BROOKHAVEN
NATIONAL LABORATORY

NSRL-06B RUN

June 2006

FINAL REPORT

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http://www.bnl.gov/medical/NASA

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EXECUTIVE SUMMARY

During June 2006, a series of radiobiological and physics experiments were performed using the proton and heavy ion beams available at the NASA Space Radiation Laboratory (NSRL). These experiments were part of the ninth NSRL scientific run (NSRL-06B) sponsored by NASA's Space Radiation Health Program (SRHP) heavy ion radiobiology research program at BNL.

A total of twenty nine proposals were approved for participation in the NSRL-06B run. Ninety three users from thirty five institutions were represented, thirty from the United States, and five foreign institutions. More than 2500 biological samples were exposed at the NSRL beam line, employing 189:06 hours of beam time (18:41 hours for in vivo studies, 111:44 hours for in vitro studies, 2:06 hours for plant studies, and 56:35 hours for physics experiments) delivered in a three and a half-week period. In addition, 15:47 hours were used for dosimetry and beam development. Machine set-up took a total of 42:00 hours, and 10:30 hours for wrap-up of the beam. Accelerator problems accounted for 13:40 hours lost. This gave a total NSRL usage time of 271:03 hours.

Part of the NSRL-06B run included time spent with the fifteen students from five countries who attended the NASA Space Radiation Summer School. The students conducted both physics and biology experiments during the 16:13 hours of beam time allocated for their experimental work.

During NSRL-06B, Booster provided iron (600 and 1000 MeV/nucleon), protons (1 GeV/n), sequential fields of iron and protons (1000 MeV/n), oxygen (1000 MeV/n), and titanium (1000 MeV/n) beams for biology and physics experiments. The maximum dose/rates used for biology experiments were as high as 5 Gy/min (Fe 1000 MeV/n). The general spill rate employed was 20 spills per minute with durations of 300 msec/spill. The spill fluence range was (particles/spill) from 1.5×10^{11} (max) and 2×10^{2} (min). Square beam spots as big as 20 x 20 cm^2 and as small as 1 x 1 cm^2 were employed for biology and physics experiments. The Tandem-Booster-NSRL complex delivered a sequential field composed of iron and protons with energies of 1 GeV/n with a steady and repeatable switching from protons to iron.

Tandem-Booster set-up started on June 6 with the transport and circulation of Fe beams at the NSRL complex. Beam was tuned into the target cave on June 7 and 1000 MeV/n Fe beams were available for tuning at 7:00 AM 8 June 2006. NSRL-06B officially ended at 5:00 PM 30 June 2006.

Projects Reviewed by the BNL Scientific Advisory Committee in Radiobiology

NSRL Proposal	Principal Investigator	NSRL Sponsor	NSRL-06B Participation
B-44	DURANTE	ASI	Yes
B-52	SUTHERLAND/GEWIRTZ*	NSBRI	Yes
N-64	VAZQUEZ	NSBRI	Yes
N-65	VAZQUEZ	NSBRI	Yes
B-73	SUTHERLAND	DOE/NASA	Yes
N-88	SUTHERLAND	NASA	Yes
N-89	HELD	NASA	Yes
N-102	HALL*	NASA	Yes
N-103	BARCELLOSHOFF*	NASA	Yes
N-113	OBENAUS*	NASA	Yes
N-116	BENTON*	NASA	Yes
N-128	VAZQUEZ	NASA	Yes
N-129	LIMOLI	NASA	Yes
N-134	CHEN*	NASA	Yes
N-135	PLUTH	NASA	Yes
N-136	BRITT	NASA	Yes
N-155	RABER	NASA	Yes
N-156	PISACANE	NASA	Yes
N-157	SCHIESTL*	NASA	Yes
N-159	KLEIMAN	NASA	Yes
N-167	BURMA	NASA	Yes
N-168	PUTCHA*	NASA	Yes
N-169	SHELBY*	NASA Shield	Yes
N-170	WANG*	DOE/NASA	Yes
N-172	BERKOWITZ	NASA	Yes
N-173	GEARD*	NASA	Yes
N-174	WARE	NASA	Yes
N-175	FIKE*	DOE NASA-NSCOR	Yes
N-176	CUCINOTTA	DOE/NASA	Yes

***Not Present During Actual Run**

PARTICIPANTS (Principal Investigators are highlighted)

Exp.	Participants	Affiliation	Title
B-44	**DURANTE**	Universita di Napoli	Ph.D, Principal Investigator
	VAZQUEZ	BNL, Medical Dept., Upton, NY	Ph.D, Principal Investigator
	GROSSI	Universita di Napoli	Guest Scientist
	DIFINO	University of Rome II	Guest Research Associate
	PURSCHKE	Massachusetts General Hospital	Guest Research Associate
B-52	**SUTHERLAND GEWIRTZ***	University of Pennsylvania	Ph.D, Principal Investigator
	BENNETT	BNL, Biology Dept., Upton, NY	M.S., Co-Worker
	ROY	BNL, Biology Dept., Upton, NY	PhD., Co-Worker
	NAIDU	BNL, Biology Dept., Upton, NY	PhD., Co-Worker
	SUTHERLAND	BNL, Biology Dept., Upton, NY	PhD., Co-Worker
	MONTELEONE	BNL, Biology Dept., Upton, NY	B.S., Co-Worker
	TRUNK	BNL, Biology Dept., Upton, NY	PhD., Co-Worker
N-64	**VAZQUEZ**	BNL, Medical Dept., Upton, NY	MD, PhD.,Principal Invest.
	GUIDA	BNL, Medical Dept., Upton, NY	Ph.D., Co-Worker
	BILLUPS	BNL, Medical Dept., Upton, NY	B.A., Co-Worker
	PYATT	BNL, Medical Dept., Upton, NY	M.S., Co-Worker
	THOMPSON	BNL, Medical Dept., Upton, NY	B.S., Co-Worker
	KIM	BNL, Medical Dept., Upton, NY	B.S., Co-Worker
N-65	**VAZQUEZ**	BNL, Medical Dept., Upton, NY	MD, PhD.,Principal Invest.
B-73	**SUTHERLAND**	BNL, Biology Dept., Upton, NY	Ph.D, Principal Investigator
N-88	**SUTHERLAND**	BNL, Biology Dept., Upton, NY	Ph.D, Principal Investigator
N-89	**HELD**	Massachusetts General Hospital	Ph.D, Principal Investigator
	PURSCHKE	Massachusetts General Hospital	Guest Research Associate
	SPANTCHAK	Massachusetts General Hospital	Guest Scientific Associate
	SCHUSSLER	Massachusetts General Hospital	Guest Scientific Associate
N-102	**HALL***	Columbia University	Ph.D, Principal Investigator
N-103	**BARCELLOS-HOFF***	Lawrence Berkeley National Laboratory	Ph.D, Principal Investigator
	MUKHOPADHYAY	Lawrence Berkeley National Laboratory	Guest Jr.Research Associate
	KRONENBERG	Lawrence Berkeley National Laboratory	Guest Scientist

PARTICIPANTS (Principal Investigators are highlighted)

Exp.	Participants	Affiliation	Title
N-103 (cont.)	BOISSIERE	Lawrence Berkeley National Laboratory	Guest Research Associate
	ANDARAWEWA	Lawrence Berkeley National Laboratory	Guest Research Associate
	SUDO	Lawrence Berkeley National Laboratory	Guest Research Associate
	GROESSER	Lawrence Berkeley National Laboratory	Guest Research Associate
	RYDBERG	Lawrence Berkeley National Laboratory	Guest Scientist
N-113	**OBENAUS***	Loma Linda University	Ph.D, Principal Investigator
	NELSON	Loma Linda University Medical Center	Guest Scientist
	SMITH	Loma Linda University	Guest Scientific Associate
	JONES	NASA - Loma Linda University Medical School	Guest Scientific Associate
	LLOYD	Loma Linda University	Guest Scientific Associate
	PECAUT	Loma Linda University	Guest Scientist
N-116	**BENTON***	Eril Research, Inc.	Ph.D, Principal Investigator
N-128	**VAZQUEZ**	BNL, Medical Dept., Upton, NY	MD, PhD., Principal Invest.
	BLYTH	Flinders University of South Australia	Guest Research Assistant
	HU	Columbia Nevis Lab.	Guest Research Associate
	GRABHAM	Columbia University	Guest Scientist
	MOZHAEVA	Joint Institute for Nuclear Research (JINR)	Guest Research Assistant
	ANDERSON, B	Medical Research Council	Guest Scientific Associate
	ANDERSON, J	NASA - Langley Research Center	Guest Research Assistant
	REDD	Texas A&M University	Guest Jr.Research Associate
	ZWART	Universities Space Research Association	Guest Scientist
	PIGNALOSA	University Federico II	Guest Scientific Associate
	HARRISON	University of Kentucky	Guest Research Assistant
	DZIEGIELEWSKI	University of Maryland	Guest Research Associate
	HATCHER	University of Tennessee	Guest Research Associate
	MASHIMO	University of Texas Southwestern	Guest Scientist
	BERTUCCI	Universita di Napoli	Guest Research Assistant
	VAN BAALEN	NASA - Johnson Space Center	Guest Research Assistant
	YAMAMOTO	University of California @ Los Angeles	Guest Jr.Research Associate

PARTICIPANTS Cont. (Principal Investigators are highlighted)

Exp.	Participants	Affiliation	Title
N-128 (cont.)	CASEY	Universities Space Research Association	Guest Scientist
N-129	**LIMOLI**	University of California @ San Francisco	Ph.D, Principal Investigator
	GIEDZINSKI	University of California @ San Francisco	Guest Scientific Associate
N-134	**CHEN***	University of Texas Southwestern	Ph.D, Principal Investigator
	BURMA	University of Texas Medical Branch	Guest Scientist
	ZENG	University of Texas Southwestern	Guest Jr.Research Associate
	AROUMOUGAME	University of Texas Southwestern	Guest Scientist
	ORTEGA	University of Texas Southwestern	Guest Scientist
	UEMATSU	University of Texas Medical Branch	Guest Jr.Research Associate
N-135	**PLUTH**	Lawrence Berkeley National Laboratory	Ph.D, Principal Investigator
	WHALEN	Lawrence Berkeley National Laboratory	Guest Scientific Associate
N-136	**BRITT***	University of California @ Davis	Ph.D, Principal Investigator
	CULLIGAN	University of New Hampshire	Guest Scientist
	HUEFNER	University of California @ Davis	Guest Jr. Research Associate
N-155	**RABER**	Oregon Health & Science University	Ph.D, Principal Investigator
	POAGE	Oregon Health & Science University	Guest Scientific Associate
N-156	**PISACANE**	U.S. Naval Academy	Ph.D, Principal Investigator
	ZHAO	University of Cincinnati	Guest Scientist
	WROE	Loma Linda University Medical Center	Guest Jr. Research Associate
N-157	**SCHIESTL***	University of California @ Los Angeles	Ph.D, Principal Investigator
	HAFER	University of California @ Los Angeles	Guest Jr. Research Associate
N-159	**KLEIMAN**	Columbia University	Ph.D, Principal Investigator
	DAVID	Columbia University	Guest Scientific Associate
N-167	**BURMA**	University of Texas Medical Branch	Ph.D, Principal Investigator
	UEMATSU	University of Texas Medical Branch	Guest Jr. Research Associate
	MUKHERJEE	University of Texas Southwestern	Guest Scientist

PARTICIPANTS Cont. (Principal Investigators are highlighted)

Exp.	Participants	Affiliation	Title
N-168	**PUTCHA***	National Aeronautics and Space Admin. (NASA)	Ph.D, Principal Investigator
	VAKSMAN	Wyle Laboratories @ Houston	Guest Scientific Associate
	DU	Wyle Laboratories @ Houston	Guest Scientist
N-169	**SHELBY***	Alfred University	Ph.D, Principal Investigator
N-170	**WANG***	Lawrence Berkeley National Laboratory	Ph.D, Principal Investigator
	RYDBERG	Lawrence Berkeley National Laboratory	Guest Scientist
N-172	**BERKOWITZ**	Johns Hopkins University	Ph.D, Principal Investigator
	SOUCY	Johns Hopkins University	Guest Research Assistant
N-173	**GEARD***	Columbia University	Ph.D, Principal Investigator
	GRABHAM	Columbia University	Guest Scientist
	HU	COLUMBIA NEVIS LAB	Guest Research Associate
	ZACONTE	University of Rome II	Guest Research Assistant
N-174	**WARE**	University of Pennsylvania	Ph.D, Principal Investigator
	DONAHUE	University of Pennsylvania	Guest Scientific Associate
	KENNEDY	University of Pennsylvania	Guest Scientist
N-175	**FIKE***	University of California San Francisco	Ph.D, Principal Investigator
	LLOYD	Loma Linda University	Guest Scientific Associate
	SMITH	Loma Linda University	Guest Scientific Associate
N-176	**CUCINOTTA**	NASA - Johnson Space Center	Ph.D, Principal Investigator
	ELLIOTT	Wyle Laboratories @ Houston	Guest Scientific Associate
	HARPER	Medical Research Council	Guest Research Associate
	PLUTH	Lawrence Berkeley National Laboratory	Guest Scientist
	GEORGE	Wyle Laboratories @ Houston	Guest Scientific Associate

***Not Present During Actual Run**

PARTICIPANT INSTITUTIONS

Universities (26)

Columbia University, Nevis Laboratories
Columbia University
Flinders University of South Australia
Johns Hopkins University
Loma Linda University
Loma Linda University Medical Center
Medical Research Council
Oregon Health & Science University
Prairie View A&M University
Texas A&M University
U.S. Naval Academy
Universita di Napoli
Universities Space Research Association
University Federico II
University of California @ Davis
University of California @ Los Angeles
University of California @ San Francisco
University of Cincinnati
University of Kentucky
University of Maryland
University of New Hampshire
University of Pennsylvania
University of Rome II
University of Tennessee
University of Texas Medical Branch
University of Texas Southwestern

National Laboratories/Institutions (2)

Brookhaven National Laboratory
Lawrence Berkeley National Laboratory

NASA Related Centers/institutions (4)

NASA - Johnson Space Center
NASA - Langley Research Center
NASA - Loma Linda University Medical School
National Aeronautics and Space Admin. (NASA)

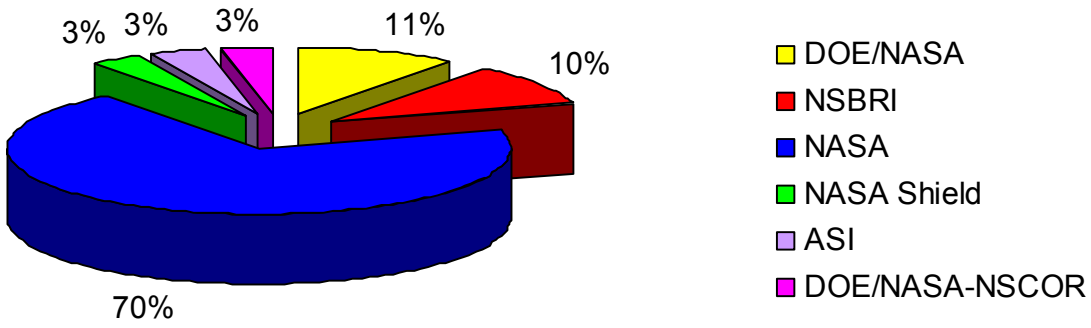
Private Institutions (1)

Massachusetts General Hospital

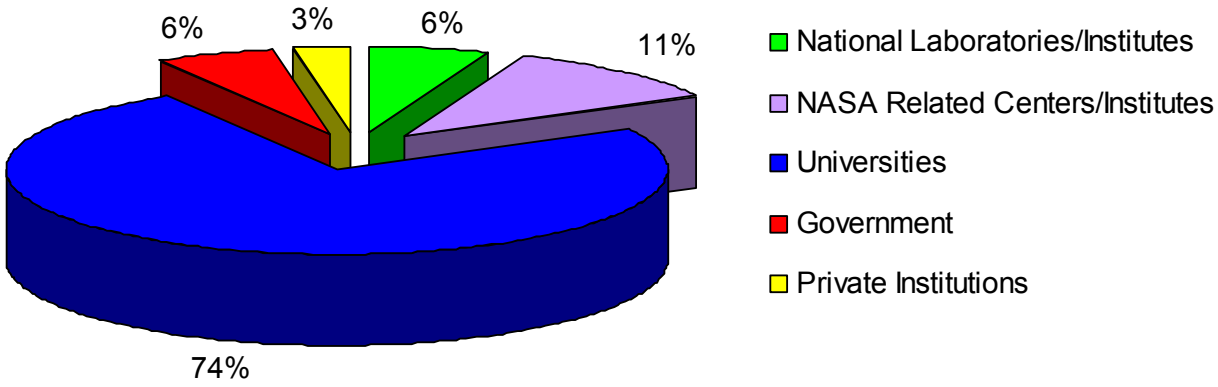
Government (2)

Joint Institute for Nuclear Research (JINR)
Wyle Laboratories @ Houston

RESEARCH PROJECT SPONSORS

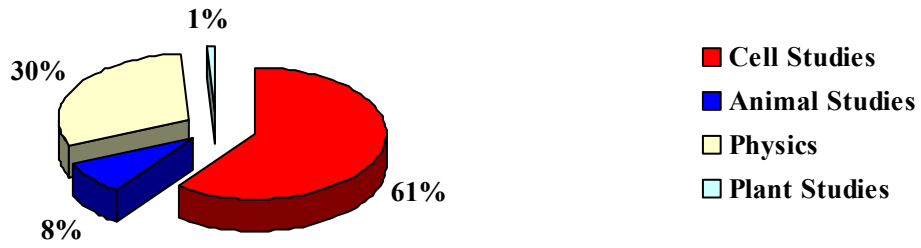


INSTITUTION STATISTICS

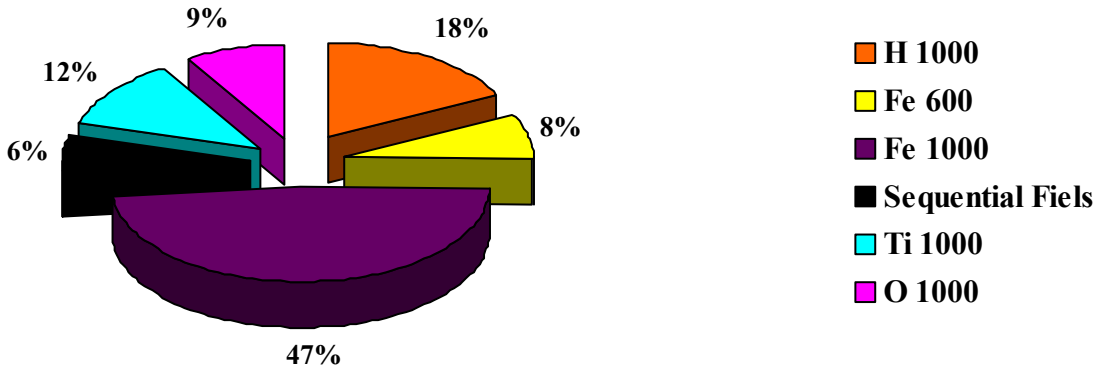


TOTAL RUN-TIME STATISTICS

SCIENCE STUDIES STATISTICS



ION SPECIES AND ENERGY (MeV/n) DISTRIBUTION



RUN TIME DESCRIPTION (hours)

NSRL-06B	ION SPECIES AND ENERGIES (MeV/nucleon)						
	H 1000	Fe 600	Fe 1000	Fe-H 1000	Ti 1000	O 1000	Totals
Machine Set-Up	6:00	8:00	16:00	4:00	4:00	4:00	42:00
Wrap-Up	1:30	2:00	4:00	1:00	1:00	1:00	10:30
Non-Science Sub-Total: 52:30							
Development	1:44	5:00	5:49	0:00	0:00	3:14	15:47
Biology							
In Vitro	28:46	2:18	51:05	9:23	15:37	4:35	111:44
In Vivo	0:00	5:54	12:47	0:00	0:00	0:00	18:41
Others	0:00	0:00	2:06	0:00	0:00	0:00	2:06
Physics	8:16	0:00	27:11	0:00	10:31	10:37	56:35
Science Sub Total: 189:06							
Time lost	1:00	0:10	9:40	2:00	0:50	0:00	13:40
Totals	47:16	20:28	128:38	16:23	31:58	23:26	271:03

BEAM CHARACTERISTICS

Ion	Fe		H	Sequential Field	Ti	O
Energy (MeV/n)						
Planned	600	1000	1000	1000	1000	1000
Extracted	600	1000	1000	1000	1000	1000
On Target	575	968	1000*	968/1000*	975	1000*
Fluence (particles/cm^2/sec)						
Maximum on target	2.60E+06	7.50E+06	2.10E+08	1.60E+07	2.60E+06	2.10E+05
Minimum on target	200	200	200	200	200	200
Spill Period (sec)	3	3	3	3	3	3
Spill rate (spills/min)	20	20	20	20	20	20
Spill length (msec)	300	300	300	300	300	300
Particles/spill						
Maximum	1.20E+09	2.60E+09	9.00E+10	2.6E9/9.0E10	1.03E+09	3.00E+09
Minimum	1.00E+05	1.00E+05	2.00E+02	1.00E+05	1.00E+05	1.00E+05
Beam Cut Off Accuracy	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
Actual LET on Target (keV/µm)	174	151.4	0.222*	151.4/0.222	108.2	14.2
Max. Dose Rate						
(Gy/min)/Beam Size						
20 cm x 20 cm	3.5	4	0.7	5	2	2.5
Total Dose (Gy)						
Maximum	10	10	10	30	3	20
Minimum	.02	0.05	0.01	0.1	0.01	0.01

- No Bragg results are available for H or O beam running.

DOSIMETRY AND BEAM DEVELOPMENTS

Target Room Access:

Since NSRL experiments overlapped with RHIC for most of the NSRL-06B running, extra safeguards were required for access to the target room. This necessitated longer access time for experimenters. Typical times for target room entrances and exits were five minutes longer than during running periods when RHIC was off. This made exposures slower, and generally prolonged the schedule, emphasizing the importance of making NSRL access independent of Booster/AGS/RHIC beam components.

Digital Beam Imager:

After four running periods (NSRL-5, 6, 7, and 06A) using the Digital Beam Imager, radiation damage to the pixel plane required us to send the camera out for refurbishing. We installed the backup camera for NSRL-06B and it gave as good service as the previous one.

Beam Development:

During NSRL-06B beam development periods we were able to prepare and expose a series of pharmaceutical samples for the N-168 protocol that had otherwise not been scheduled.

Energy Switching:

Our experience from NSRL-06A gave us confidence that changing beam energy was a simple matter of loading a different file with magnet settings. This was accomplished by the experts in less than 4 minutes during the last run. The responsibility for energy switching for this run was handed over to routine operators. Final beam tuning for the new energy proved to be too difficult for the operators, so we need to continue working with the experts in order to improve the energy switching program before we can rely on operators.

Locally-captured sweep key:

Doing target-room sweeps with a locally captured sweep key made life much easier for all. We lost sweeps several times this run, but lost only a few minutes for each. In the past we lost about 20 minutes per sweep, and some times even more.

Data Acquisition:

Physics Users made use of the NSRL data acquisition system to record data for a variety of physics experiments. This VME-based system records events at ~2000 events per second, allowing for much higher data rates and quicker exposures than most users could make use of previously.

RUN DATES

Ion Beam	Energy	Scheduled start	Scheduled End	Actual Start	Actual End
Fe-56	1000	6/8/06 7:00 AM	6/12/06 5:00 PM	6/8/06 7:00 AM	6/12/06 6:00 PM
O-16	1000	6/13/06 7:00 AM	6/14/06 5:00 PM	6/13/06 7:00 AM	6/14/06 6:12 PM
Ti-48	1000	6/15/06 7:00 AM	6/16/06 5:00 PM	6/15/06 7:00 AM	6/16/06 4:58 PM
Fe-56	1000	6/17/06 7:00 AM	6/22/06 11:30 AM	6/17/06 7:00 AM	6/22/06 11:52 AM
Fe-56	600	6/22/06 11:30 AM	6/22/06 12:30 PM	6/22/06 11:52 AM	6/22/06 12:05 PM
Fe-56	1000	6/22/06 12:30 PM	6/24/06 7:30 PM	6/22/06 12:05 PM	6/25/06 2:04 AM
Fe-56	600	6/25/06 7:00 AM	6/25/06 3:30 PM	6/25/06 7:00 AM	6/25/06 4:55 PM
H-1	1000	6/26/06 7:00 AM	6/28/06 7:00 PM	6/26/06 7:00 AM	6/28/06 5:00 PM
Sequential Field	1000	6/29/06 7:00 AM	6/30/06 9:00 PM	6/29/06 7:00 AM	6/30/06 5:27 PM

EXPERIMENTERS AND RUN STATISTICS

Exp.	Principle Investigator	Ion Species	Energy (MeV/n)	Beam Time Approved	Beam Time Used	Dose Range	Dose Rate	Samples
B-44	Durante, Marco	Titanium	1000	4:30	3:50	.00001-100	100	22
	Durante, Marco	Oxygen	1000	4:30	0:00	-	-	-
	Durante, Marco	Iron	600	4:00	0:00	-	-	-
	Durante, Marco	Iron	1000	8:00	9:48	25-300	50-100	10
	Durante, Marco	Protons	1000	3:30	4:10	100		12
N-52	Sutherland/Gewirtz	Sequential Field	1000	12:00	3:34	20-3000	20-500	51
N-65	Vazquez, Marcelo	Iron	1000	3:20	3:30	50-200	100	50
	Vazquez, Marcelo	Protons	1000	2:12	1:15	200	30	9
B-73	Sutherland,Betsy	Titanium	1000	0:00	1:13	20-200	20-200	20
	Sutherland,Betsy	Iron	600	1:30	0:00	-	-	-
	Sutherland,Betsy	Oxygen	1000	1:30	3:10	20-2000	20-250	100
	Sutherland,Betsy	Protons	1000	0:00	4:14	10-5000	10	28
	Sutherland, Betsy	Sequential Field	1000	0:00	1:12	20-3000	20-500	17
N-88	Sutherland, Betsy	Sequential Field	1000	13:00	9:11	0.0001-3000	0.0001-500	49
N-89	Held, Kathy	Titanium	1000	6:20	5:46	.00001-300	10-100	36
	Held, Kathy	Iron	1000	7:00	7:35	.00001-300	.00001-200	98
	Held, Kathy	Protons	1000	6:12	5:12	.00001-300	20	448
	Held, Kathy	Sequential Field	1000	4:15	4:21	10	20	100
N-102	Hall, Eric	Iron	1000	2:30	1:34	20-300	50-100	0
N-103	Barcellos-Hoff	Iron	1000	10:00	8:08	5-500	10-100	220
N-113	Obenaus, Andre	Iron	600	2:00	3:00	50-400	100	48
N-128	NSRSS	Iron	1000	0:00	16:13	10-400	20-200	32
	NSRSS	Titanium	1000	12:12	0:00	-	-	-
N-129	Limoli, Charlie	Iron	1000	6:00	6:10	10-500	20-200	152
	Limoli, Charlie	Iron	600	2:30	2:28	10-500	20-200	100
N-134	Chen, David	Iron	1000	2:00	2:37	20-200	50	59
	Chen, David	Oxygen	1000	2:30	1:25	50-150	50	11

EXPERIMENTERS AND RUN STATISTICS (cont.)

Exp.	Principle Investigator	Ion Species	Energy (MeV/n)	Beam Time Approved	Beam Time Used	Dose Range	Dose Rate	Samples
N-135	Pluth, Janice	Iron	1000	8:00	6:58	5-600	10-100	141
N-136	Britt, Ann	Iron	1000	3:00	2:07	1000-10000	300	34
N-155	Raber	Iron	600	7:42	2:55	-	-	48
N-156	Pisacane, Vincent	Iron	1000	8:00	8:58	low dose	low rate	0
	Pisacane, Vincent	Oxygen	1000	8:00	10:37	low dose	low rate	1
	Pisacane, Vincent	Titanium	1000	8:00	10:32	low dose	low rate	1
	Pisacane, Vincent	Protons	1000	8:00	9:17	low dose	low rate	1
N-157	Schiestl, Robert	Iron	1000	3:30	2:45	100	50	171
N-159	Kleiman, Norman	Iron	1000	5:30	5:14	5-25	10-40	56
N-167	Burma, Sandeep	Iron	1000	2:00	10:29	5-500	100	24
	Burma, Sandeep	Protons	1000	2:30	1:31	50-400	30	20
N-172	Berkowitz	Iron	1000	2:30	3:15	50-100	100	40
N-173	Geard	Iron	1000	2:30	1:07	20-80	50-60	32
	Geard	Protons	1000	3:00	1:09	20-160	50	22
N-174	Ware, Jeffrey	Iron	1000	2:00	2:08	20-200	20-200	36
	Ware, Jeffrey	Protons	1000	6:30	4:18	60-600	20	90
N-176	Cucinotta, Francis	Titanium	1000	6:00	5:37	10-150	10-100	80
	Cucinotta, Francis	Iron	1000	3:30	4:13	10-300	10-100	62