



BNL-6 RUN

FINAL REPORT

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EXECUTIVE SUMMARY

During the Fall of 1999, a series of radiobiological and physics experiments were performed using the BNL's Alternating Gradient Synchrotron to accelerate iron and silicon ion beams (Experiment 947, BNL-6). These experiments were part of the sixth consecutive run sponsored by NASA's Space Radiation Health Program (SRHP) heavy ion radiobiology research program at BNL.

A total of 20 proposals were approved to participate in the BNL-6 run, 16 of which were returnees and four which were new proposals. From the total number 18 were full proposals and 2 were piggyback experiments. Two proposals declined to participate (B-2 and B-30). Sixteen institutions from the United States (10 states), and 1 from Italy were represented, totaling 55 users. More than 1322 biological samples were irradiated at the AGS A-3 beam line, employing 79 hours of beam time. In addition, 54.5 hours were used for physics experiments, and a total of 46.5 hours were necessary for beam characterization, tuning, dosimetry, and calibration. A total of 19 hours of beam time were lost (10%) due to accelerator or power supply related problems.

During BNL-6, AGS provided iron beams with an energy of: 1 GeV/nucleon (1.046 GeV/nucleon*, LET: 148 keV/ μm), for biology and physics experiments. The dose/rates used were as low as 0.2 cGy/min and as high as 3.5 Gy/min. The spill rate employed was 30 spills/min with a duration of 500-600 msec/spill. The spill fluence was (particles/spill) 1×10^8 (max) and 1.5×10^5 (min). The intensities (particles/ cm^2 /sec on target) used during the run were 1×10^8 (max) and 400 (min). A 7.5-cm diameter beam spot was employed as a nominal spot for the majority of the exposures. For larger samples (animals), an elliptical spot was used (up to 9 cm).

As a pilot run, AGS delivered silicon beams with energies of 1.182* GeV/nucleon (LET: 42 keV/ μm) for a limited series of biological and physics experiments, and 0.6 GeV/nucleon for physics studies (LET: 50 keV/ μm). The dose/rate used was 8-120 cGy/min, the spill rate employed was 18 spills/min, with a duration of 500-600 msec/spill. The spill fluence was (particles/spill) 1.2×10^8 (max) and 1.5×10^5 (min). The intensity (particles/ cm^2 /sec on target) used during the run was 1.2×10^8 and 400 (min). A 7.5-cm diameter beam spot was employed for the exposures. A total of 34 hours were used to expose biological samples and plastic detectors at the AGS A-3 beam line, employing 6 hours for biology, 20 hour for physics, and 8 h for dosimetry and beam characterization.

Tandem-Booster set-up started on Nov.5 with the transport and circulation of Fe beams at the AGS complex. Beam was tuned into cave on Nov. 9 and 1.08 GeV/u ^{56}Fe beam was available for tuning on Nov. 10. The next several shifts were spent on tuning into the target area, beam diagnostics and establishing several different combinations of beam intensities and spot shapes and sizes for physics and biology running.

The first experiment (physics, Colorado State University, T. Borak) started taking data early on Nov. 11, followed by the Lawrence Berkeley National Laboratory (LBNL, C. Zeitlin) physics experiment, which used a similar setup. Biology studies started early on Nov. 13 (National Space Biomedical Research Institute, J. Dicello) and proceeded with no serious interruptions through early Nov. 17, after

which the Tandem-AGS complex changed over to accelerating ^{28}Si . Biology experiments with ^{28}Si beams began late on Nov. 17 (Brookhaven National Laboratory, B. Sutherland) and continued for about 6.5 hours. After all biology experiments were completed, LBNL ran 10.5 hours of fragmentation physics studies with 1.2 GeV/u ^{28}Si . After a 1 hour changeover, a final physics run used 10 hours of 600 MeV/u ^{28}Si . BNL-6 finished at 12:10 AM on Nov. 19.

Radiobiological experiments employed cells, tissues, and intact specimens, which required a complex coordination and planning of their respective logistic support. Biological studies used human, mouse, rat and hamster cell lines, human-hamster hybrid cell lines, tumor cell lines and intact specimens (rodents and worms). Physics experiments involved the exposure of solid state detectors, spacecraft and spacesuit materials. The full program was completed in 8.6 days under the AGS's operation schedule directives.

* Actual beam energy on target

BNL-6 PARTICIPANTS

Exp.	Participants	Affiliation	Title
B-1	J. Miller L. Heilbronn C. Zeitlin R.P. Sigh W. Holley B. Ludewigt	Lawrence Berkeley National Laboratory, CA " " " " "	Ph.D., Principal Investigator Ph.D., Co-Principal Investigator Ph.D., Co-Worker Ph.D., Co-Worker Ph.D., Co-Worker Ph.D., Co-Worker
B-7	B. Rabin J. Joseph B. Sukit-Hale J. McEwen N. Denissova	University of Maryland, Baltimore County, MD Human Nutrition Research Center on Aging, MA " " "	Ph.D., Principal Investigator Ph.D., Co-Principal Investigator Co-Worker Co-Worker Co-Worker
B-9	B. Sutherland P. Bennett J. Sutherland J. Trunk D. Monteleone	Brookhaven National Laboratory, NY " " " "	Ph.D., Principal Investigator MS., Biology Associate. Ph.D., Co-Worker Co-Worker Co-Worker
B-19 B-20	A. Kronenberg C. Wiese S. Gauny	Lawrence Berkeley National Laboratory, CA " "	Ph.D., Principal Investigator Post-Doctoral Student Senior Research Associate
B-22	M. Vazquez	Brookhaven National Laboratory, NY	MD, Ph.D., Principal Investigator
B-24	T. Borak B. Gersey S. B. Guetersloh	Colorado State University, CO " "	Ph.D., Principal Investigator Post-Doctoral Student Post-Doctoral Student
B-25	H. Evans T. Evans	Case Western Reserve University, OH "	Ph.D., Principal Investigator Co-Worker
B-32	J. Dicello D. Huso Y. Zhang J. Man D. Simonson R. Arbona	NSBRI, John Hopkins University, MD " " " " "	Ph.D., Principal Investigator DVM, Ph.D., Co-Worker MD. Co-Worker DVM Co-Worker MS. Co-Worker MD. Co-Worker
B-35	G. Nelson T. Jones	Loma Linda University, CA "	Ph.D., Principal Investigator BS., Co-Worker
B-36	G. Illiakis Z. Zeng	Thomas Jefferson University "	Ph.D., Principal Investigator Ph.D., Co-W
B-38	F. Burns J. Xu P. Zohng	New York University Medical Center, NY " "	Ph.D., Principal Investigator Co-Worker Co-Worker
B-40	S. Gonda S. Barrientes H. Soehnge	NASA, JSC, TX " "	Ph.D., Principal Investigator Co-Worker Ph.D., Co-Worker
B-41	R. Pearlstein M. Kudo M. Vazquez	Duke University, NC " BNL, NY	Ph.D., Principal Investigator M.D., Co-Worker M.D., Ph.D., Co-Worker
B-42	M. Barcellos-Hoff R. Henshall S. Ravani	Lawrence Berkeley National Laboratory, CA " "	Ph.D., Principal Investigator Co-Worker Co-Worker
B-43	G. Nelson M. Pecaut A. Smith G. Peterson	Loma Linda University, CA " " "	Ph.D., Principal Investigator Ph.D., Co-Worker BS, Co-Worker BS, Co-Worker

BNL-6 Piggyback Experiments

B-1	S. Cechini V. Togo	Nat. Institute of Nuclear Physics, Bologna, Italy “	Ph.D., Co-Principal Investigator M.S. Co-Worker
B-22	L. Peña P. Recksiek	Brookhaven National Laboratory, NY “	Ph.D., Co-Principal Investigator M.S. Co-Worker

PARTICIPANTS STATISTICS

PARTICIPANTS	BNL-6
Ph.D., Principal Investigators	15
Ph.D., Co-Principal Investigators	4
Co-Workers	11
Ph.D.	8
MD, Ph.D.	1
DVM, Ph.D.	1
M.D.	3
B.S.	3
M.S.	3
DVM	1
Post-Doctoral Students	3
MS Biology Associate	1
Senior Research Associates	1
Total:	55

Participant Institutions

- Brookhaven National Laboratory, NY
- Columbia University, NY
- New York University Medical Center, NY
- Lawrence Berkeley National Laboratory, CA
- Loma Linda University Medical Center, CA
- NASA, Johnson Space Flight Center, TX
- University of Texas Medical Branch, TX
- National Space Biology Research Institute, TX
- NASA, Langley Research Center, VA
- University of Maryland, Baltimore County, MD
- John. Hopkins University, MD
- Case Western Reserve University, OH
- Human Nutrition Research Center on Aging, MA
- Colorado State University, CO
- Duke University, NC
- Thomas Jefferson University, PA
- National Institute of Nuclear Physics, Bologna, Italy

IRON RUN

RUN DATES

Run dates	Scheduled		Actual	
	Date	Time	Date	Time
Run start	11/10	0800	11/10	0800
Run end	11/18	1630	11/17	0500
Tuned into cave	11/9	0800	11/9	1400
Beam delivered for Biology				
Fe 1 GeV/n	11/12	1700	11/13	0400
End run	11/16	1730	11/17	0500

BEAM TIME DESCRIPTION (hours)

Total Clock Time	(from 11/10 0800 to 11/17 0500)		165
Total Beam-on Time		146	
Total Beam-off time		19	
Beam Time for Biology			
1 GeV/n	73		
Beam Time for Physics			
1 GeV/n	34		
Sub-total		107	
Beam time for dosimetry, calibration, tuning, etc.			
1 GeV/n	39		
Sub-total		146	
Totals		165	

SILICON RUN

RUN DATES

Run dates	Scheduled		Actual	
	Date	Time	Date	Time
Run start	11/17	0600	11/17	1430
Run end	11/18	0800	11/19	0000
Tuned into cave	11/17	1600	11/17	1400
Beam delivered for Biology				
Si 1 GeV/n	11/17	1900	11/17	2000
End run	11/18	0000	11/18	0230
Beam delivered for Physics				
Si 1 GeV/n	11/18	0000	11/18	0230
End run	11/18	0900	11/18	1200
Beam delivered for Physics				
Si 0.6 GeV/n			11/18	1300
End run			11/19	0000

BEAM TIME DESCRIPTION (hours)

Total Clock Time	(from 11/17 1400 to 11/19 0000)	43
Total Beam-on Time	43	
Total Beam-off time	0	
Beam Time for Biology		
1 GeV/n	6	
Sub-total	6	
Beam Time for Physics		
1 GeV/n	10.5	
0.6 GeV/n	10	
Sub-total	20.5	
Tandem and AGS operations for Si	9.5	
Beam time for dosimetry, calibration, tuning, etc.		
1 GeV/n	6.5	
0.6 GeV/n	1	
Sub-total	7.5	
Totals	43	

BNL-6

FINAL RUN DATES

Run dates	Scheduled		Actual	
	Date	Time	Date	Time
Run start	11/10	0800	11/10	0800
Run end	11/18	0900	11/19	0000
Tuned into cave	11/9	0800	11/9	1400

BEAM TIME DESCRIPTION (hours)

Total Clock Time	(from 11/10 0800 to 11/19 0000)	208.5
Total Beam-on Time	189.5	
Total Beam-off time	19	
Beam Time for Biology	79	
In Vivo Studies	38.5	
In Vitro Studies	40.5	
Beam Time for Physics	54.5	
Beam time for dosimetry, calibration, tuning, etc.	46.5	
AGS and Tandem ops.	9.5	
Totals	189.5	

BEAM CHARACTERISTICS

	$^{28}\text{Si}^{14}$		$^{56}\text{Fe}^{26}$
	600 MeV/n	1000 MeV/n	1000 MeV/n
Fluence (particles/cm²/sec)			
Maximum on target	TBD	400	1 x 10⁸
Minimum on target	400	400	400
Spill rate (spills/min)	18	18	18
Spill length (msec)	500-600	500-600	500-600
Particles/spill			
Maximum	1 x 10⁸	1.2 x 10⁸	1 x 10⁸
Minimum	1.5 x 10⁵	1.5 x 10⁵	1.5 x 10⁵
Beam spot diameter (cm)	5*	5* - 7.5 - 9	5* - 7.5 - 9
Beam cut off length.	<1%	<1%	<1%
Actual Energy (MeV/n)			
Extracted	TBD	1200	1078
On Target	TBD	1182	1046
Actual LET on Target (keV/μm)	49.5	42	148
Dose/rate recorded (cGy/min)			
Maximum	TBD	120	350
Minimum	TBD	8	0.2
Minimum dose exposure (cGy)	TBD	5	0.1
No of hours for beam characterization, tuning and dosimetry	2	6	39

BNL-6 Run Statistics and Incidents

Date	Shift	HIP Avail.	Non-HIP*	Remarks
11/10/99	2	8	0	1 GeV Iron run start, beam tuned into the cave
	3	8	0	TBD
11/11/99	1	8	0	No incidents.
	2	8	0	No incidents.
	3	8	0	No incidents. Biology run start.
11/12/99	1	7.5	0.5	Controller for the Booster RF failed
	2	2.5	5.5	Power supply trip off
	3	6	2	RF problems
11/13/99	1	8	0	Dosimetry set-up for Biology. Biology start
	2	7	1	TTB beamstop failure
	3	8	0	No incidents.
11/14/99	1	8	0	No incidents.
	2	8	0	No incidents.
	3	8	0	No incidents.
11/15/99	1	7.5	0.5	Beam drift, magnets problems (AQ7&8)
	2	7	1	Beam drift, magnets problems (AD4-9)
	3	5.5	2.5	Beam drift, magnets problems (AD4-9)
11/16/99	1	6	2	Failed trigger module for the Booster F3 kicker
	2	7	1	Power supply trip
	3	8	0	No incidents.
11/17/99	1	1	7	AGS extraction changed
	2	2	6	Change-over to Silicon 1 GeV/n
	3	8	0	No incidents.
11/18/99	1	8	0	No incidents.
	2	8	0	Setting up for 600 MeV Silicon.
	3	8	0	No incidents.
11/19/99	1	0	0	End BNL-6
Totals:	29	189 hr. (86.5%)	29 hr. (13.5%)	

*Time loss due to machine or power supply problems, setting up operations.

BNL-6 EXPERIMENTERS AND RUN STATISTICS

Exp. ID	Principal Investigator	Ion & Energy	Beam Time Approved	Beam Time Used	Dose Range (cGy)	Dose/Rate (cGy/min)	Number of Samples
B1	Miller (Giacomelli)	Fe, 1 GeV/n 0.6 GeV/n Si, 1 GeV/n 0.6 GeV/n	16 16	18 - 10 10	NA	NA	NA
B7	Rabin	Fe, 1 GeV/n	8.5	7	100-150	50-150	100
B9	Sutherland	Fe, 1 GeV/n Si, 1 GeV/n	6.5	5.5 2	NA	NA	NA
B12	Hei	Fe, 1 GeV/n	4	2.5	20-400	100	75
B19-20	Kronenberg	Fe, 1 GeV/n Si, 1 GeV/n	19	6.5 1.5	31 - 189	50-100	NA
B22	Vazquez (Pena)	Fe, 1 GeV/n	6	6	1-10	5-10	100
B24	Borak	Fe, 1 GeV/n	16	16	NA	NA	NA
B25	Evans	Fe, 1 GeV/n	2.5	2	10-320	20-100	35
B32	Dicello	Fe, 1 GeV/n	20	18	1 - 100	1-100	600
B35-43	Nelson	Fe, 1 GeV/n Si, 1 GeV/n	2.8	4.5 2	10 - 200	100 - 200	120
B36	Illiakis	Fe, 1 GeV/n	5	2	150 - 300	100	20
B39	Burns	Fe, 1 GeV/n	15	10	150-900	160	150
B40	Gonda	Fe, 1 GeV/n	2.5	3	30-600	100	40
B41	Pearlstein	Fe, 1 GeV/n	0.5	1	200	100	32
B42	Barcellos-Hoff	Fe, 1 GeV/n Si, 1 GeV/n	4	3 0.5	50-200	100	50
Totals		Fe Si	134.8 hr	107 hr 26 hr	1-900	5 to 200	1322+

BNL-6 PARTICIPANTS AND EXPERIMENTAL SAMPLES

Exp.	Participants	Samples	Endpoints
B-1	Heavy Ion Fragmentation and Transport in Matter J. Miller (PI) , Giacomelli*	Solid state detectors	Heavy ion fragmentation Spacesuits dosimetry CR39 calibration
B-7	Effects of Exposure to Heavy Ions. B. Rabin (PI)	Sprague-Dawley Rats	Neurological and neurochemical changes
B-9	DNA Damage & Restoration in Mammalian Cells and Tissues. B. Sutherland (PI)	Human skin fibroblast and epithelial cells	DNA damage: clustered damages
B-12	Cytogenetic and Neoplastic Transforming Effects of Heavy Ions in Mammalian Cells. T. Hei (PI)	Human bronchial epithelial cells (BEP2D) and breast cells (MCF-10F)	Neoplastic transformation, Differential gene expression, mutation spectra by PCR
B-19 B-20	Mutagenesis and Genomic Instability. A. Kronenberg (PI)	Human lymphoid cells (TK6) and WTK-bclX _L	Apoptosis induction, mutat collection, cell killing and mutation, DSB rejoining/fidelity
B-22	In vitro Cellular and Molecular Effects of Heavy Ions and Fragmentation on Neural Cells M. Vazquez (PI) , L. Peña	NT-2 Cells CNS-1 ,C6	Apoptosis induction, neurotoxicity Survival
B-24	Microdosimetry Studies of High Energy Heavy Ions. T. Borak (PI)	Solid state detectors	Microdosimetry/wall effects
B-25	Induction of Genomic Instability in Human Lymphoblasts. H. Evans (PI)	Human lymphoblast (TK6 and WTK1), Colon cancer cell line (HCT16)	Colony formation, expression of mutations at the thymidine kinase locus
B-32	Tumor Formation in Rat Mammary Glands J. Dicello (PI)	Sprague-Dawley Rats, Rat and lymphocytes, RMC, HCT116, 80S4	Tumor induction and Tamoxifen protective effects and chromosomal aberrations
B-35	Differential Gene Expression in Nematodes and Thyroid Cells Following Charge Particle Irradiation. G. Nelson (PI)	Worms (C. Elegans)	Gene expression alterations
B-36	Activity of GAMA After Exposure of Cells to High-LET Radiation. G. Illiakis (PI)	A1-5 cell line	G2 arrest, flow cytometry.
B-39	Multiple Doses of High-LET Radiation on Rat Skin. F. Burns (PI)	Sprague-Dawley Rats	Skin tumor induction and modulation by dietary retinyl acetate.
B-40	3-Dimensional Transgenic Cell Models S. Gonda (PI)	Rat Fibroblast (Rat 2 λ), Human mammary epithelial cells (H184B5F5M10)	Mutation frequencies at specific genes, chromosomal aberrations and compare 2D and 3D cultures.
B-41	Neurologic Health Risk from Heavy Ion Radiation Exposure. R. Pearlstein (PI)	Mouse C57B	Neurological and neurochemical changes
B-42	Particle Irradiation of Human Mammary Epithelial Cells M. Barcellos-Hoff (PI)	Human mammary epithelial cells (HMT 3522)	Microenvironment changes, TGF- β and bFGF levels, immunocitochem., apoptosis and neoplastic potential
B-43	Preliminary Assessment of Immune System and behavioral Responses to Accelerated Iron Ion Exposure in the C57B1/6 Mouse. G. Nelson (PI)	Mouse (C57B1/6)	Neurological and immunological alterations

BNL-6 HIGHLIGHTS

- AGS started up on schedule, and ran generally smoothly. The run finished several days in advance of the allotted elapsed time.
- Tandem source change from Fe to Si and AGS operations took about nine hours, as compared to the original estimate of approximately 16 hours.
- Change from 1.2 to 0.6 GeV/u Si took less than three hours.
- First radiobiology with 1.2 GeV/u Si.
- J. Dicello ran for approximately 20 consecutive hours (over 400 samples) without interruption.
- Physics running included heavy ion radiation transmission studies of EVA spacesuits (U.S. EMU and Russian Orlan) and ISS sleeping quarter wall mockups.
- First time with two runs (BNL-5 and BNL-6) in the same calendar year.

List of personnel that participated in the planning, organization and execution of BNL-6 run

BNL Management:

- Associate Director for High Energy and Nuclear Physics: **Tom Kirk**

Scientific Advisory Committee:

- **Betsy Sutherland** (Chair), BNL
- **Jeff Coderre** (BNL)
- **Richard Setlow**, BNL
- **Mike Fry**, ORNL
- **Les Braby**, PNL
- **Charles Geard**, Columbia University

Collider Accelerator Department-AGS:

- Department Head: **Derek Lowenstein**
- Experimental Planning and Support Head: **Philip Pile**
- Accelerator Division Head: **Thomas Roser**
- Accelerator Physicist lead by: **Leif Aherns**
- Tandem Group leader: **Peter Thieberger**
- A3 beam line instrumentation responsible: **I-Hung Chiang**
- AGS Radiation Safety Committee: **Ken Reece**
- AGS Experimental Safety Committee: **Ed Lessard**
- AGS Control Section lead by: **Don Barton**
- Liaison Engineering Group lead by: **Al Pendzick**
- E898 liaison physicist: **Don Lazarus**
- Mechanical Service Technicians led by: **Fred Kobasiuk**
- Survey Group led by: **Frank Karl**
- Beam Service Technicians led by: **Paul Valli**
- Electronic Service Technicians led by: **Bill Anderson**
- AGS Instrumentation Group led by: **Pete Stillman**
- AGS Main Control Room and Operations led by: **Pete Ingrassia**
- Health Physics Group led by: **Chuck Schaefer**
- AGS Electricians led by **Bill Softye**
- AGS Riggers led by: **Nick Cipolla**
- Carpenter and Welder Support Service and Technical Support led by: **Roger Hubbard**

Medical Department:

- Dept. Chair: **Nora Volkow**
- E898 Medical Liaison: **Marcelo E. Vazquez**

- Secretarial support: **D. Akras**
- Safety and Training and Building manager: **Jim Bullis**
- Administration: **B. Coughlin-Byrne, and Donna Russo**
- Animal Care Facilities: **Maryann Kershaw**
- Tissue Culture Facility manager: **Michael Maker**
- Technical support: **Katherine Conckling, Bae Piatt**
- Property Representative: **Gina Flippen**
- S & E. P.: **Robert Colichio**

Biology Department:

- Chairman: **Carl Anderson**
- **Betsy Sutherland**
- Administration: **Bonnie McGahern**
- Cesium Source Manager: **Richard Satkoulis**

Safety & Environmental Protection Division:

- Manager: **William Fortunato**
- **Dean Atcheson**

NASA

- **Walter Schimmerling**
- **Frank Cuccinota**

Lawrence Berkeley National Laboratory,

- **Jack Miller**
- **Lawrence Heilbronn**
- **Bernhard Ludewigt**
- **R. P. Singh**
- **W. Holley**