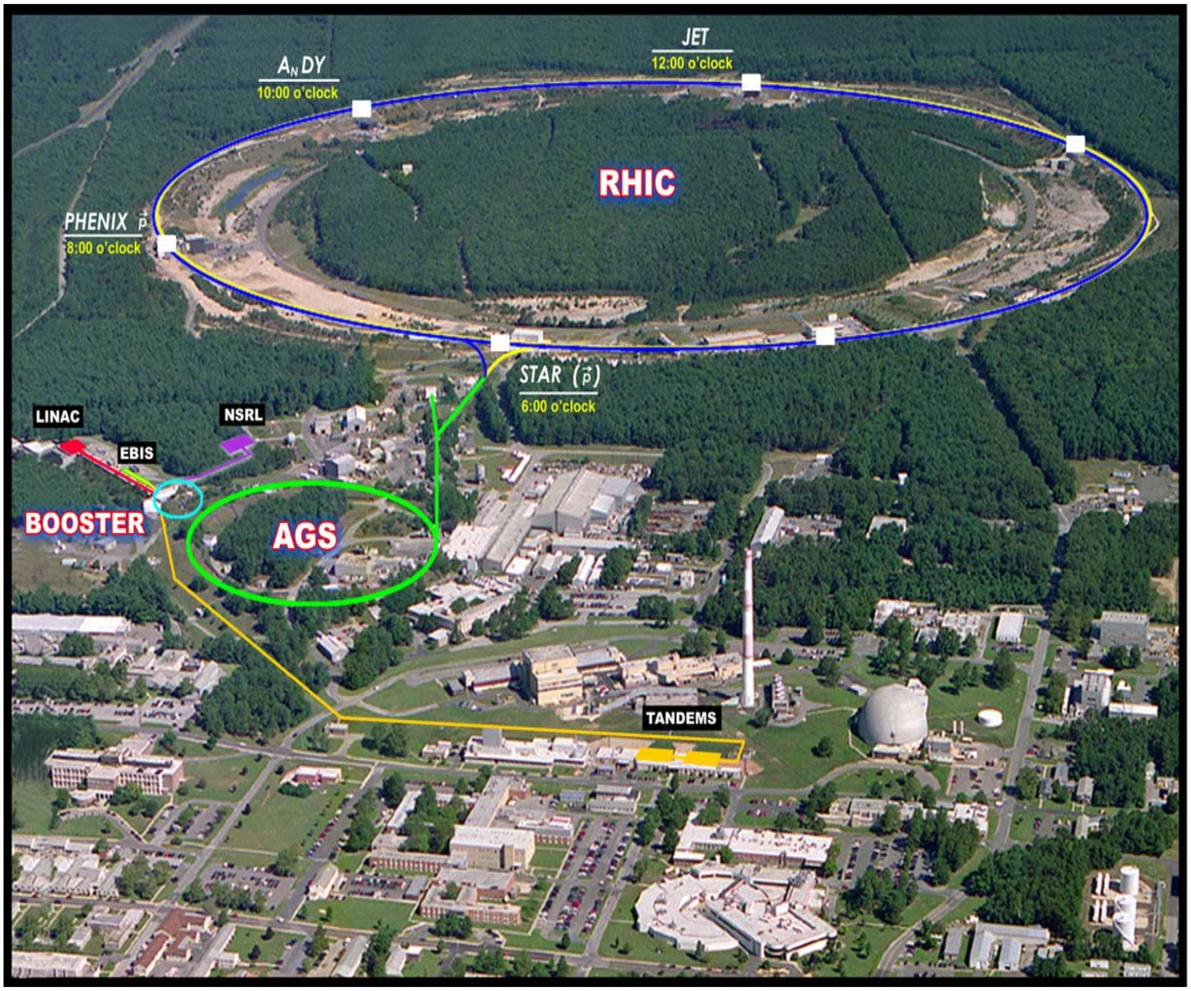

Figure 2. Accelerator facility layout

NSRL has been designed to transport any particle beam that the Booster can provide. Figures 2 and 3 illustrate some representative LET curves and maximum dose rates for various ion species. Dose delivery can be adjusted over typically five orders of magnitude for a given ion species, as the experiments require. The selection of ion species for each campaign is provided as guidance from NASA. To date the following beams have been delivered to experiments: proton, helium, neon, carbon, chlorine, iron, gold, oxygen, silicon and titanium at energies ranging from 50 MeV / nucleon to 1100 MeV / nucleon. Until 2011, the Tandem Van de Graaff has provided a selected set of beams from protons to iron and higher masses to the Booster. The new EBIS injector, a joint NASA and DOE Office of Science Nuclear Physics project, replaces the Tandems in 2010-2011. EBIS will

Ion Species [1]	Energy [2] (MeV/nucleon)	Maximum Intensity [3] (ions per spill)	LET [4] (keV/m)
H-1	50 - 2500	6.4×10^{11}	1.26 - 0.21
He-4	300	0.88×10^{10}	1.413
C-12	135 - 1000	1.2×10^{10}	21.21 - 8.01
O-16	100 - 1000	0.4×10^{10}	47 - 14
Ne-20	300	0.10×10^{10}	35.34
Si-28	94 - 1000	0.3×10^{10}	151 - 44
Cl-35	500 - 1000	0.2×10^{10}	80 - 64
Ti-48	150 - 1000	0.08×10^{10}	265 - 108
Fe-56	100 - 1000	0.2×10^{10}	494 - 150
Sequential Field (Fe/H)	1000	Various	150/0.2
Solar Particle Event	50 - 1000	Various	1.26 - 0.21

Table 1. Beam ion species and energies provided for experiments prior to March 2011. See below for range and LET (Fig. 3) and dose rates (Fig. 4).

supply any desired ion species. The Linac also provides protons to the Booster (see Table 1).

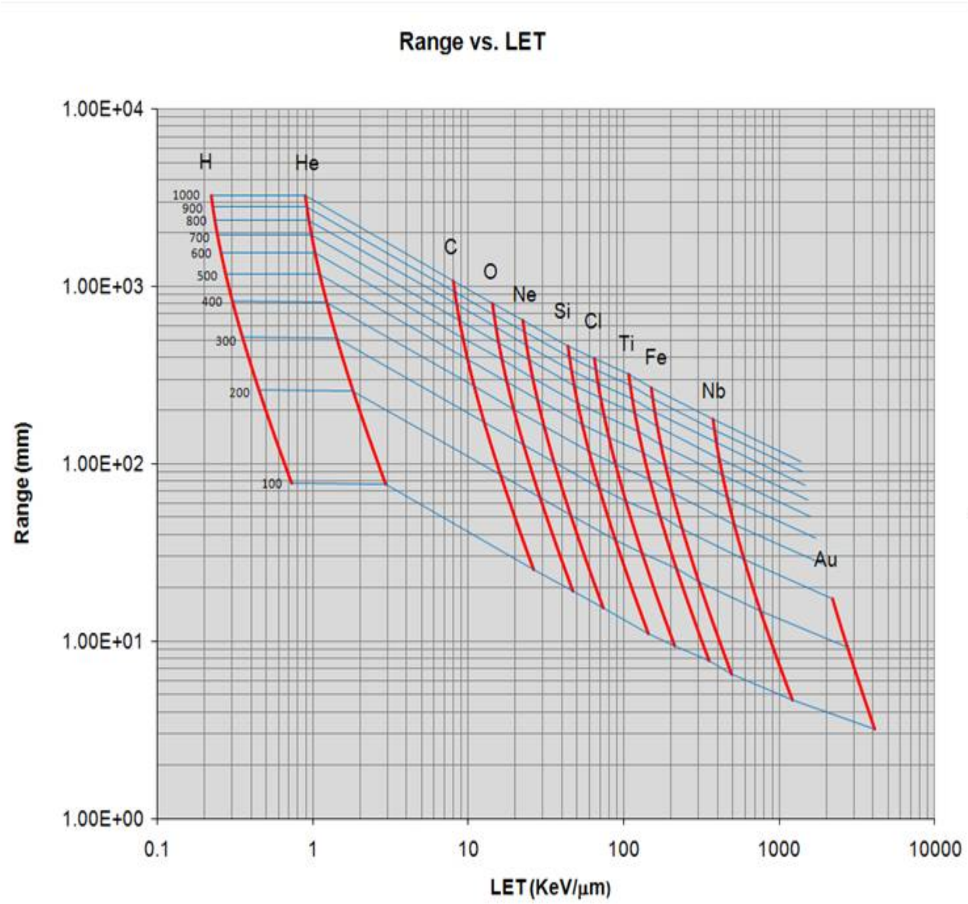

Figure 3. Range vs. LET as a function of ion species and kinetic energy

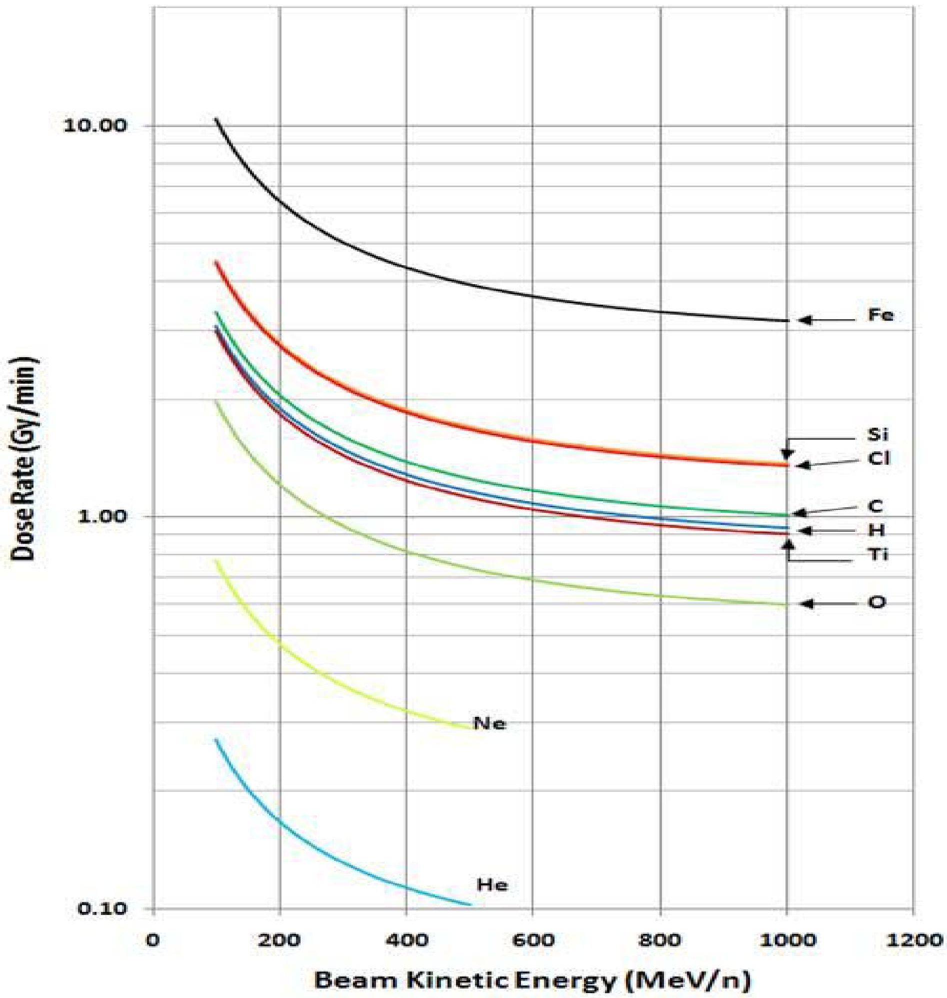

Figure 4. Ion dose rates

NSRL EXPERIMENTAL AND ACCELERATOR FACILITY

The NSRL facility consists of a 100-meter transport tunnel and beam line to deliver the beam to a 400-square-foot shielded target hall for NASA funded space-effects experiments (Figures 5 and 6).

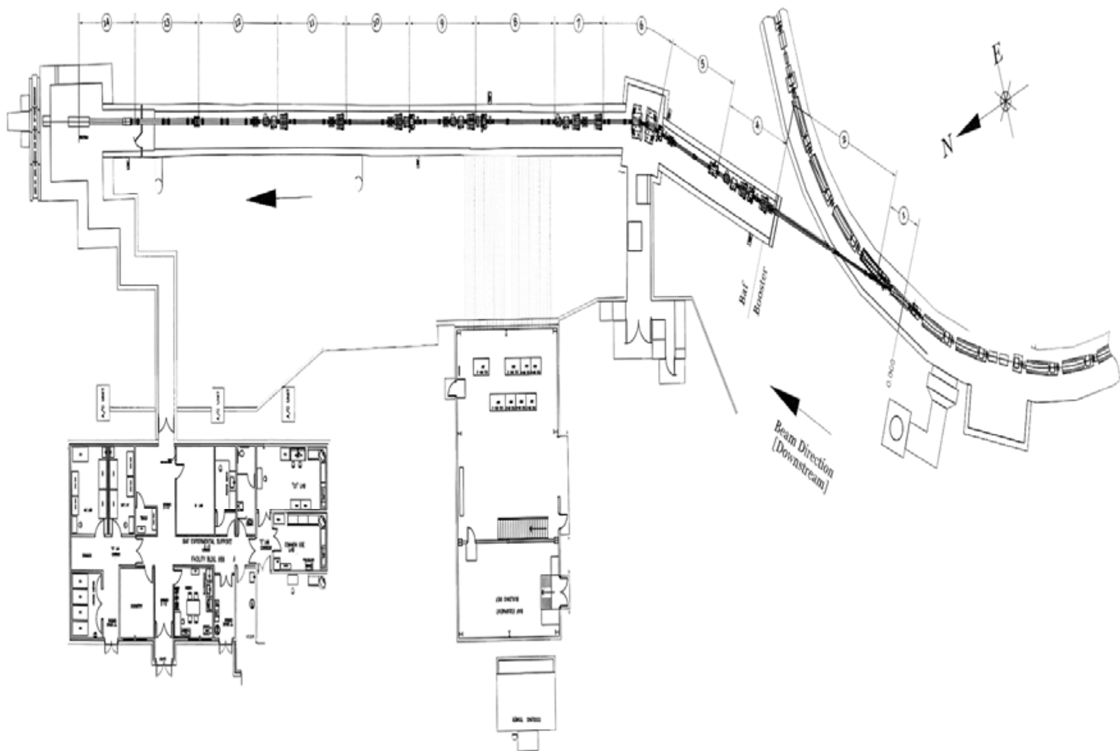

Figure 5. Booster synchrotron and NSRL beam line and experimental area

Figure 6. NSRL Beam Line

The target hall is connected to a 4,560- square-foot support building, which includes five laboratories for biological and materials experiments; and specimen, dosimetry, and control rooms (Figures 7 & 8).

Figure 7. NSRL Experimental Hall

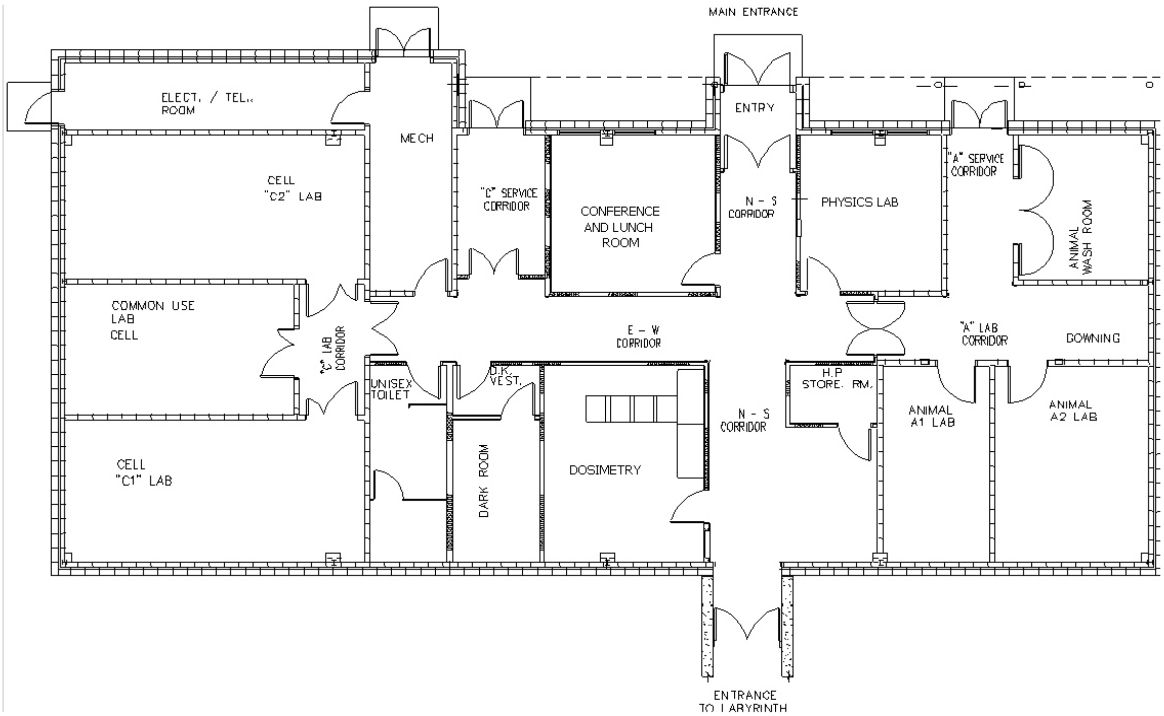

Figure 8. NSRL Experimental Support Building

Beginning in 2010-2011, the EBIS injector system [1] replacement of the Tandem Van de Graaffs began operations. The EBIS Project was jointly financed by the DOE Office of Science Nuclear Physics and NASA. The system consists of an Electron Beam Ion Source (EBIS) followed by a Radio-Frequency Quadrupole (RFQ) Linac and an IH Linac, which produces 2 MeV/nucleon ions of any species with subsequent transmission and injection into the Booster synchrotron. Neon and helium beams were first delivered during the Fall 2010 run. This new system allows for pulse-to-pulse (2-3 seconds) switching of ion species. The past switching time was several minutes from ions to protons and back. In addition NSRL will deliver helium and other beams of noble elements, which are not available from the Tandems. The EBIS system is situated in the same building as the proton linac (Figures 9 & 10), thus providing for a much simpler optics configuration.

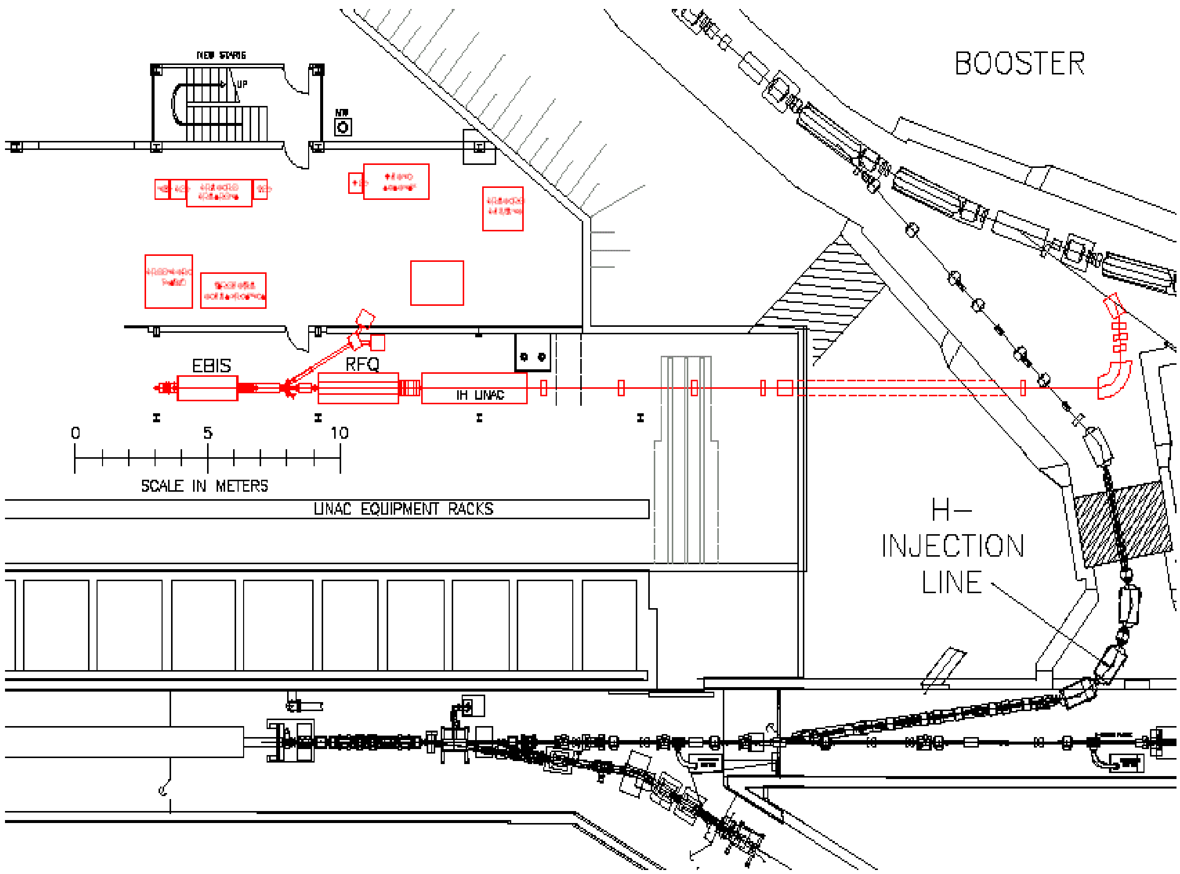

Figure 9. EBIS Injector Layout

[1] "Commissioning of the EBIS-based heavy ion preinjector at Brookhaven", J. Alessi et al, Proceedings of the 2010 Linear Accelerator Conference, JACoW (to be published).

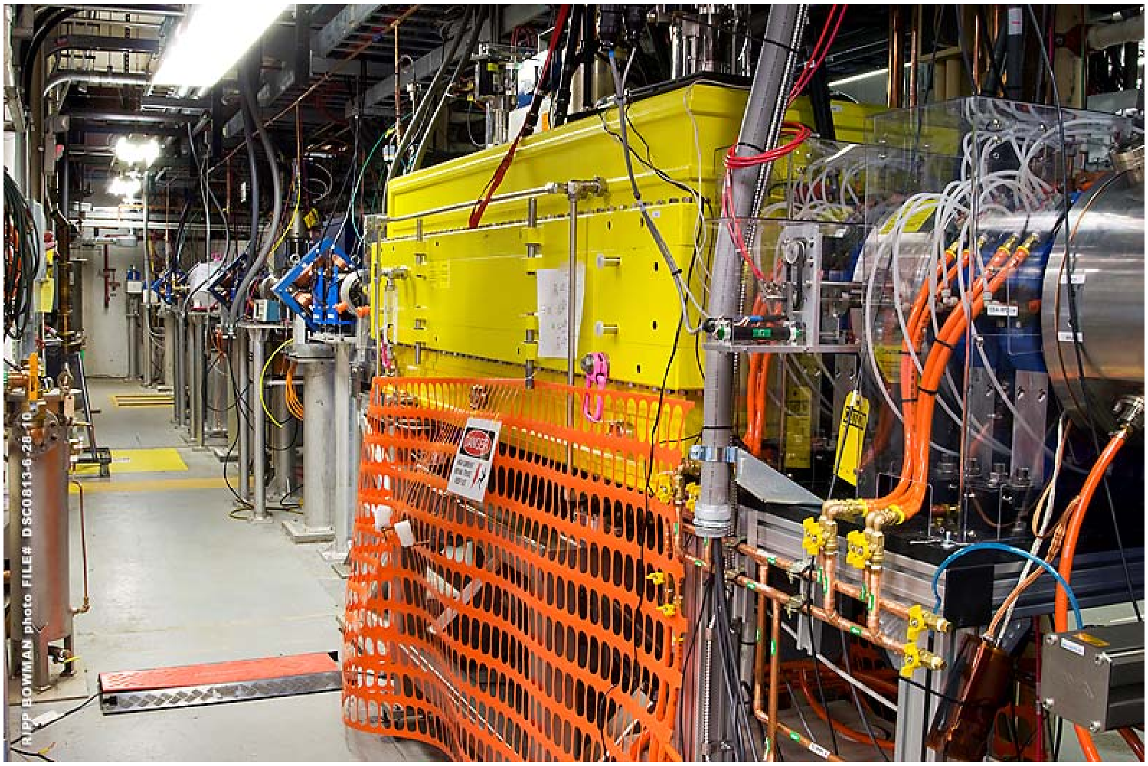

Figure 10. EBIS Injector System

Guidelines for Submission of a Beam Time Request for the NASA Space Radiation Laboratory (NSRL)

POLICY CATEGORIES OF USERS AND PRIORITIES

The following categories of NSRL users are defined, together with the corresponding access priorities:

CATEGORY 1: investigators selected following competitive peer-review of proposals submitted in response to a research solicitation sponsored by the Space Radiation Program of HHP alone or in collaboration with another agency, such as DOE, or international partners, under a current award. Scientific Merit: review provided by peer review panel; Technical Merit: review provided by SACRR in conjunction with review panel; Scheduling: Priority 1.

CATEGORY 2: investigators with a current award sponsored by NASA, but not by the Space Radiation Program, whose home institution has negotiated an agreement with the Space Radiation Program, Scientific Merit: review documented by investigator on applying for beam time; Technical Merit: review provided by SACRR; Scheduling: Priority 2.

CATEGORY 3: experiments intended to obtain preliminary data for inclusion in an application to an identified research solicitation sponsored by the Space Radiation Program alone or in collaboration with another agency, such as DOE or international partners. The resources required by such experiments shall be modest and compatible with the experiment objectives, as determined by SACRR. Scientific Merit: determined by SACRR; Technical Merit: review provided by SACRR; Scheduling: Priority 3, depending on availability.

CATEGORY 4: “parasite” or ”piggyback” experiments (i.e., irradiations requiring no significant BNL resources as determined by the BNL SACRR). Scientific Merit: review documented by investigator on applying for beam time; Technical Merit: review provided by SACRR; Scheduling: Priority 2, depending on availability.

CATEGORY 5: occasional full-scale experiments, not part of the Space Radiation Program, and not sponsored by NASA, that can document peer-review or other appropriate review process. Scientific Merit: review documented by investigator on applying for beam time; Technical Merit: review provided by SACRR; Scheduling: Priority 4, depending on availability.

CATEGORY 6: experiments performed in conjunction with an educational or outreach activity sponsored by the Space Radiation Program (e.g., Summer Study, HBCU experiments); Scientific Merit: determined by Space Radiation program management;

Technical Merit: review provided by SACRR; Scheduling: Priority 3, depending on availability.

CATEGORY 7: irradiations performed as part of industrial or commercial testing by NASA-funded projects, including SBIR grantees. Scientific/Technological Merit: documented by investigator on applying for beam time; Technical Merit: review provided by SACRR; Scheduling: Priority 5, depending on availability.

CATEGORY 8: experiments not able to document scientific or technical review. Scheduling: not allowed

- Proposals become inactive after (1) one year has elapsed, (2) the maximum beam time allotment has been reached, or (3) a replacement proposal has been submitted.
- Only experimental proposals with approved beam time requests may utilize NASA-funded beams and NASA-funded facilities.

TYPES OF REQUEST

1. Experimental Proposals

A. New Proposal: describes a single project to which no previous NSRL beam time has been assigned.

B. Renewal Proposal: describes a single project with previous assigned beam time.

C. Replacement Proposal: rewrite of a proposal to address SACRR comments. A resubmitted proposal will be re-rated and will replace the original request.

2. Beam Time Request
Justification for beam time REQUIRED FOR ALL PROPOSALS

PRIOR TO SUBMISSION

New users MUST (and returning investigators are encouraged to) contact beam line and biology/ laboratory facility personnel (see Radiobiology Contact list) to determine suitability of the beam available and the laboratory support facility for the experiments proposed. The Users' Manual provides much useful information, and can be accessed at http://www.agsrhichome.bnl.gov/NSRL/NSRL_DRAFT_MANUAL.pdf

ABOUT YOUR PROPOSAL

1. Proposals must be submitted ELECTRONICALLY in computer-readable word processing format (MS Word or equivalent). Send all required sections to NSRL Administrator. Note that two items must be sent in hard copy to: NSRL Administrator, at the address below.

A. The SIGNED face page of the Physics/Instrumentation User Proposal,
B. The SIGNED Physics/Instrumentation Users Safety Experimental Approval Form (signature on last page).

2. Proposals must not exceed the specified page limits.

3. Proposals for beam time must be submitted on or before the deadline for each scheduling cycle in which beam time is desired.

4. Proposals must include completed copies of the following safety/controlled research forms, as appropriate:

To be submitted ELECTRONICALLY:

A. Physics/Instrumentation Proposal and Request for Beam Time
B. Physics/Instrumentation Users Safety Experimental Approval Form
C. Support Form
D. Signed face page of Att.3 - Physics/Instrumentation Proposal and Request for Beam Time
E. Signed copy (last page) of Att.4 –Physics/Instrumentation Users Safety Experimental Approval form

To be submitted in HARD COPY to:
NSRL Administrator
Brookhaven National Laboratory
50 Bell Ave.
Biology Dept.
Bldg. 463
Upton, NY 11973-5000

5. Proposals received after the deadline will not be considered in the upcoming review cycle, but will be considered as submitted for next subsequent deadline and review cycle.

6. Investigators must provide, either through their web site or as an email attachment, a copy of their grant proposal funded by NASA/NSBRI/DOE-NASA under which the research is being carried out. The copy should have proprietary and salary information removed. This copy of the grant will be sent to reviewers upon request to aid in their review of the beam time proposal.

Facility and Experiment Scheduling

The Biology and Medical Departments provide the life science support for the facility and experimental program. In addition, the experiment review and scheduling of individual experiments are the responsibility of these departments. The scheduling of accelerator operations is the responsibility of the Collider-Accelerator Department.

The Scientific Advisory Committee for Radiobiology Research (SACRR) advises the BNL Associate Laboratory Director for Nuclear and Particle Physics (ALD, NPP) on assignments of beam time of experiments related to radiation biology at the NASA Space Radiation Laboratory. The Committee includes a Chair and six other reviewers from BNL and other institutions, plus Ex Officio members of the BNL directorate and departmental members, and observers from relevant funding agencies. The SACRR and administrative staff send out Tri-yearly Calls for Beam Time Proposals, advise proposers on experimental feasibility, receive proposals, select qualified reviewers, circulate proposals to reviewers, and via a meeting or teleconference, reach a consensus recommendation to the ALD, NPP of beam time for each proposal and then communicates this recommendation to the proposers. These actions follow the format and schedule set by NASA, with each Call being issued no later than 6 months before the pertinent run and proposers being informed of their beam time assignment no later than 4 months before that run. Currently proposers may request beam time in any or all of the three next upcoming runs. Table 2 shows the time table for beam time applications.

The scheduling guideline is the following:

1. For radiobiology research, NSRL is scheduled to operate 5 days per week at 8 science hours per day. If the scheduled experiments for the day are not completed at the end of the 8 hours, operations continue to complete that day's schedule. There is additional time set aside each morning to bring the Booster to operational status for NSRL scientific program use.
2. For physics research, NSRL is scheduled for round-the-clock operation until the experiment is completed.

An additional constraint to the scheduling process is the need to schedule experiments 4-6 months in advance of beam delivery and constrain it to periods of time that are not deleterious to the transport of animals and cells. Periods of extreme cold or hot weather conditions are to be avoided.

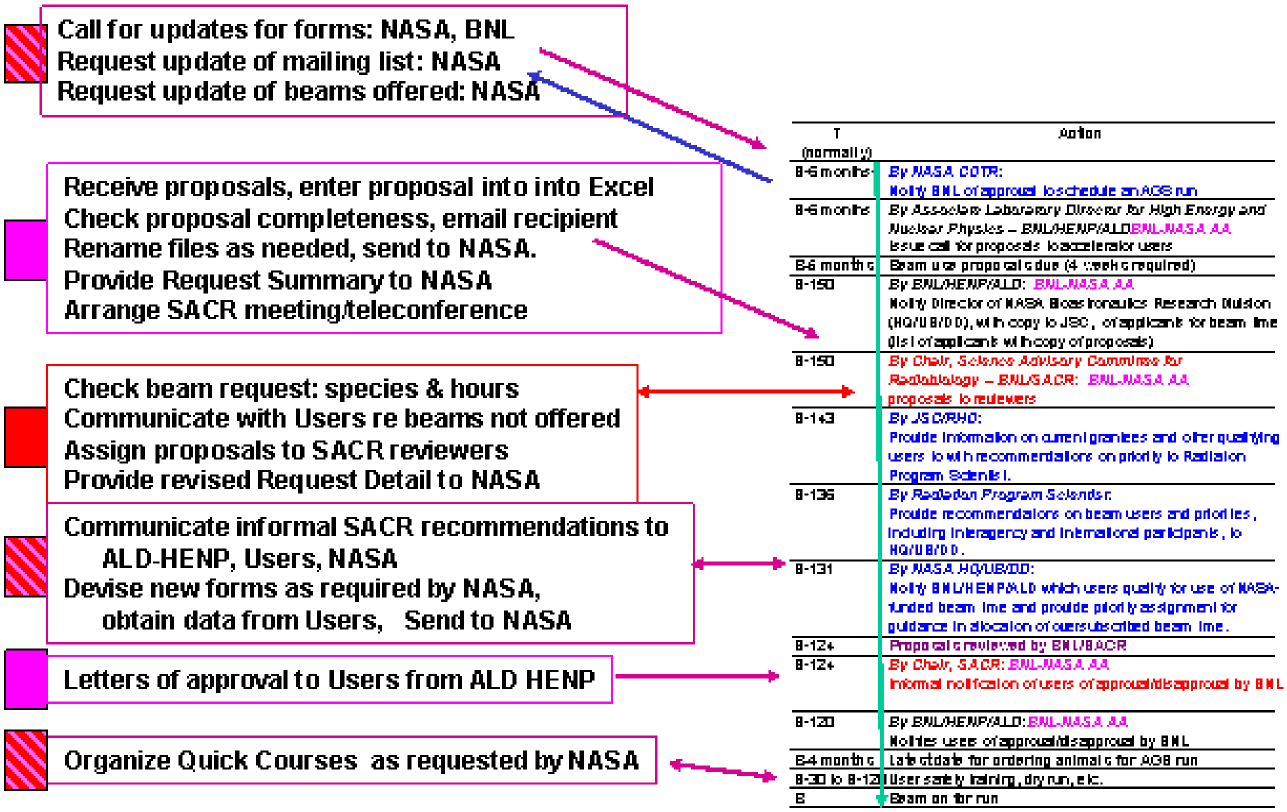

Table 2. Time Table for Beam Time Applications

Life Science Operations

Biology Department staffers provide support for the NSRL facilitiy and for Users during their runs at these facilities. This includes selection, installation, maintenance and calibration of equipment, including instructing Users in safe and effective use of equipment. Between runs, duties include maintenance of equipment including the water purification system, obtaining required certifications, reviewing User requests for additional equipment, purchasing and installing such items, and conference with Users concerning requirements for the upcoming run.

Pre-Run set up begins two months prior to the start of the run. If construction or other dust-generating activities have been carried out during the Inter-Run period, protective plastic covers are removed. Equipment are checked and certification and safety compliance requirements are determined, supplies obtained as needed, including CO_2 for incubators and Biological Safety Cabinets, ordering other chemicals, as well as cartridges for the water purification system. One month prior to the run, incubators are turned on, temperature stability checked, and operation of all other equipment verified. Supplies for incubators and Biological Safety Cabinets are checked, and non-standard equipment settings required by Users are tested. Two weeks before the run, CO_2 supplying Biological Safety Cabinets is turned on, equilibrated and checked; the performance of all equipment is rechecked, and availability of supplies verified.

During runs, duties include daily early-morning startup by the Research Services Assistant with a Beam Line Scientist backup (facility check, equipment check and calibration, film processor startup and check). Beam Line Scientists provide support for Users during experiments at the NSRL, including attendance at the morning conference with Dosimetry Physicists and Main Control Room Personnel, and as needed, operation of dosimetry computers to control beam delivery to samples, running samples to the target area, and limited experimental support. At the conclusion of the experimental day, the Biology Associate closes down the facility, including removal of incubator shelves and humidification trays and insertion of sterile replacements, cleaning of counters and floors of the Cell Culture Facility, including Preparations Room, cleaning of the Users' Break Room, and, with coordination of the Medical Department staff, after hours transport of Users to the Long Term Facility. With backup and supervision of a Beam Line Scientist, the Biology Associate remains at the facility until all Users have exited the facility.

At the conclusion of the run, the facility is closed in an End Of Run Shut Down. This includes cleaning and shutting down equipment (incubators, Biological Safety Cabinets, water baths, centrifuges, ice machine, etc.), cleaning the film processor and arranging for disposal of used/waste solutions, cleaning of floors and counters in Cell facility, and cleaning the Users' Break Room (refrigerator, microwave, counters, tables, etc.). If construction or other dust-generating activities are anticipated, all equipment is secured and covered with protective plastic.

Long-Term Support Facility (LTSF) and Brookhaven Laboratory Animal Facility (BLAF)

The Long-Term Support Facility (LSTF) and the Brookhaven Laboratory Animal Facility (BLAF), located at the Medical Department, provide the infrastructure support of life sciences research at NSRL. More than two dozen laboratories and offices within the LTSF are clustered by scientific discipline to enable a broad range of NASA user support of radiobiological studies at the NSRL. The user community are provided support in the following areas:

- Cell and tissue culture
- Molecular biology
- Flow cytometry
- Invertebrates studies (worms)
- Animal radiobiology (rodents)
- Microbiology
- Educational programs

A partial list of the equipment currently available for users is shown below.

CORE EQUIPMENT	TOTAL
HOODS	19
INCUBATORS	61
MICROSCOPES	18
COULTER COUNTERS	9
FLOW CYTOMETER	1
REFRIGERATORS-FREEZERS	30
CENTRIFUGES	30
WATER BATHS	32
SPECTROPHOTOMETER	1
FLUORESCENCE MICROSCOPE	1
PLATE READER	1
PERSONAL COMPUTERS	30

The Medical Department staff provides primary support and operation of the NSRL Long-Term Support Facility. The responsibilities of the department staff are to develop and coordinate the individual experiment schedules, support the individual experiment needs pertaining to the user's experimental design requirements, NSRL beam and laboratory support scheduling and availability, maintenance of laboratory equipment, stocking of consumables, transportation of animals and veterinary services. The department provides for the daily set up and close down of the animal facility at NSRL, including providing the required supplies and laboratory set-up, certification and quality control of the anesthesia system. Assistance is provided to visitors concerning safety issues, including treatment and disposal of human and animal tissue, logistics, and plans for and purchases equipment/supplies needed at LTSF and BLAF. Shipping of supplies, reagents, animals and other biological samples to the investigator's home institution is also coordinated. Consultants are provided to assist experimenters with information, training, and operation of experiment stations and laboratories at LTSF and BLAF. Information on beam access and logistic support for investigators desiring to obtain pilot data to support applications to NASA and assistance to investigators with approved "piggyback" status are also provided.

The department coordinates and hosts NSRL research collaborators appointments through the RHIC/AGS User Center. The department ensures that life science training requirements are met, that protocol reviews are completed. Space and equipment is provided at LTSF and BLAF in support of NSRL experiments. This includes, but is not limited to dedicated laboratory and office space for the NASA program, technical staff support to set up labs according to visitors' needs and re-distribute equipment and critical supplies between dedicated labs as required and conduct maintenance and repair of core laboratories and equipment.

The department arranges and coordinates video/teleconferences, provides run summary reports to NASA, maintains an information webpage, provides computer network communications and provides an updated experiment schedule. Support of the NASA Space Radiation Summer School is an ancillary activity in support of the NASA radiobiology program.

We provide below a series of time tables that outline a typical year's LTSF activities (Tables 3-6).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SU		Run		CD SU	Run	CD	SU	Run			CD SU
					Report		Report				Report

Table 3. Typical Calendar Year LTSF Activities

LTSF PRE-RUN ACTIVITIES																				
	M	-4 M				-3 M				-2 M				-1 M				RUN		
	W	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16			
SACR (ex-officio advice)																				
Teleconferences																				
User Questionaire																				
Ground Support Req. Doc																				
Laboratories Set-up																				
Equipment Set-Up																				
ES&H Review																				
Shipments reception support																				
Run schedule definition																				
BLAF Animal Care Support																				
Dry runs coordination																				
Training coordination and control																				
LTSF Readiness Review																				
Maintenance and QC-servicing																				
NASA Summer School Support																				

Table 4. LTSF pre-run activities

LTSF RUN ACTIVITIES																				
W	1					2					3					4				
D	M	T	W	T	F	M	T	W	T	F	M	T	W	T	F	M	T	W	T	F
User Meeting AM-PM																				
User Transportation																				
Medical Waste																				
NSRL Lab Support																				
NSRL Animal Lab. Supp																				
BLAF Animal Lab. Supp.																				
Veterinary Support																				
Shipping Support																				
NASA Summer School Sup																				
Scientific Support																				
Controll. Subst. Support																				
Run Sched. Coord.-Control																				

Table 5. LTSF run activities

LTSF POST-RUN ACTIVITIES										
	M	+1 M				+2 M				
	W	1	2	3	4	1	2	3	4	
Laboratories De-con.										
Equipment Shut-down.										
Preventive Maintenance										
User' debriefing										
Shipping Support										
Records keeping										
Final Reporting (w/CAD)										

Table 6. LTSF post-run activities

The LTSF consists presently of approximately 9,000 ft.^{2} of laboratory, office, and storage space (Figure 11). It is imbedded within the greater Medical Department facility. There is flexibility for expansion as the NSRL program develops.

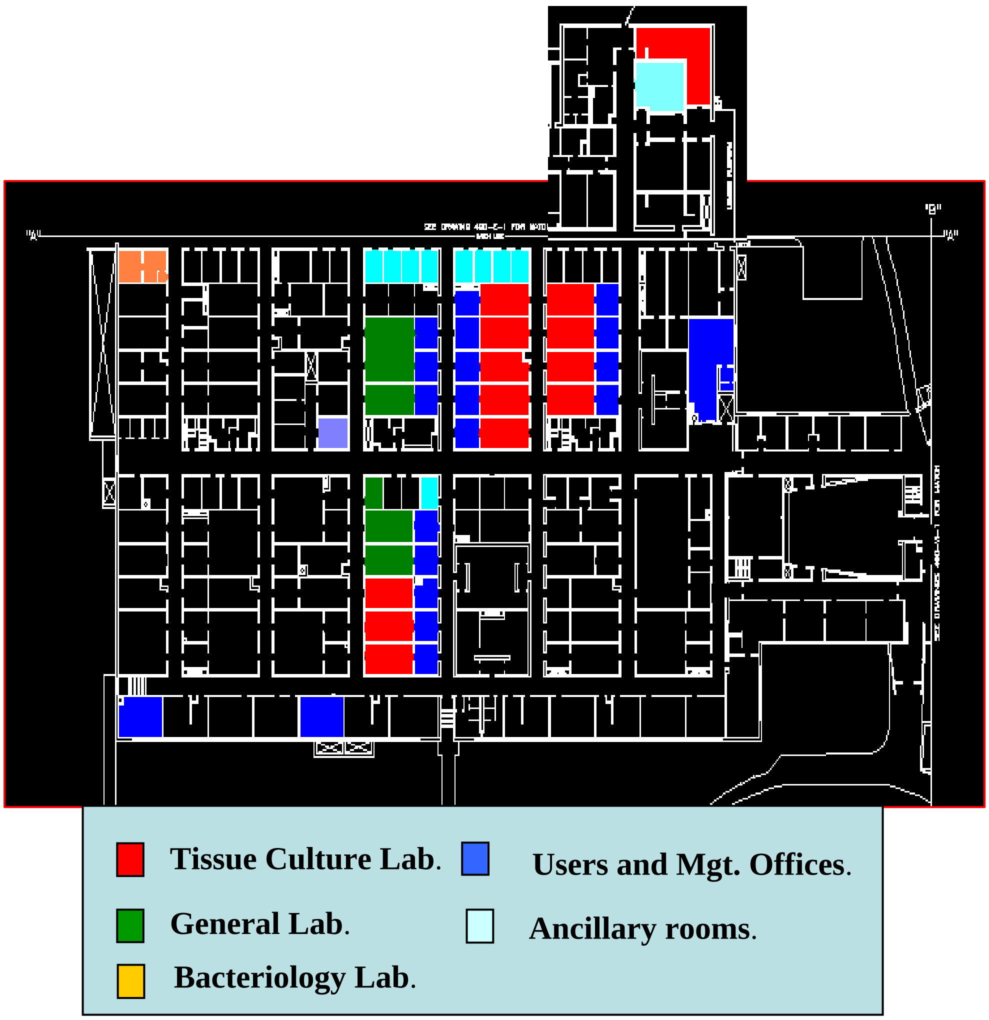

Figure 11. Tissue culture and general laboratories

The current BLAF (Figure 12) capacity to support animal studies for rodents is 2000 animals (80% mice, 20% rats) per run simultaneously using conventional caging. In addition, the LTSF-BLAF staff support animal operations at NSRL covering the logistics of 2 animal rooms, one rack-washing room and animal anesthesia operations.

Figure 12. NASA dedicated animal rooms

Reviewed
February 28, 2011