BOOSTER APPLICATIONS FACILITY REPORT PHASE II

Brookhaven National Laboratory

BNL--52291

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BOOSTER APPLICATIONS FACILITY REPORT

PHASE II

JUNE 1991

EDITED BY

PETER THIEBERGER

SPONSORED BY

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

**LYNDON B. JOHNSON SPACE CENTER
SPACE AND LIFE SCIENCES
PROCUREMENT BRANCH
HOUSTON, TX 77058**

**ALTERNATING GRADIENT SYNCHROTRON DEPARTMENT
BROOKHAVEN NATIONAL LABORATORY
UPTON, LONG ISLAND, NEW YORK 11973**

UNDER CONTRACT NO. DE-AC02-76CH00016

UNITED STATES DEPARTMENT OF ENERGY

MASTER

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Opening Remarks
by
N.P. Samios

OPENING REMARKS

by

N.P. Samios

Brookhaven National Laboratory was established in 1950 to provide advanced research facilities for a wide community of visiting and local scientists. Since then, we have continually upgraded and extended our multi-disciplinary activities and installations. Forty years ago, the "user" mode of doing research at large central facilities was unusual for most disciplines. We in fact developed at Brookhaven user modalities in high energy and nuclear physics, which served as models for other such facilities in the USA and abroad. Over the years we have successfully extended to other scientific and technological disciplines, this tradition of providing easy, efficient and user-friendly access to modern research facilities.

We are certainly happy to explore with NASA the possibility of further expanding the BNL user community by developing new capabilities of specific relevance for the space program. In particular we believe that particle beams from the AGS Booster would satisfy most of the national requirements for laboratory simulation of heavy ion space-radiation. We further believe that we could develop and operate the required facilities without undue interference with other activities. In fact our expectation is that such a project would be beneficial for all of the activities associated with our heavy ion accelerators.

The existence of local "core" programs has proven to be important for the efficient operation, utilization and upgrading of other user facilities. Many of our scientists will be eager to participate in the new research programs if a Booster Application Facility is constructed for NASA. We in fact already have well established and prestigious programs in radiobiology and radiation medicine. There also are scientists and engineers who would be very interested in participating in other areas of research such as shielding studies and detector developments.

In conclusion, I believe that the construction of a Booster Applications Facility for NASA would be a natural extension of our present plans. The ion beams from the Booster are the ones which are required, there should be no doubt about our technical capability to develop and operate the required hardware, and some of our scientific interests and expertise match the types of research which are important for the space program.

Introduction
by
P. Thieberger

INTRODUCTION

This report summarizes studies and planning performed by Brookhaven National Laboratory (BNL) personnel at the request of NASA for the design, construction and operation of experimental areas and facilities for utilization of ion beams from the BNL Booster synchrotron particle accelerator. These facilities would be primarily utilized to simulate space radiation for radiobiological research, shielding studies and detector calibrations. The feasibility of such a project has been established, preliminary designs and cost estimates have been developed and a formal proposal can be submitted pending DOE concurrence.

The main body of this report (sections IV through XXIII) consists of the material presented by BNL during the meeting with a NASA appointed Panel on December 10 and 11, 1990. The individual speakers have provided brief summaries of their talks and explanations of their figures. In addition there are two appendices. One, (section XXIV) contains detailed discussion of the shared mode of operation and the corresponding beam compatibility tables. The second appendix (section XXV) contains cost estimate details.

An executive summary on budgets and schedules (section III) has been added, containing possible phased construction and outfitting scenarios and the corresponding expense and commitment profiles as well as new operational cost estimates. Material contained in the executive summary reflects the correction of some errors and new studies performed in response to the NASA Panel suggestions. Some of the financial information contained in section XXII has been edited and is now consistent with the figures presented in the executive summary.

NASA FACILITIES PANEL
MEMBERS

Donald E. Robbins, Ph.D. (Chairman)
Deputy Director, Space and Life Sciences
NASA Johnson Space Center
Mail Code SA
Houston, TX 77058
(713) 483-0393/FAX 483-6089

Walter Schimmerling (ex officio)
Radiation Health Program Manager
NASA
600 Maryland Avenue, SW, Suite 600
Washington, DC 20024
(202) 863-5246/FAX 863-5240

Edmund Conway
High Energy Science Branch
NASA Langley Research Center
Mail Stop 403
Hampton, VA 23665-5225
(804) 864-1435/FAX 864-7730

Thomas W. Crooker
Program Manager for Materials Technology
NASA Headquarters
Mail Code RM
Washington, DC 20546
(202) 453-2837/FAX 775-4068

Herman A. Grunder
CEBAF
12070 Jefferson Avenue
Newport News, VA 23606
(804) 249-7553/FAX 249-7398

W. Vernon Jones
Chief, Cosmic and Heliospheric Physics Branch
NASA Headquarters
Mail Code SS
Washington, DC 20546
(202) 453-2837/FAX 755-4383

Humbolt Mandell
NASA Johnson Space Center
Code XP
Houston, TX 77058
(713) 283-5458/FAX 283-5818

Gregory A. Nelson
Technical Group Supervisor
Biotechnology Group
Jet Propulsion Laboratory
Mail Stop 89-2
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-4401/FAX 393-4176

Paul Reardon
Director, Accelerator Division
SSC Laboratory
2550 Beckleymeade Avenue
Dallas, TX 75237
(214) 708-3087/FAX 298-5451

Executive Summary

by

H. Foelsche, D. Lowenstein and P. Thieberger

Executive Summary of Costs and Schedules

A) Design, Construction and Installation Scenarios.

The plan presented at the meeting with the NASA Panel aimed towards a fully operational facility with three experimental areas and with a dual injector capability for shared operation by the end of 1994. This is the base-line plan described in the main body of the report. Here, in response to the Panel's request, we have analyzed other possibilities which are summarized in the tables on pages 4 through 6. For the purpose of this analysis we have separated costs and schedules for the Booster Applications Facility (BAF) itself including required beam transports and Booster modifications (schedules A-D on pages 4 and 5), from the MP6 tandem upgrade and interconnection (schedules 1-3 on page 6). These two aspects of the project can be phased independently and overall scenarios are obtained by combining appropriate pairs of schedules.

Two examples of preferred combined schedules are given on page 3. The first one shows the base-line plan with three experimental areas and dual injectors ready in 1994, while the second one is a project of reduced scope with only two experimental areas. The possible expansion to three or even four experimental areas would be left as future options.

BAF schedules A and B on page 4 call for a 1994 completion of the construction of the three experimental areas as initially planned but schedule B delays the outfitting of two of these until 1996. Such a delay may open the possibility of using some of the BEVALAC equipment should it become available. Devices which may be useful in this respect include the "wobbler" system, some quadrupole magnets, ionization and secondary emission chambers, recycling integrators and optical benches. Considering costs for dismantling, transporting and adapting such equipment, savings would probably be limited to a few hundred thousand dollars. Such savings have not been included in the estimates.

BAF schedule C on page 5 shows the cost profiles for a project of reduced scope which would provide only two irradiation rooms that would be built and equipped by the end of 1994. The corresponding drawing on page 7 shows this configuration. Note that the building containing the laboratories, preparation rooms and offices has not been reduced and that expansion capability is maintained for two additional experimental areas.

Finally BAF schedule D on page 5 would lead to a single operational experimental area in 1994 with another one built but to be equipped in 1996 and a third one to be built and equipped by 1996. Costs for schedules A, B and D differ only as a consequence of the annual inflation factors assumed in the analysis.

Tandem upgrading scenarios are shown in the three tables on page 6. Again costs differ because of inflation factors. MP6 schedule 1 is strongly preferred by BNL because it would provide maximum flexibility for NASA and would minimize interference with other activities during the commissioning and initial operation of the BAF facility. MP6 schedule 2 would delay dual injector capability by one year and MP6 schedule 3 by about 1.5 years. These schedules are acceptable but delays during the critical commissioning phase are likely and the total first year usage of the facility by NASA would have to be restricted to less than 1000 hours.

Below we show two preferred overall scenarios (A1 and C1) obtained by combining BAF schedule A (page 4) and C (page 5) with MP6 schedule 1 (page 6). These options would provide respectively three or two operational experimental areas and dual injector capability by the end of 1994.

Schedule A1
(Three experimental areas and dual injectors by 1994)

	Commitment (at year K\$)	Expense (at year K\$)
1991	556	457
1992	13489	7188
1993	8226	11605
1994	6277	9298
1995		

TOTAL: 28548

Schedule C1
(Two experimental areas and dual injectors by 1994)

	Commitment (at year K\$)	Expense (at year K\$)
1991	556	457
1992	10988	5902
1993	7373	9886
1994	5426	8098
1995		

TOTAL: 24343

BAF Schedule A

	Rooms B+C built	Room B equipped	Room C equipped	Room A built	Room A equipped	Commitment (at year K\$)	Expense (at year K\$)
1991						556	457
1992						11028	5951
1993						5752	8934
1994	✓	✓	✓	✓	✓	5464	7458
1995							
1996							
1997							

TOTAL : 22800

BAF Schedule B

	Rooms B+C built	Room B equipped	Room C equipped	Room A built	Room A equipped	Commitment (at year K\$)	Expense (at year K\$)
1991						556	457
1992						10724	5746
1993						5393	8589
1994	✓	✓		✓		3701	4631
1995						1309	1887
1996			✓		✓	1452	1825
1997							

TOTAL : 23135

BAF Schedule C

	Rooms B+C built	Room B equipped	Room C equipped	Room A built	Room A equipped	Commitment (at year K\$)	Expense (at year K\$)
1991						556	457
1992						8527	4665
1993						4899	7215
1994	✓	✓	✓			4613	6258
1995							
1996							
1997							

TOTAL : 18595

BAF Schedule D

	Rooms B+C built	Room B equipped	Room C equipped	Room A built	Room A equipped	Commitment (at year K\$)	Expense (at year K\$)
1991						556	457
1992						8701	4760
1993						5393	7552
1994	✓	✓				5953	5726
1995						1308	3044
1996			✓	✓	✓	1453	1825
1997							

TOTAL : 23364

MP6 Schedule 1

	Tandem Upgraded	Tandem Connected	Commitment (at year K\$)	Expense (at year K\$)
1991				
1992			2461	1237
1993			2474	2671
1994	✓	✓	813	1840
1995				
1996				

TOTAL : 5748

MP6 Schedule 2

	Tandem Upgraded	Tandem Connected	Commitment (at year K\$)	Expense (at year K\$)
1991				
1992			1350	658
1993			1428	1425
1994	✓		2341	2090
1995		✓	871	1598
1996				219

TOTAL : 5990

MP6 Schedule 3

	Tandem Upgraded	Tandem Connected	Commitment (at year K\$)	Expense (at year K\$)
1991				
1992				
1993			1641	837
1994			3619	2821
1995	✓	✓	871	2254
1996				219

TOTAL : 6131

B) BAF Operations costs

The operations cost analysis presented at the meeting with the NASA Panel was based on a facility operated by a fully dedicated staff. This situation would be desirable and cost effective for an estimated number of yearly operating hours equal or larger than 4000. If only 2000 hours/year are utilized then a large fraction of the personnel can be time-shared with other Booster activities and therefore the corresponding costs can be shared accordingly. This is the basis for the operating cost analysis presented on the next three pages.

The services to be provided to the users remain the same as the ones described at the meeting with the NASA Panel. The accelerators and beam delivery and diagnostic systems will be professionally operated and complete dosimetry and calibration services will be provided. In addition there will be a modest level of technical support available in the experimental areas. Other services such as machine shops, shipping, animal housing etc. will be available at the official laboratory rates.

BOOSTER APPLICATIONS FACILITY OPERATIONS COST

The Booster Applications Facility (BAF) is expected to supply 2000 hours of ion beams yearly to NASA supported radiobiological and physics experiments. The funds necessary to support this endeavor will be supplied by NASA to BNL to provide for machine and beamline operations. We have considered two possible modes of operations. The first being concurrent operations of the Booster with other programs, such as high energy and nuclear physics. The second being dedicated operations of the Booster for the BAF. Note that the calculated costs are in FY1991 dollars and that the present DOE guidance for Booster and Tandem operations funding is assumed. The BAF costs will be reviewed on a yearly basis and be modified in response to changes in the DOE funding guidance and projected power costs.

For the concurrent running case we expect, for the near term future, to run the Booster approximately 26 weeks per year. An operational week is 168 hours, with a 36 hour maintenance period every 3 weeks, and a machine availability uptime of greater than 90%. We assume, for the NASA supported BAF program, that the Booster will supply beam for 24 hours per day, 7 days per week, except for maintenance periods. This results in 13 weeks of elapsed time per year to acquire 2000 hours. In our cost calculation, we assume that most of the machine and personnel costs to provide beam is covered in the fractional base cost of items A and B in Table 1. The costs in Table 1 are broken down into labor (including fringe and overhead costs), purchases of materials and services (including overhead) and power costs (no overhead applied). We assume that the 13 weeks of operations are contiguous and are run concurrently with the AGS physics program. The determination of the fraction of the base costs is based upon the rationale that BAF requires 1/2 the Booster resources when it is operational, which in turn is 1/2 the available Booster operating time. We thus arrive at a fraction of $0.25(A+B)$. In addition to this base cost are the BAF specific items that are not covered under the base Booster operation costs. These are identified as items C and D in Table 1. Item C identifies those costs related to Booster pulsing, extraction and external beamline operations. Item D identifies those costs related to experimental area operations. Included here are the incremental power costs, purchases for materials and services, and the cost of additional personnel that are not presently available. The additional personnel include professional support, such as for dosimetry, optics, life science liaison, and engineering liaison, and the additional

technical support to maintain the extensive machine, beamline and experimental area equipment. We have not identified the costs for animal care. We note that the shift operator and administrative support is included in the fractional base costs of A+B. In addition, we also note that the costs to be incurred by NASA, on a yearly basis, would be reduced if other programs, yet to be identified, were to use the BAF and thus share the costs. Not identified are any possible interagency cost recovery factors that NASA may have to bear. We expect that the DOE and NASA will determine what additional costs, if any, will be loaded onto the BNL estimate. This should be clearly defined in the Memorandum of Understanding. The present projection of hourly costs is \$1950 for 2000 hours per year. Should the desired number of operations hours be otherwise, then the fraction of A+B costs and power costs in C+D would scale accordingly. The labor costs in C+D would not change and the purchase costs in C+D would vary slowly.

For the case of dedicated Booster operations for the BAF, the hourly cost of \$1950 / hour would rise to ~\$3700 / hour. We obtain this value by setting the fractional base cost of A+B equal to 1.0. Thus from Table 1, the cost for a dedicated 2000 hour operating period would equal $A+B+C+D = \$7.3M$. The total cost for 2000 hours of shared use is \$3.9M.

TABLE 1

**BOOSTER APPLICATIONS FACILITY YEARLY OPERATIONS COSTS
(FY1991\$)**

	MPWR	Labor*	Purchases* etc.	Power (@ \$70/MWH)		
	(FTE)	(M\$)	(M\$)	(M\$)	(MW)	(Weeks)
A.Tandem	18	1.8	0.4	0.3	1.0	26
B.Booster	15	1.5	1.2			
C.Additional Pulsing				0.1	0.8	13
Extraction (33% DF)				0.3	1.6	13
Beamline	4	0.4	0.5	0.1	0.8	13
D.Experimental Areas	5	0.5	0.5	0.2	0.2	52

Proposed Charging Algorithm
for 2000 hours of shared use

TOTAL= .25(A+B)+C+D 1.7 1.4 0.8 = 3.9

* Includes 48.5% G&A

Project Overview
by
P. Thieberger

The Feasibility Study (Phase I) was performed by a BNL study group, the members of which were H. Foelsche, Y.Y. Lee and P. Thieberger. Two members were added, Drs. A.D. Chanana and C.L. Snead, to form the BNL Booster Applications Task Force. The members of this task force are listed on Figure 1. The present Phase II report, containing preliminary designs and cost estimates, was generated by this task force with the assistance of other BNL employees. Most of these other contributors are authors of sections of this report. In addition, the architectural designs and cost estimates developed by Jack Feldman should be especially acknowledged.

We also received important help and advice from many visiting specialists listed on Figure 2. Two of us visited the Lawrence Berkeley Laboratory (LBL) where we obtained excellent cooperation and valuable information. Figure 3 shows a schematic layout of the various accelerators and their interconnecting beam transfer lines. At present the Alternating Gradient Synchrotron (AGS) accelerates either protons from the linac to ~30 GeV or heavy ions from the MP7 Tandem to ~14.6 GeV/AMU. The heavy ions available now are oxygen and silicon and for the silicon beams an ion source is used which is located in the high voltage terminal of the MP6 tandem.

Due to residual gas charge exchange losses in the AGS only fully stripped beams can be accelerated in that machine. Silicon is the heaviest ion from which all electrons can be efficiently removed at the energies available from the tandems. The AGS Booster, now nearing completion (see Section IX), with a vacuum of $\sim 10^{-11}$ Torr, will be capable of accelerating any partially stripped ions which will then be injected into the AGS after further stripping. Thus all ions up to gold will become available at AGS energies and the requirement for the ion source in the MP6 tandem will be removed.

If the proposed Booster Applications Facility (BAF) (Sections XI, XII and XIII) were built, useful beams could be delivered to this Facility by developing a new slow extraction system for the Booster (Section X) and an appropriate beam transport (Section XII).

Dedicated use of the Booster for the Applications Facility, although possible, would be expensive and restricted to periods when no beams are required for the AGS. Since the Booster is a fast cycling synchrotron, it will be capable, for most operating modes, to deliver a pulse to the AGS and then another pulse (of different ions and/or energy) to the BAF before the next AGS pulse is required (Section VIII). To make this possible pulse-to-pulse modulation will be implemented for the Booster (Section XIV). For time sharing between two different heavy ions, the MP6 tandem needs to be upgraded (Section V) and connected to the heavy ion transfer line (HITL) (Section VI). Also the beams

transported through HITL need to be of equal magnetic rigidity since this line cannot be rapidly retuned. This rigidity matching requirement results in only minor occasional intensity and/or energy limitations (Section VII).

The construction of the Relativistic Heavy Ion Collider (RHIC) has now been approved. When fully operational, this collider will only require injection once or twice a day and thus only minor interruptions of other activities will be required.

Figure 4 shows the maximum beam energies of all present and future BNL heavy ion accelerators as functions of mass and the BEVALAC maximum energies for comparison. Should Booster energies be too low for some applications, experiments could be performed at the AGS. Energies lower than the maximum Booster energies are available essentially down to Tandem energies.

Examples of maximum energies, estimated intensities, ranges in water and surface dose-rates for heavy ion beams from the Booster are shown in Figure 5. The main components of the project are listed on Figure 6.

Figure 7 summarizes the construction and outfitting costs of the base-line version of the BAF facility with three experimental areas and dual injector capabilities fully operational by the end of 1994 (Section XXII). Other options and possible alternative schedules are given in the executive summary (Section III).

The operating cost per hour of \$1830 shown on Figure 8 is based on 26 weeks of shared operation and assumes a fulltime, fully dedicated staff (Sections XV and XXIII). Another alternative, for 2000 hours of shared operation, is discussed in the executive summary (Section III).

Advantages of utilizing HZE particles at Brookhaven are outlined in Figure 9. The planned facilities for in-vivo and in-vitro radiation biology research and the existing animal care facilities are described in Section XVI and XVII. Sections XVIII through XXI summarize relevant local research interests, capabilities and plans.

BNL BOOSTER APPLICATIONS TASKFORCE MEMBERS

Dr. Arjun D. Chanana
Medical Department

Dr. Horst W. Foelsche
AGS Department

Dr. Yong Y. Lee
AGS Department

Dr. C. Lewis Snead
Nuclear Energy Department

Dr. Peter Thieberger
Physics Department

VISITS RELATED TO THE PROJECT

TO BNL:

**E. John Ainsworth, Scientific Director
Armed Forces Radiobiology Research Institute**

**Ann Bruger Cox
Radiation Science Division
U.S. Air Force School of Aerospace Medicine**

**Eric John Hall, Professor of Radiology
Radiological Research Laboratory, Columbia University**

**John Lett
Department of Radiation & Radiation Biology
Colorado State University**

**Lauren Leveton
Senior Scientist, Life Sciences Division
Lockheed Corporation**

**Donald E. Robbins
Deputy Director, Space and Life Sciences
NASA Johnson Space Center**

**Walter Schimmerling, Visiting Senior Scientist
Life Sciences Division, NASA Headquarters**

**Frank Sulzman, Chief, Life Support Branch
Life Sciences Division, NASA Headquarters**

**Tracy Chui-hsu Yang
Lawrence Berkeley Laboratory**

TO LBL:

**Avraham Dilmanian
Medical Department, BNL**

**Peter Thieberger
Physics Department, BNL**

Figure 3

Figure 4

Examples of maximum energies estimated intensities
and dose rates for BNL Booster heavy ion beams

Ion	Energy (MeV/AMU)	Average Intensity (Ions/sec x 10 ⁸)	Range in water (cm)	Surface dose-rate in water for a 10 cm ² beam (Gy/min x 10 ²)
₆ C ¹²	1500	33	185	2.4
₈ O ¹⁶	1500	24	139	3.1
₉ F ¹⁹	1500	23	131	3.8
₁₄ Si ²⁸	1500	15	79	5.9
₁₅ P ³¹	1500	10	77	4.5
₁₆ S ³²	1500	10	69	5.2
₁₇ Cl ³⁵	1500	9	67	5.2
₂₆ Fe ⁵⁶	1248	0.5	36	0.7
₂₉ Cu ⁶³	1127	6	29	10.5
₃₂ Ge ⁷⁰	1097	5	27	10.8
₃₅ Br ⁷⁹	917	6	19	16.0
₅₃ I ¹²⁷	620	4	7.4	27.4
₇₉ Au ¹⁹⁷	350	4	2.2	77.5
₇₉ Au ¹⁹⁷	445	0.2	3.2	3.5

Figure 5

PROJECT COMPONENTS

- MP6 Tandem upgrade
- MP6 - HITL interconnection
- New Booster extraction system
- Beam transport and conditioning
- New experimental facility
- Instrumentation, controls and dosimetry
- Experimental support hardware and services

COST SUMMARY
 CONSTRUCTION AND OUTFITTING COSTS
 BOOSTER APPLICATIONS FACILITY
 BASELINE ESTIMATE, COMPLETION FY 1994

TOTAL COST	28.5 M\$ (AT YEAR \$) 25.9 M\$ (FY 91 \$)	Revised 1/12/91 Revised 1/12/91
------------	--	------------------------------------

MATERIALS	21.8 M\$ (AT YEAR \$)	Revised 1/12/91
BNL LABOR	6.7 M\$ (94.2 MANYEARS)	Revised 1/12/91

INCLUDING:

CONTINGENCY

MATERIALS	25 %
LABOR	35 %

BNL OVERHEAD	5 %
--------------	-----

ESCALATION (FY 91 = 1.000)
 CUMULATIVE (DOE)

FY 92	1.045	Revised 1/12/91
FY 93	1.098	Revised 1/12/91
FY 94	1.160	Revised 1/12/91

Figure 7

Applications Facility Operating Cost Estimate

\$1830 per hour

Based on 26 weeks of shared operation.

- Highest energy high-Z particle beams in the USA
- Forefront research in radiobiology and radiotherapy
- Cell-culture facilities and fully accredited animal handling facilities
- Successful cooperative programs with NASA, many universities, other laboratories and industry
- A long tradition of efficient and user-friendly access to BNL facilities

Tandem Upgrade
by
P. Thieberger

The reasons for upgrading the MP6 tandem to match the present MP7 performance are explained in Figure 1. In principle, shared BAF operation with a single tandem would be possible when the Booster is accelerating protons for the AGS. This, however, is not a desirable alternative because the overutilization of MP7 would lead to maintenance problems, delays during the commissioning phase, and serious interference with ongoing programs.

The upgrading of MP7 took place over a ten year period from 1972 until 1982. During this time many original developments led to unprecedented performance for this type of accelerator. The maximum energies for three typical beams are shown as function of time on Figure 2. The upgrading of MP6 would be performed by utilizing the existing experience and designs developed for MP7. The items involved and their cost are listed on Figure 3. Figures 4 and 5 show the geometry of the extended acceleration tubes as well as other items involved in the upgrading such as additional vacuum pumps, power drive shaft systems, etc.

Details of the compact dead section geometry with the BNL designed acceleration tube terminations are shown in Figures 6 and 7. Figure 8 shows the last and very successful scheme for protecting the voltage dividing resistors with cylindrical shields, annular spark-gaps and LC filters. Finally, Figures 9 and 10 summarize the plans and the reasons for upgrading the MP6 tandem.

For Booster injection a single tandem will be used for any required ion beam.

At present:

Only the MP7 Tandem has the required terminal voltage and reliability.

Only the MP7 tandem is connected to the Heavy Ion Transfer Line (HITL).

For shared Booster operation we need two independent and equivalent injectors.

Therefore:

The MP6 tandem must be upgraded.

The MP6 tandem must be connected to HITL through a short beam transport.

BNL TANEC FACILITY ENERGIES OF THREE TYPICAL BEAMS

Fig. 2. Maximum energies for three typical beams as a function of time.

MP6 UPGRADING ESTIMATE

New, extended acceleration tubes and dead-section chambers	1,200,000.
Dead-section vacuum pumps, supplies and second drive	200,000.
New voltage dividers (tube and column)	260,000.
Improved column connections	20,000.
Improved equipotential ring mounts	20,000.
Additional SF6	200,000.
Improved charging system and chain charge monitors	200,000.
Pulsing ion source supplies, telemetry and controls	30,000.
Beam chopper supply and controls	30,000.
Additional corona actuator	30,000.
Additional generating voltmeter	10,000.
Chart recorder	10,000.
Additional terminal foil changer	10,000.
Manpower — 3 man-years	300,000.
20% Contingency	504,000.
TOTAL	<u>3,024,000.</u>

Figure 3

Schematic representation of the main components involved in the recent upgrade programme.

Figure 4

Schematic representation of one half of the MP column showing how the extended tubes protrude into the dead sections, the terminal and the end of the column.

Figure 5

New acceleration tube termination incorporating an integral flexible bellows.

Figure 6

Schematic representation of the configuration of a dead section containing a 110 l/s ion pump.

Figure 7

Cylindrical shielding arrangement for column resistors.

● The upgrading of the MP7 tandem has been very successful. Excellent reliability has been demonstrated during several AGS runs.

The MP6 tandem upgrading will take full advantage of the experience gained with the MP7 tandem.

● Essentially no new design is required. The same high quality HVEC acceleration tubes are available and will be used.

Why MP6 should be upgraded now

MP6 upgrading for NASA operation during the RHIC era is indispensable.

Concurrent heavy ion operation now will make the ~ 2000 hr/year NASA scheduling more flexible and efficient.

We will be able to accommodate additional facility users which will lower operating costs and enhance resource utilization.

The present local Tandem program (SEU testing + radiobiology) would be destroyed if we start a new NASA program with a single tandem.

Good acceleration tubes may no longer be available in 5 years.

The MP6 upgrading will benefit NASA and BNL by providing more redundancy and therefore enhanced reliability for all operations.

Tandem — HITL Interconnection
by
T. Robinson

The present proposal to deliver interleaved heavy ion beams to the AGS Booster in order to serve simultaneous users at the AGS and also at the proposed Booster Applications facility requires that the second of the two BNL Tandems, MP-6, be upgraded to a terminal voltage of 16 MV and also that its beam be injected into the present HITL beam line. Injection of two different species from the two Tandems, having different masses but identical magnetic rigidities, will allow this scenario. This presentation will outline the effort necessary at the TVDG to achieve these goals.

Figure 1 is a schematic diagram of the accelerator complex at BNL, including existing and proposed facilities, and the heavy ion transfer lines connecting them. The Tandem Van de Graaff facility is presently connected to the AGS accelerator via the Heavy Ion Transfer Line (HITL), which delivers fully stripped heavy ions up to the mass of sulphur from the MP-7 Tandem to AGS. The maximum design beam rigidity for this link is 1.2 Tesla-meter, although the nominal beams presently transported have rigidities of about 0.7 Tesla-meter. These ions are accelerated in the AGS to energies of about 14.6 GeV/n for fixed-target experiments located on the AGS experimental floor.

HITL is in the process of being extended to the new Booster accelerator via the HITL-to-Booster (HTB) beamline, identical in construction and transport philosophy to the HITL, with the exception that it can handle beams having rigidities up to 2.2 Tesla-meter. Completion of this new link will allow transport of partially-stripped ions throughout the periodic table to the Booster, where they will be accelerated further and fully stripped prior to insertion into AGS. There, they will undergo acceleration to 14.6 GeV/n for fixed target experiments, and ultimately for delivery to the Relativistic Heavy Ion Collider (RHIC), now beginning construction.

The proposed Booster Applications facility is shown being serviced from the Booster, with ejection energies ranging from 1.5 GeV/n for protons to 350 MeV/n for gold.

To highlight the scope of the work required at the Tandem, Figure 2 shows schematically a typical horizontal beam envelope being injected into the HITL from MP-7. Note that the transverse dimension of the beam is greatly magnified for clarity in all the beam envelope drawings, and that for all practical purposes the vertical extent of the beam is the same as that of the horizontal in this quadrupole doublet, double-waist lattice. Figure 3 indicates a solution for the upgraded MP-6 beam injection into the HITL. We will return to these diagrams later during the presentation for a detailed look at the injection optics of these regions.

Figures 4 and 5 indicate some of the physical parameters of the existing HITL beamline, including the quadrupole doublet tuning lattice as well as the two types of double-focussing, doubly-achromatic, dispersion-free dipole bends.

The two types of dispersion-free bends are shown in more detail on Figure 6. The double 90° bend features two dimensional beam waists at both the object and image points of each of the double-focussing magnets. The image of the first magnet forms the object of the second at a point where Tandem energy regulation information is obtained. The beam at this point has become mono-energetic due to the momentum selection properties of the first dipole. If desired, further post-acceleration stripping can also occur at the intermediate point. Beam transport continues through the second dipole to its image point, which forms the beginning of the HITL lattice.

The other type of dispersion-free bend is used for the double 24° and double 69° bends; the 24° type is shown schematically here. In this case, a double waist is forced at the center of each of the two dipoles, with quadrupole doublets forming a parallel beam in the region of the mid-point. The quads, along with the symmetry of the system, produce the desired double achromaticity and dispersion-free qualities.

The HTB extension to HITL is explained in somewhat more detail in Figure 7. The heavy ion beams to the Booster must be

transported through the existing double 24° bend area, but not the double 69° bend which serves only to inject AGS in the present transport scheme. The 24° magnets must be replaced with magnets of a larger radius in order to accommodate the stiffer 2.2 T-m beams required at the Applications Facility.

Figures 8, 9 and 10 describe the optics of the existing MP-7 injection into HITL. After traversing the double 90° bend area, the beam is relatively highly divergent, and must be captured rather quickly by a quadrupole doublet and focussed downstream to a second set of quads (the first quad doublet is the one requiring the highest fields throughout the transport; it is quite adequate for the 1.2 T-m beams but must be stronger for the higher rigidity beams). The relative tune of these four quad lenses, commonly termed a "zoom" lens, determines the properties of all subsequent waists in the downstream beamline. After the zoom lens, the lattice falls into the typical waist-to-waist transport having cell lengths of about 250' with intermediate quad doublets centrally located between waists.

The upgraded MP-6 Tandem will inject beam into HITL in a somewhat similar but not quite identical manner. It would at first appear that a simple solution would be to duplicate the MP-7 injection geometry, but in order to accommodate switching rapidly between beams from both machines, investigation shows that the second dipole needs to be a fast cycling, pulsed magnet rather than the less expensive DC magnets now in use. In addition, the yoke structure would have to allow for a penetration of the beampipe from MP-7, thus making the homogeneity requirements of the dipole harder to achieve. A simpler solution, and the one described in Figures 11, 12 and 13, shows a 90° DC magnet for the first bend, identical to that at MP-7. The second magnet is reduced to an 80° bend using another DC magnet and is followed by a small, fast-cycling 10° magnet of laminated construction. This magnet can be made in a "C" configuration to accommodate a straight-through MP-7 beampipe. This results in a much cheaper, easier to control, fast-cycling selection of beams. Changing the position and bending

angle of the second magnet results in an asymmetry in the natural focal lengths of the system, but these changes can be corrected by selecting appropriate entrance and exit pole-face (shim) angles for the dipoles.

The beam dynamics at the final image point of this MP-6 achromatic bend will determine the optic properties of beams through the rest of HITL and HTB. The problem now is to alter the existing MP-7 transport so that its beam will look identical to that from MP-6 at this image point. Figures 14, 15 and 16 describe the effort required to achieve this. The zoom lens must move so that it is now located downstream of MP-6 so that it can be utilized for both machines. In order to accomplish this, the second of the two MP-7 zoom lens quads will be moved to a point very close to the desired MP-6 image point, so that it will produce a sharply-divergent double waist at this point. Thus, the MP-7 beam will appear identical to that from MP-6. The first of the present MP-7 zoom lens quads will not move, but will be replaced with a more powerful set that will force a new double waist halfway to the MP-6 injection area. A duplicate of this higher power quad doublet will be placed downstream of the MP-6 injection point, in a position analogous to that of the old MP-7 zoom lens. This will form the first set of the new zoom lens quads, with an existing set of HITL quads located further downstream forming the second set. Although the separation of these pairs of doublets is greater than that of the existing HITL transport, a parallel beam condition can be easily achieved to the next quad doublet, and no further magnet position changes will be required throughout HITL.

Figure 17 shows schematically the two beams at the matching area, while Figure 18 gives a comparative view of the three transport configurations.

In order to allow the beam from MP-6 to enter the HITL tunnel, some conventional construction is required to build a conjunction area. This is described in Figures 19, 20 and 21. The floor level of HITL is about 45 feet below grade at this point, and is located

parallel to and 10 feet separated from the outer wall of the TVDG facility. The similar HITL construction was accomplished by sinking a 45 foot deep vertical shaft behind the building, and then cutting through the 30" of concrete from both sides in order to remove the section of wall that forms the conjunction area. The debris from this operation was easily removed by crane via the shaft. In the case of MP-6, a similar vertical shaft is precluded due to the presence of gas storage tanks buried below grade directly over this location. The construction effort must be mounted from within the Tandem, which will make penetration of the wall, removal of debris and pouring new concrete somewhat more difficult. Transition into and alteration of the existing liner-plate HITL tunnel is also a delicate operation and must be done with care to avoid loss of integrity of the existing tunnel structure.

Figure 22 summarizes several required magnet changes, including upgraded larger radius 24° dipoles to accommodate 2.2 T-m beams, and also the higher power quads needed both for the already mentioned zoom lenses and also for the parallel-beam matching quads between the 24° dipoles.

Figure 1

EXISTING MP-7 INJECTION

Figure 2

NEW MP-6 INJECTION

Figure 3

Existing HITL

Tunnel is 10' diameter, 2000' long.

All magnets are DC.

Transport lattice is quad doublet.

~ 125' focal length.

Double waists at crossovers.

Steerer correction for
earth's field perturbation.

Maximum design rigidity 1.2 T-m.

AGS uses up to $^{32}\text{S}^{16+}$; ~ 0.7 T-m).

Emittance is ~ 1 pi.

Existing HITL

All dipole bends doubly achromatic.

2 kinds of doubly achromatic.

24° & 69° types:

Waist at center of dipole.

Parallel transport between.

90° type:

Double waist between dipoles.

Has energy regulation point.

No beam motion due to slight E change.

Vacuum system utilizes NEG strip.
(10^{-10} Torr pressure.)

TYPES OF HITL DOUBLY-ACHROMATIC
DIPOLE BENDS.

HTB (under construction)

Will abandon HITL 69° dipoles.

HTB is designed to 2.2 T-m.

Mass to gold ($^{197}\text{Au}^{33+}$).

Need new 24° dipoles for
Q=13.

Q=13 gives better transmission
due to better emittance & yield.

HTB to be commissioned mid-91.

Existing MP-7 injection.

Uses 90° double focussing magnets.

Doubly achromatic bend.

Quad "zoom" lens; 1st lens captures
divergent beam, the 2nd lens
focusses at the next crossover.
Parallel transport between quads.

Energy regulation slits located at the
image point of the 1st dipole.

EXISTING MP-7 INJECTION

Figure 10

New MP-6 Injection.

90° DC dipole followed by an 80° DC dipole followed by a 10° pulsed switcher magnet.

System is doubly achromatic.

Energy regulation slits between 90° and 80° magnets.

The MP-6 optics at the D2/3 image will now determine HITL transport characteristics.

Will need a new "zoom" lens with a longer parallel run to an existing quad.

1st "zoom" lens needs a more powerful quad.

NEW MP-6 INJECTION

Figure 12

Figure 13

Altered MP-7 Injection

Need to make beam look like MP-6 at D2/3 image.

Move old "zoom" Q2 lens downstream to look like object is at MP-6's D1 image.

Will force a crossover between quads.

Zoom lens Q1 needs to be much stronger.

ALTERED MP-7 MATCHING INJECTION

Figure 15

Figure 16

Figure 17

ALTERED MP-7 MATCHING INJECTION

NEW MP-6 INJECTION

EXISTING MP-7 INJECTION

New MP-6/HITL Tunnel Penetration.

Need to penetrate TVDG wall and existing
HITL liner plate tunnel.

Must build new concrete transition section.

Will have to reinforce HITL tunnel at
penetration point.

Figure 20

MP-6/HITL CONJUNCTION
AREA

Figure 21

Replace 24° dipoles and quads.

For best utilization of Tandem beams to the NASA facility, we need to change the 2 ea 24° dipoles to longer radius in order to transport 2.2 T-m beams.

Several quadrupole doublets will have to be strengthened for 2.2 T-m.

This will give better transmission for low Q due to higher yield, better emittance.

**Beam Transport to Booster,
Rigidity Matching and
Other Alternatives**

by

P. Thieberger

When injecting two different heavy-ion species into the Booster, e.g. gold from MP7 for the AGS and iron from MP6 for the BAF, we must consider the fact that the existing transfer line cannot be rapidly retuned. It turns out, however, that the magnetic rigidity of pairs of different heavy ions can always be matched by choosing appropriate charge states and energies. These facts are summarized in Figure 1.

Tables 1 and 2 show examples of BAF beams that will be available when sulfur and gold beams are used in the AGS and Table 3 gives the maximum iron beam energies compatible with various primary operating modes. One can see that frequently there is no energy penalty for shared use and that even in the worst cases the energy is only reduced by ~27%. A complete set of compatibility tables as well as further discussion on this subject can be found in the Appendix (Section XXIV).

As an alternative to rigidity matching, a separate beam transport in the existing tunnel could be built to provide maximum flexibility and to avoid any restrictions. This possibility as well as the possibility of constructing a new injector based on a yet to be developed high charge state high intensity ECR source are mentioned in Figure 2. Such developments should be viewed as possible future improvements and are not part of the present plans.

Finally, Figure 3 summarizes the reasons which make rigidity matching a viable choice for the transport of different beams through the heavy ion transfer line.

Using the single existing Heavy Ion Transfer Line (HITL) to transport pairs of different beams is advantageous for reasons of simplicity and cost.

HITL can not be rapidly retuned.

The magnetic rigidity of pairs of different heavy ions can be matched by choosing appropriate charge states and energies.

The rigidity matching can be performed without large penalties in final energies or intensities.

Alternatives other than rigidity matching will be mentioned.

Primary Tandem Beam: 150 MeV $^{16}\text{S}^{32}$ $Q_{\text{HITL}} = 14$ $B\rho_{\text{HITL}} = 0.7126$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} (MeV/AMU)	IONS PER PULSE ($\times 10^6$)
^{12}C	5	8.5	51.0	5	6	1500	82
^{16}O	6	7.9	55.1	6	8	1500	63
^{19}F	6	6.6	46.4	6	9	1500	50
^{28}Si	9	12.6	125.9	12	12	1500	21
^{31}P	9	13.3	133.4	13	13	1462	20
^{32}S	9	15.0	149.9	14	14	1500	24
^{35}Cl	9	13.7	137.1	14	14	1368	28
^{35}Cl	10	14.3	157.3	15	15	1500	17
^{56}Fe	11	14.6	174.9	20	20	1277	1.3

Table 1

Primary Tandem Beam: 210 MeV ^{197}Au $Q_{\text{HITL}} = 13$ $B\rho_{\text{HITL}} = 2.2515$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
^{56}Fe	4	14.0	69.9	4	17	916	2.3
^{63}Cu	4	12.4	62.2	4	18	835	28
^{63}Cu	4	12.4	62.2	4	20	980	5.7
^{70}Ge	5	14.6	87.4	5	21	900	21
^{70}Ge	5	14.6	87.4	5	23	1031	3.6
^{79}Br	5	12.9	77.5	5	21	748	24
^{79}Br	5	12.9	77.5	5	23	860	4.6
^{127}I	8	13.7	123.3	8	26	491	18
^{127}I	8	13.7	123.3	8	29	588	4.2
^{197}Au	13	15.0	210.0	13	34	369	9.1
^{197}Au	13	15.0	210.0	13	38	445	1.1
^{197}Au	13	15.0	210.0	13	34		4.6
^{197}Au	13	15.0	210.0	13	38		0.7

Table 2

EXAMPLES OF IRON BEAM COMPATIBILITY WITH OTHER BOOSTER OPERATIONS

Operating Mode	Maximum Fe-beam energies (MeV/AMU)
Dedicated use	1248
During RHIC operation	1248
Shared use with:	
H ¹	1248
C ¹²	916
S ³²	1248
Cu ⁶³	1081
I ¹²⁷	916
Au ¹⁹⁷	916

Figure 2

POSSIBLE ALTERNATIVES TO MAGNETIC RIGIDITY MATCHING IN HITL

- a) Separate beam transport in the existing
tunnel.....~\$4M

- b) New heavy-ion linac injector with high in-
tensity, high charge ECR source (not yet
developed).....\$?

Rigidity matching works
because of the wide ranges
of available:

- terminal voltages
- charge states
- Booster frequencies

Booster Requirements and Operation Cycles
by
H. Foelsche

BOOSTER REQUIREMENTS AND OPERATING CYCLES

As the AGS Booster comes on-line in 1991 the BNL AGS accelerator complex will be configured as shown in the first figure. Protons from the 200 MeV Linac, or heavy ions from the Tandems, will be preaccelerated in the Booster prior to injection into the AGS. The Booster will be sufficiently versatile to provide beams for the Booster Applications Facility, while simultaneously serving the AGS physics program. Figure 2 shows a closeup view of the Booster ring layout, with the two injection lines, from the Linac and from the HTB line.

Basic AGS and Booster magnet cycles are shown for the AGS physics program alone in Figure 3, and for joint AGS and Booster Applications Facility service in Figure 4. What makes the joint operation possible is the fact that the basic AGS physics cycle includes a 1.5 second flattop period for delivery of a slow spill to the physics program. This creates sufficient time to alternate Booster cycles for the service of both facilities, without loss of time in the AGS program. Thieberger, in the preceding chapter, describes the compatibility scenarios for alternating use of the beam transfer line from the two Tandems with different ion species.

Figure 5 illustrates a conceivable annual operating schedule, permitting both shared and standalone operation of the Booster Facility.

Extraction of beam from the Booster is at present available only in the "Fast Spill" mode, but a "Slow Spill" can be added for the Booster Applications Facility. The fast spill consists of a single spike of beam, delivered in three sharp bunches over a time of 0.45 microseconds, repeated typically every 3.3 seconds (see Figure 6) for direct transfer into the AGS in a single turn. By adding equipment to drive the beam across a betatron stopband one may extract a slow spill, stretched more or less uniformly over a controllable time period (see Figure 7).

Upon extraction from the machine the beam can be distributed into various experimental areas of the Booster Applications Facility. Typical beam characteristics are summarized in Figure 8.

Technical requirements for the Booster Applications Facility include a new external beam switchyard area, new experimental areas, new extraction equipment for the slow spill, the full implementation of the pulse-to-pulse switching mode for all Booster equipment, and, as discussed by Thieberger and Robinson elsewhere, upgrades of the voltage capability of the Tandem "MP-6", and an additional beam transfer branch from MP-6. See Figure 9.

**BROOKHAVEN NATIONAL LABORATORY
BOOSTER - AGS**

Figure 1

Figure 2

BOOSTER CYCLES

HIGH ENERGY AND NUCLEAR PHYSICS

a. HIGH INTENSITY PROTONS

b. HEAVY IONS

Figure 3

ALTERNATING BOOSTER CYCLES

a. PROTONS - HEAVY IONS

b. HEAVY IONS (1) - HEAVY IONS (2)

Figure 4

AGS BOOSTER

OPERATING SCENARIOS

(Typical 1 Year Schedule)

HEALTH RESEARCH	----- (off) -----	off
	Shared Mode	Alone
IONS	-----	
AGS PROTONS	-----	off
POL PROT	(-----)	off
RHIC (1997)		off

In a typical year the Health Research Program may run in the shared mode together with the heavy ion or proton physics program at the AGS, using pulse to pulse switching of the Booster cycle. Polarized proton physics in the AGS would preclude providing beam to the Health Program. With the exception of maintenance shutdowns, the Health Research Program may operate in the stand-alone mode when the other programs are off. The operation of the Relativistic Heavy Ion Collider (RHIC), expected to start in 1997, would preempt the other programs for about 1 hour, perhaps twice a day.

Figure 5

FAST SPILL

SINGLE TURN

Figure 6

SLOW SPILL

etc.

Figure 7

BOOSTER APPLICATIONS FACILITY

BEAM CHARACTERISTICS

TARGET SPOT	0.5 to 10 cm	AREA A
	5 to 100 cm	AREA B
	1 to 20 cm	AREA C
MICROBEAM OPTION	25 to 50 microns (LOW INTENSITY)	

BEAM SPOT UNIFORMITY +- 10 %

BEAM SPILL UNIFORMITY +- 20 % SLOW SPILL

Figure 8

AGS BOOSTER

TECHNICAL REQUIREMENTS FOR BOOSTER APPLICATIONS FACILITY

EXTERNAL BEAM	BEAM TRANSPORT SYSTEM AND TUNNEL WITH BRANCH LINES
EXPERIMENTAL AREAS	NEW BUILDING AND EXPERIMENTAL EQUIPMENT
BEAM EXTRACTION	SLOW SPILL EXTRACTION SYSTEM
BOOSTER OPERATIONS	PULSE TO PULSE SWITCHING CONTROLS & INSTRUMENTATION
TANDEM SYSTEMS	MP-6 BEAM TRANSPORT BRANCH MP-6 VOLTAGE UPGRADE

Figure 9

CONCLUSIONS

- * IT IS FEASIBLE TO SUPPORT A HEALTH RESEARCH PROGRAM AT THE AGS BOOSTER.
- * AFTER AN INITIAL INVESTMENT IN A NEW RESEARCH FACILITY AND A NEW EXTERNAL BEAM LINE THE PROGRAM CAN OPERATE STAND-ALONE OR IN CONJUNCTION WITH THE PHYSICS RESEARCH PROGRAMS OF THE AGS AND RHIC.
- * THE PROGRAMS CAN BE SERVICED SIMULTANEOUSLY BY A RAPID PULSE TO PULSE SWITCHING TECHNIQUE.
- * A SLOW BEAM SPILL CAN BE PROVIDED.
- * FACILITY PLANS CAN BE DEVELOPED IN CLOSE COLLABORATION WITH THE USER COMMUNITY.
- * PRECEDENTS EXIST FOR SUPPORT STRUCTURES AND FUNDING SCENARIOS FOR SUCH PROGRAMS.

**Status of the Booster Construction
Commissioning Plans**

by

W.T. Weng

The objective of the AGS Booster Project is to construct an intermediate energy synchrotron accelerator. The purposes of the accelerator include: increasing the intensity of the beam of protons in the AGS by a factor of four, accumulating and accelerating polarized protons so that their intensity in the AGS may be increased by an order of magnitude, and extending the AGS heavy ion capability from intermediate mass ions (up to sulfur) to the heaviest elements (gold, uranium).

The Booster Project is now near the final phase of assembly, testing, and installation. The status and work to be completed are briefly summarized below.

1. The proton injection line is 100% in place, except the last section connecting to the Booster ring. Beam test of the LTB is scheduled to begin in March, 1991.
2. The Booster ring is 85% complete. The remaining magnet cells and straight section components will be installed by April, 1991. System tests of two-thirds of the vacuum system have been successfully carried out in the tunnel to an average vacuum of 10^{-10} Torr. System tests of two-thirds of the power supply system will be performed in January 1991. Beam tests with protons are planned for May, 1991.
3. The extraction system and beam transfer from the Booster to the AGS is 60% complete. Complete installation will be accomplished by May, 1991.
4. The heavy ion beam transfer line from HITL to the Booster is 80% complete. Complete installation will be accomplished by March, 1991. The remaining task is the re-configuration of power supplies to magnet components. Beam tests of the HTB line can start in May or June up to the beam stop before the Booster tunnel.
5. Before beam testing, we need approval from:
 - a. The Advisory Panel on Accelerator Radiation Safety (approved April, 1990).
 - b. BNL Safety Committee on Booster Safety Analysis Report (to be held January, 1991).
 - c. DOE Operation Readiness Review (to be held in February, 1991).

BOOSTER MAJOR DESIGN PARAMETER LIST

CIRCUMFERENCE	201.78 m (1/4 AGS)
AVG. RADIUS	32.114 m
MAGNETIC BEND RADIUS	13.75099 m
NO. OF PARTICLES/PULSE	Protons, 1.5×10^{13} (AGS 6×10^{13} ppp) Polarized Protons, 10^{12} $\frac{C}{54} \quad \frac{S}{15} \quad \frac{I}{6.6} \quad \frac{Au}{3.2 \times 10^9 \text{ ions}}$
LATTICE TYPE	Separated function, FODO
NO. OF SUPERPERIODS	6
NO. OF CELLS	24
BETATRON TUNE, X, Y	4.82, 4.83
NUMBER OF MAGNETS	36 Dipoles, 48 Quads
MAGNET TYPE	Iron-Dominated, Water-Cooled Cu Conductor
DIPOLE LENGTH (Magnetic/Physical)	2.4/2.34 m
MAXIMUM DIPOLE FIELD	5.46KG (for Protons)
MAXIMUM DIPOLE FIELD	12.74KG (for heavy ions)
QUAD LENGTH (Magnetic/Physical)	0.50375/0.472 m,
VACUUM CHAMBER DIMEN.	70 X 152 mm, Dipoles 152 mm (Circular), Quads
ACCELERATION TIME	62 ms, Protons and Polarized Protons 500 ms Heavy Ions
REPETITION RATE	7.5Hz (4 Pulse/AGS Pulse), Protons 1Hz (1 Pulse/AGS Pulse), Polarized Proton 1Hz (1 Pulse/AGS Pulse), Heavy Ions
INJECTION KINETIC ENERGY	200 MeV (Proton) 4.688 MeV/Nuc (S) 1.066 MeV/Nuc (Au)
EJECTION KINETIC ENERGY	1.5 GeV (Proton) 0.967 GeV/Nuc (S) 0.350 GeV/Nuc (Au)

Figure 1

BOOSTER PROJECT OVERVIEW

W.B.S. 1.0

OBJECTIVES OF THE BOOSTER PROJECT

1. INCREASE PROTON INTENSITY IN AGS BY A FACTOR OF 5 TO 6×10^{13} ppp TO SATISFY DEMAND FOR BEAM TIME FROM RARE K DECAY AND NEUTRINO EXPERIMENTS.
2. INCREASE POLARIZED PROTON INTENSITY IN AGS BY A FACTOR OF 20 TO 10^{12} ppp FOR SPIN PHYSICS AND MULTI-TARGET OPERATION.
3. ACCELERATE HEAVY ION IN AGS FROM S TO Au FOR HEAVY ION PHYSICS AND EVENTUALLY FOR INJECTION TO RHIC.

AGS CYCLE

1.8 SEC. (FEB)
2.8 SEC. (SEB)

0.4

BOOSTER CYCLE

PROTON CYCLE

POL. PROTON CYCLE

(LINAC PULSES)

HEAVY ION CYCLE

1-2 SEC.

Figure 3

Figure 4

SCOPE OF BOOSTER PROJECT

1) BOOSTER RING: Six Technical Systems

MAGNET	: 36 Dipole, 48 Quadrupoles, 48 Correctors, Kickers, Septums (48 Sextupoles)
POWER SUPPLY	: Main Supply, Correctors, Trim Supplies, Kickers, Septums
VACUUM	: 36 Half Cell Chambers 12 Quarter Cell Chambers, Pumps, Gauges, Bakeout
RADIO FREQUENCY:	2 Proton Acceleration Stations 2 Heavy Ion Acceleration Stations, Low Level Systems
INSTRUMENTATION:	48 EPMS, Loss Monitors, (Tune Meter, Profile Monitor)
CONTROL	: Computers, Consoles, Timing, Controllers, Softwares

2) BOOSTER TUNNEL (and HTB TUNNEL)

3) THREE TRANSFER LINES and INJ/EJEC

LTB (Proton)

HTB (HI)

BTA (Proton and HI)

4) UTILITIES and SAFETY

BOOSTER PROJECT STATUS

(Percentage Complete as of Dec. 3, 1990)

	(36) <u>Dipole</u>	(48) <u>Quad</u>	(48) <u>Sextupole</u>	(48) <u>Correctors</u>
Core	100	100	100	100
Coil	100	75	100	100
Whole Magnet	95	70	100	90
Measurement	75	60	70	10 (planned)

100%
100%
100%
90%
60%
40%

CORRECTOR P.S.
VACUUM CHAMBER
PICK-UP ELECTRODE
ALGORITHM
RING VACUUM TEST
Ring P.S. Test

100
100
90
95
60
20%
85%

TEC Committed
Conventional Facility
Tray & Cable Pulling
LTB Installation
Booster Installation
BTA Installation
HTE Installation

Figure 6

Figure 7

Slow Extraction

by

Y.Y. Lee

SLOW EXTRACTION FROM THE AGS BOOSTER

Y.Y. LEE

ABSTRACT

A possibility of slow extraction from the AGS Booster has been studied. It is possible to slow extract from the D-6 straight section with a thin wire septum located in the B-6 straight section which is presently not assigned. The extraction efficiency is estimated to be about 99%.

There are two ways to extract from the AGS booster. The fast extraction which is presently implemented extracts the entire accelerated beam in single turn. A fast rising kicker and an extractor septum are required for this task. In this case the ions are extracted in three approximately 10 nano-second long bunches and separated by about a quarter of a micro-second. Another possibility is to extract the ions uniformly for the duration of the machine flat top. This extraction is called slow extraction and will be discussed below.

Figure 1 shows the plan view of the booster with the location of equipment to be installed. The booster has twelve long straight sections which are listed with the present assignments in Table I.

TABLE I

<u>SUPERPERIOD</u>	<u>LOCATION 3</u>	<u>LOCATION 6</u>
A	RF (HI)	RF (P)
B	RF (HI)	AVAILABLE
C	INJECTION (HI)	INJECTION (P)
D	DUMP KICKER ETC.	BEAM DUMP
E	DAMPER KICKER ETC.	RF (P)
F	EXTRACTION KICKER	EXTRACTION SEPTUM

As can be seen in the table, there is only one straight section available for whatever additional function the booster may perform. Because of the very stringent high vacuum requirement, it is very difficult to place a water cooled current septum or its magnetic core lamination inside the vacuum chamber. Therefore the extraction magnetic septum has to be isolated from the ring vacuum, and consequently the septum is rather thick - about 1 cm. Therefore we have to find an additional location for a thin electrostatic septum, which can be placed inside the vacuum chamber in order to have reasonably high extraction efficiency. In this note we look into the possibility that the straight section D-6, where the beam dump is located, be used for one of the extraction septa. Since the beam dump only occupies the inside aperture of the ring, the outside aperture can be used for the extraction septum.

We plan to use third integer resonance extraction, which is used at the AGS and has proven to be very efficient. For the booster we will extract at a horizontal tune of 4 and $2/3$ where the resonance is driven by the 14th harmonic of sextupoles. Since the booster ring is rather congested with equipment, it is very hard to find a location for extra drive sextupoles. Therefore we should utilize the existing lattice sextupoles in the ring. This means that the strength of the drive sextupoles is limited to the maximum field strength of the lattice sextupoles.

At the horizontal third integer resonance, the horizontal phase space grows in three different directions (or legs), which has a phase space of 120 degrees with respect to each other. The particle jumps from one leg to the next every turn, and comes back to original leg on the third turn where it is further away from the center than on the first pass. The increase in distance along the leg every third turn is called the spiral pitch.

In general one wants the phase between the thin septum and the thick septum to be 90 degrees in order to have maximum spacial displacement for a given angular kick from

the thin septum. In the case of third integer resonance, however, the ideal phase advance between septa is 60 degrees because of the other leg of growth. The phase advance between B-6 and D-6 is 560 degrees ($360+200$) on the first encounter ($1/3$ turn), 2240 ($6 \times 360 + 80$) degrees one turn later, and 3920 ($10 \times 360 + 320$) degrees after another turn. The particles have to be ejected by this turn, otherwise the leg comes back to the thin septum again. The phase advance at one and a third turn is 80 degrees which is acceptable though not ideal. We will use a one and a third turn extraction for the booster.

Figure 2 shows the pattern of phase space growth at the thin electrostatic septum with drive sextupoles at A-2 and D-2 which produce all even harmonics. A slow orbit bump will bring the center of the closed orbit one inch away from the septum where particles inside the septum will be kicked 1.5 milliradian by the electrostatic force. On the next turn the kicked beam appears on the other leg toward the inside of the vacuum chamber. The particles are extracted before the following turn so we do not see them on the third leg. Figure 3 shows the same phase space at the thick extractor septum. On the first encounter the kicked beam appears inside, but one turn later the beam appears at the septum about 1 cm away from the closest part of the circulating beam. At this point the ejector magnet would extract the kicked beam.

An extraction efficiency of about 99% is estimated from the ratio of the electrostatic septum wire thickness (1 mil.) to the size of ejected beam. The spill stability or smoothness of the slow extracted beam is mainly influenced by the main magnet power supply and estimated to be about 4% modulation for every 10^{-4} variation of the main magnet supply. A spill servo system using the slow orbit bump may alleviate the problem since the spill modulation would be about 3% for every percent change in the slow orbit bump.

AGS BOOSTER SLOW EXTRACTION

AT ELECTROSTATIC SEPTUM ($K = -.5$ at B2)

Figure 2

AGS BOOSTER SLOW EXTRACTION

AT EXTRACTOR SEPTUM (K = -.5 at B2)

Figure 3

Physical Layout, Shielding, etc.

by

H. Foelsche

PHYSICAL LAYOUT SHIELDING

The summary tables and figures which follow these introductory paragraphs illustrate various aspects of the beam switchyard, the target areas, the support laboratory building, and include a summary of beam stop and shielding considerations. These are the physical characteristics of the facility which have become the basis for the cost estimates discussed elsewhere.

It is proposed to extract and transport the beam to a new experimental area by breaking through the Booster tunnel in a northerly direction. After emerging from the Booster, the beam can be directed to any of two or three branch lines, each serving a separate experimental area.

Three target areas, denoted as A, B, and C, with expansion capability for a fourth one, have been included in the baseline proposal. The growth of the facility can be phased by first constructing the two target areas B and C, and adding the third or fourth as the need arises at a later time. Each target room encloses an area of 35 ft x 45 ft. There is about 20 ft of earth shielding over the top, sloping sideways down to ground level. Equipment access is provided through labyrinths from the laboratory support building. Each target room is provided with a moveable shield door, and a beam stop which is interred in the back wall.

The Laboratory Building, enclosing about 6000 sqft in area, provides the necessary support facilities for three experimental areas. A new branch road is provided for access to the building. There are six support laboratories, four offices, a beam control room, a mechanical service equipment area, as well as rooms for radioactive storage and miscellaneous items. Power supplies for the beam transport magnets and various other equipment are located in a separate building with about 1200 sqft of enclosed area.

Shielding is provided by an earth berm over the entire facility. There is a minimum of 20 ft of earth cover over the top of the target areas and transport lines, falling off sideways, as appropriate, with a 2:1 slope toward ground level. Toward the laboratory support building there is a minimum of 35 ft of earth side shielding, which is retained by the high side wall of the building. Toward the rear of each area there is a minimum of 40 ft of earth shielding, enclosing the beam stops.

BEAM SWITCHYARD

TARGET AREAS

LABORATORY

SHIELDING & BEAM STOPS

Figure 1

BEAM SWITCHYARD

- * EXTRACTION TO THE NORTH
- * THREE BRANCHES
Use one at a time
- * SERVING THREE SEPARATE
EXPERIMENTAL AREAS: A, B, and C
- * MOMENTUM DISPERSION-FREE
BEAM SPOTS

Figure 2

Figure 3

TUNNEL CROSS SECTION

Figure 4

TARGET AREAS

- * THREE TARGET ROOMS
 - A: left 15 degrees
 - B: left 5 degrees
 - C: right 5 degrees
- EXPANSION OPTION: right 15 degrees
- * 35 x 45 ft EACH
- * EARTH COVER 20 ft ON TOP
SLOPING 2:1 SIDEWAYS
- * RIGGING ACCESS THROUGH
WIDE CORRIDORS
- * MOVEABLE SHIELD DOORS
- * BACKSTOPS

Figure 5

LABORATORY BUILDING

- * TOTAL ENCLOSED AREA 6000 sqft
- * TWO SUPPORT ROOMS PER TARGET
- * FOUR OFFICES
- * BEAM CONTROL ROOM
- * MECHANICAL SERVICE EQUIPMENT AREA
- * RADIOACTIVE EQUIPMENT STORAGE
- * MISCELLANEOUS SERVICE ROOM
- * SEPARATE BEAM POWER SUPPLY BUILDING
1200 sqft

Figure 7

Figure 8

SHIELDING

- * BACKSTOPS
- * MOVEABLE SHIELD DOORS
- * EARTH COVER 20 ft ON TOP
SLOPING 2:1 SIDEWAYS
- * REAR SHIELDING >40 ft EARTH
- * SIDE SHIELDING 35 ft EARTH
TOWARD LABORATORY
- * RETAINING WALL AT LABORATORY BUILDING
- * SIDE ACCESS LABYRINTH

Figure 9

**Beam Optics of Extracted Beam
with Octupole System**

by

N. Tsoupas

A schematic diagram of the (RBF) beam transfer line from the booster extraction point to the three target locations (-15° , -5° , $+5^\circ$) is shown in Fig. 1. The beam optics from the extraction point to the exit of the switching magnet (Fig. 1) is designed to provide achromatic beam at the exit of the switching magnet, irrespective of the beam direction after the switching magnet (-15° , -5° , $+5^\circ$). The beam optics for each of the three target lines (Fig. 1) must provide for minimum and maximum beam diameters on target. The required lower and upper limits of the beam diameters are shown in the table of Fig. 1. The lower and upper limits of the beam diameters on the target location of each beam line can be changed by adjusting the location of the quadrupoles from the exit of the switching magnet to the target location of the corresponding beam line.

In an attempt to improve the uniformity of the beam profile at the target location of the -15° beam line we have applied third order optics using octupoles, thus creating a beam at the target with a profile having a square cross section where 100% of the beam is included.

Figure 2 shows the actual location of the quads and dipoles from the extraction point of the booster to the exit of the switching magnet. This magnet arrangement provides achromatic beam to all target locations. The problem of providing beam at the exit of the switching magnet does not have a unique solution. We will adopt the solution which is compatible with the building constraints, available magnets, (field strength aperture, etc.).

The beam parameters at the booster extraction point were calculated from the program SYNCH which was used to calculate the beam optics of the booster ring. The beam parameters constitute a six-dimensional ellipsoid in phase space. The projection of the ellipsoid in the (x, θ) and (y, ϕ) plane is shown in Fig. 3. The magnitude of the beam parameters corresponding to 2.5 standard deviations are also shown in Fig. 3.

The first order beam optics calculations were performed using the TRANSPORT computer code. The horizontal and vertical beam profiles of the beam optics which provides achromatic beam to the three target locations is shown in Fig. 4.

The beam profiles enclose 95% of the beam intensity and start from the booster extraction point and end at the exit of the switching magnet. The dispersion (R_{16}) of the beam shown in Fig. 4 goes to zero at the exit of the switching magnet in all three cases.

Figure 5 shows the horizontal and vertical beam profiles from the exit of the switching magnet to the target location of each of the beam lines (-15° , -5° , $+5^\circ$). These profiles include 95% of the beam intensity and create the minimum target spot at the target location for the particular quadrupole arrangement shown.

By changing the magnet strength of the -15° beam line quadrupoles we adjust the first order beam optics to provide large beam on the target. Figure 6 shows the corresponding beam profiles from the exit of the switching magnet to the last magnetic element. The beam expands on target to form a Gaussian beam profile of circular cross section having standard deviation of 1m (when the octupoles shown in Fig. 6 are off). With the first order beam optics adjusted properly (Fig. 6) to accept octupoles, the beam profile on the target transforms into one with square cross section, shown in Fig. 7.

The projections of the circular profile (Gaussian beam) and of the square profile on the horizontal (x-axis) and vertical (y-axis) are shown in Fig. 8.

The sides of the square profile depend on the strength of each of the octupoles. Therefore, the square profile can also be transformed into a rectangle. The maximum and minimum values of the sides of the rectangle as well as the corresponding beam uniformity within the rectangle depend on the octupole strength and are currently under study.

Schematic Diagram of the RBF Beam Line

Figure 1

Physical layout of the RBF beam transfer line from the booster extraction point to the switching magnet.
The magnetic components, quadrupoles (Q) and dipoles (D) are shown.

Design Objectives of the RBF Beam Line

- Beam achromatic at the exit of switching magnet, for all three directions (-15^0 , -5^0 , 5^0)
- The standard deviations (68% of beam intensity) of the horizontal and vertical beam profiles for both the -15^0 and 5^0 target rooms could vary from 0.5 cm to few cm.
- Adjust first order optics of the -5^0 beam line to introduce octupoles in order to improve beam uniformity on the target. The beam cross section is a square with 1m sides.

Beam parameters at the Booster extraction point used in the RBF beam line optics

All quantities correspond to 2.5 standard deviations (95% of beam intensity)

Figure 3

First Order Calculations

The beam inside the transfer line is characterized by the six dimensional beam ellipsoid which is calculated by the following matrix multiplication.

$$\sigma_{\text{out}} = R \sigma_{\text{in}} R^T$$

In the formula above, R is the first order matrix whose elements are the first order aberration coefficients of the beam line and are calculated using the TRANSPORT computer code. The beam ellipsoid is represented by the matrix, σ . The matrix multiplication is carried out by the TRANSPORT computer code.

Figure next page: Horizontal, vertical beam profiles and dispersion, of the beam line section, from the booster extraction point to the exit of the switching magnet. Top, middle, and bottom figures correspond to first order focusing of the -15^0 , -5^0 and 5^0 beam lines respectively. The beam profiles correspond to 92% of beam intensity.

Figure 4

Figure next page: Horizontal, and vertical beam profiles, of the beam line section, from the exit of the switching magnet, to the target location.

Top, middle, and bottom figures correspond to the first order focusing for small beam profiles on target of the -15° , -5° and 5° beam lines respectively. The beam profiles shown, correspond to 92% of beam intensity.

Figure 5

Horizontal, and vertical beam profiles, of the beam line section, from the exit of the switching magnet, to the exit of the last magnetic element of the -5^0 beam line. The location of the quadrupoles (Q) and octupoles (O) relative to the exit of the switching magnet is shown. These beam profiles correspond to 92% of beam intensity and form a circular beam of 1 m radius on target. The beam profile distribution is Gaussian when the octupole magnetic elements are not energized.

Figure 6

Third Order Calculations

The third order calculations are performed using the procedure bellow.

1. Select random rays from the beam ellipsoid at the entrance of the magnetic system.
2. Calculate the aberration coefficients (up to third order) of the magnetic system using the TRANSPORT or RAYTRACE computer code.
3. Calculate the beam coordinates at the exit of the magnetic system using the formula bellow.

$$X_i^{(o)} = R_{ij}X_j + T_{ijk}X_jX_k + W_{ijkl}X_jX_kX_l$$

where X_i are the beam coordinates and R_{ij} , T_{ijk} , and W_{ijkl} are the first second and third order aberration coefficients of the magnetic system respectively.

Figure 7a. Three dimensional plot of "square" profile as produced by third-order octupole focusing.

Figure 7b. A two-dimensional projection of the profile in 7a. Note the "square" shape of the profile, the steep rise at the edges of the contour, and the absence of beam outside the square.

Figure 7c. A cross cut composed of one column, taken from Figure 7a.

Horizontal and vertical beam profile distributions on target of the -5^0 beam line with the octupoles on and off.

Figure 8

**Further Discussion on Beam
Uniformity and Dosimetry**

by

P. Thieberger

Many years of research with relativistic heavy ions at the Lawrence Berkeley Laboratory's BEVALAC facility have resulted in extensive and valuable experience in the areas of dosimetry and uniform beam production. We plan to make full use of this experience and in addition may also use a BNL developed method of producing uniform beams through octupole corrections (Section XII). These plans are summarized in Figure 1.

Figure 2 shows the block diagram of the LBL dosimetry system based on segmented ionization chambers and on secondary emission detectors. We would use similar chambers and would probably adopt the recycling integrator design developed at LBL. The rest of the electronics and computer hardware would probably be replaced by more modern units.

Figure 3 shows three methods developed at LBL for the production of uniform beams. We will probably adopt the wobbler beam spreading system as an alternative to the BNL developed octupole correction system described in Section XII. It is also possible that a combination of both systems may yield even better results.

Dosimetry will follow LBL
developments and experience.

Beam uniformity will be
achieved through:

BNL developed octupole corrections
LBL developed magnetic wobblers
or a combination of both

Figure 2

T.R. Renner LBL

Figure 3

**Control System: Pulse-to-pulse
Modulation Aspects**

**by
D.S. Barton**

BOOSTER APPLICATIONS FACILITY

CONTROLS

D.S. Barton

The task of providing controls for the Booster Applications Facility and for the Tandem and AGS-Booster systems needed for its implementation is largely an extension of the Booster controls architecture to handle the new equipment. The Booster itself is being built with full capability of Pulse-to-Pulse Modulation (PPM) for up to 4 users with independent beam requirements. The basic system architecture is outlined in Fig. 1, which closely resembles that of most modern control systems. Fig. 2 lists the principal characteristics of this system which provides a user-friendly workstation interface and distributed control units which extend control and provide data reports and alarm on exceptions to normal performance.

The recent developments applied to the Booster controls are highlighted in Fig. 3. The implementation of a commercial, high bandwidth network between the control room and the distributed equipment locations provides excellent bandwidth with which to support PPM. A most important innovation which enables PPM operation has been the introduction of system for the fiber optic distribution of coded timing signals from a central timing system. Among the codes sent to the equipment are those marking a switch in "user", which can signal a local microprocessor to switch setpoint tables and prepare separate data reports. The modern workstation environment is supported by excellent software development tools which greatly enhance the productivity of application programming.

Fig. 4 is an excerpt from an internal review of plans for PPM in the Booster controls. The Booster Applications Facility can expect to take full advantage of this flexibility foreseen initially for the support of commissioning and machine studies in parallel with the physics program.

With standard program tools the operator workstation can provide a high quality graphical environment for the various control tasks. Fig. 5 shows a view of the Booster Main Magnet Power Supply control program. The operator may directly edit the reference function of magnetic field as a function of time in the cycle. The program algorithmically generates the derived current and voltage waveforms necessary to provide this function using database information on the magnet model. This program and the equipment with which it communicates have been implemented for PPM operation as indicated on the title line.

The oscilloscope photograph reproduced in Fig. 6 shows a trace of the analog reference waveform for one of the Booster corrector magnet power supplies. The coded timing system was requesting 3 cycles for one PPM user and 2 for another, where the stored waveforms for the two users have been made intentionally very different. These particular cycles have been repeated at 7.5 Hz. which corresponds to the fastest specified Linac rate for proton beams. Heavy ion beam cycles would be approximately 1.4 sec. in duration.

Finally, Fig. 7 lists the work breakdown of the tasks estimated to be necessary to design, build and install the controls for the Booster Applications Facility.

Controls Architecture

Figure 1

B.A.F. CONTROLS

- Distributed, Hierarchical System
- User interface: HP-Apollo, 32-bit Workstations
- HP-Apollo Domain 12 Mbaud Token Ring Network
- Real Time OS device controllers
- Pulse-to-Pulse Modulation (PPM)
- Modern graphical interface

D.S. Barton (12/10/90)

BOOSTER DEVELOPMENT HIGHLIGHTS

(R & D TO DATE)

COMMERCIAL LAN FOR PROCESS DATA

- **REPLACED IN-HOUSE "RELWAY" (CSMA/CD)**
- **BANDWIDTH 1 MBIT/S - 12 MBIT/S**

ENCODED TIMING DISTRIBUTION

- **REAL-TIME AND FIELD EVENTS**
- **FIBER OPTIC INTERBUILDING LINKS**

ADVANCED SOFTWARE DEVELOPMENT

- **STANDARD MENU INTERFACES**
- **TEMPLATE BUILDER FOR APPLICATIONS**
- **OBJECT-ORIENTED TOOLS, C++ CLASSES**
- **RELATIONAL DATABASE DEVELOPMENT FOR MODEL-BASED APPLICATIONS**

D.S. Barton
12/10/90

PULSE-TO-PULSE MODULATION

REQUIREMENTS AND CRITERIA

MAJOR PREMISE

AGS COMPLEX IN ALL PARTS EXCEPT SEB AND PERHAPS TANDEM WILL SUPPORT SOME MULTI-USER OPERATION. THIS WILL BE ONLY WAY TO AVOID SERIOUS CONTENTION AND DELAYS IN MEETING OUR COMMITMENTS TO THE PHYSICS PROGRAM, MACHINE STUDIES, AND NEW PROJECT COMMISSIONING.

ITEMS

- > SOME SUBSYSTEMS WILL NOT HAVE PPM, BUT CENTRAL SYSTEM PPORT WILL ALLOW FUTURE UPGRADES.

- > TIME BASIS FOR SUPERCYCLE WILL BE THE AGS REPETITION PERIOD OR A MULTIPLE THEREOF. LINAC PERIOD DETERMINED BY BOOSTER PROTON CYCLE REQUIREMENT.

- > ONE SYSTEM MASTER CLOCK FOR COMPLEX (LINE-SYNCHED).

Figure 5

PULSE-TO-PULSE MODULATION

CORRECTOR MAGNET REFERENCE WAVEFORM

Figure 6

B.A.F. CONTROLS WBS

- Timing: f/o, decoders
- Control Room: workstations, displays,
support equipment
- Network: f/o, stations, bridge
- Software Dev: computers, peripherals,
purchased software
- TDVG Ctls: magnet, vacuum,
instrumentation controls
- Extraction Ctls: magnet, stripper,
vacuum controls
- Beamline Ctls: magnet, collimator,
vacuum, instr. controls
- Interlock System: gates, interlocks,
surveillance
- System Integration: cables, racks,
misc. material

D.S. Barton (12/10/90)

Experimental Area Support
by
C.L. Snead

NOTE

by

P. Thieberger

Following discussions with the NASA Panel and further review at BNL it was concluded that a full-time staff, fully dedicated to this facility, as described in this section, would only be proposed if the total number of yearly operating hours exceeds 4000 and not for the ~2000 hours shown on viewgraph #1. Also the operation would be of 24 hours/day 7 days/week. The operating cost estimates of section XXIII are based on these assumptions.

For fewer than ~4000 hours per year we would provide equivalent services with a combination of full-time and shared positions, where some or perhaps most employees would perform other functions when the facility is not in use. Some services such as secretarial assistance could, in this case, be provided at offices located elsewhere. In the executive summary (section III) we give an example of the projected operating costs based on these assumptions for ~2000 hours/year.

EXPERIMENTAL AREA SUPPORT

The successful operation of a user facility is determined in no small measure by the level and expertise of the facility support and operations personnel. This is especially true where the facility is capable of wide flexibility in types of irradiations that are available and where there is a wide disparity in both the types of experiments to be performed and the level of experimental sophistication of the user. Herein is outlined a level of manpower support that provides the expertise to support a diverse user program at a sophisticated irradiation facility. To a large measure this scenario is based upon the several years' experience gained in the operation of the Radiation Effects Facility, a user facility very much in the mold of the anticipated Booster Applications Facility. The following is a brief enlargement on the enclosed viewgraphs.

OPERATIONS ASSUMPTIONS;

During Booster operations facility operations are possible 24 hours a day, seven days a week, excepting maintenance days. However, if one assumes that the programmatic need is for about 2000 hours of experimental time, and that the AGS/RHIC operations extend for about 26 weeks, one might envision operations at the BAF of two shifts daily 0800-2400, Monday through Friday. Of course where crunches occur or experimental runs need be extended for whatever reason, late night and weekend overtime operations are available. If more program hours are required, additional shifts can be routinely scheduled. Note that in twenty six weeks 4368 hours are possible, (less maintenance). The manpower needs, however, are projected based on the assumptions above.

The facility will provide complete dosimetry for the experimentalist. This assures that this fundamental need is always adequately covered and that dosimetry is standardized throughout the program independent of the experimenter. The enclosed manpower projection is based upon the assumption that during normal operations safety considerations dictate that only one operator is required to deliver beam to the target rooms and to perform other routine duties such as clearing the tunnel and target rooms subsequent to occupation. A final assumption is a truism that has been borne out many times: adequate user support is required to assure smooth operations and maximized results.

OPERATIONS PERSONNEL;

Herein are listed the various job slots or skills required for smooth and efficient operations. The number of full-time equivalents for each area is listed. This is the FTE need during the 26-week operations period. The balance of the year will have requirements that are somewhat less. It is not implied that there is a one-to-one correspondence between job slot and a specific person; areas of expertise will be shared by several people. This is the level of support required in total. This is also a reflection of the first-year's needs. Some of the expertise listed here may not be needed to this extent after some experience has been gained. This should be true for the areas of beam optics, diagnostics, and computer scientist.

USER SUPPORT; GENERAL;

The items listed here are ones that take place in general before and after the actual test of a user. There is a multitude of paperwork, preparation, and cleanup support for an experiment of which the experimenter himself may be only dimly aware. The operations people most involved with these stages of the experiment are the Chief Scientist, secretary, coordinator, dosimetry person, life-sciences tech, and possibly the computer specialist. This is an area of user support that is sometimes transparent to the user, but is quite vital in assuring an efficient and productive experiment.

USER SUPPORT; SPECIFIC;

There will be many aids to the user that are part of the facility. Herein is a sample of some of the major ones.

USER SUPPORT; SPECIFIC(cont'd):

Herein are listed some of the specific user aids that will be available.

BALANCE OF VIEWGRAPHS;

- View of REF beam line looking upstream from the target room.
- An experiment in place in the REF target room.
- Two viewgraphs outlining the utility of the REF User Station.
- Two viewgraphs depicting the effects of octupole focusing in producing square and uniform beam profiles.
- A typical beam profile produced by the REF dosimetry support.

OPERATIONS ASSUMPTIONS

- 5-day/week, 0800–2400, 26-week schedule: ~2000 hours
- Complete dosimetry provided
- One operator required
- Smooth operations and full User support maximizes results

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dne DEPARTMENT OF NUCLEAR ENERGY

BROOKHAVEN NATIONAL LABORATORY bnl

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viewgraph 1

OPERATIONS PERSONNEL

1 CHIEF SCIENTIST
1 SECRETARY
1 ADMINISTRATOR-COORDINATOR
1 BEAM OPTICS PHYSICIST
1 COMPUTER SCIENTIST
1 ELECTRONICS ENGINEER FOR DIAGNOSTICS
1 LIFE-SCIENCES TECHNOLOGIST
3 OPERATORS
2 DOSIMETRY PERSONNEL
1 ENGINEERING, MECHANICAL & ELECTRICAL

1/2 S&EP

13.5

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USER SUPPORT: GENERAL

- Secretarial Support
 - Prior paperwork for Guest Appointment, badging, travel, housing, scheduling required training, user accounts
- Test Plan Review
- Safety Reviews
- Shipping
- Disposal of radioactive waste
- Storage of materials
 - Regular storage
 - Radioactive storage
- Interface with shops, stores issues, etc.

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Viewgraph 3

USER SUPPORT: SPECIFIC

- Computerized Work Station
 - Dosimetry
 - Diagnostics
 - Machine Parameters
- Other User-Station Items
 - Communications
 - Video
 - Timing signals
 - Remote multiple positioning

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Viewgraph 4

USER SUPPORT: SPECIFIC (Cont'd)

- Pretest Setup Assistance
 - Dosimetry and diagnostics
 - Positioning test apparatus
 - Laser alignment
 - x-y positioners setup, as needed
 - Video coverage
 - Special hookups: 50 ohm, SHV, thermocouples, etc.
 - Collimators
 - Required timing signals
- Assist in cleanup, storage, and shipping

viewgraph 6

REF EXPERIMENTER STATION

Network Configuration:

Experimenter Station:

- Hardware:
- VAX Station 2000
 - 19" monochrome monitor
 - 4 Mb physical memory
 - 150 Mb available user disk space
 - TK-50 tape cartridge system
 - Mouse

- Software:
- VMS Operating System
 - VWS Window System
 - FORTRAN-77 Compiler
 - DECnet/Ethernet Communications
 - KERMIT Communications/File Transfer
 - Terminal Emulation of VT100, VT200, TEK4014
 - DISSPLA Graphics Library
 - BEAMPLOT software (BNL developed)

REF EXPERIMENTER STATION (Cont'd)

- Harp profiles, singly or overlaid
- Integrated current transformer bar plots
- Tabular Summary of protons/pulse and total protons/run
- 3D/contour plots of PIN diode arrays
- 3D/contour plots of thermocouple arrays
- Pulse by pulse raw data of all harp profiles, integrated CT, date, and time available as ASCII file which can be transported to users own facility via TK50, IBM-PC floppy, Apple Mac floppy, 9 track magnetic tape.
- Communication with IBM-PC
- Communication with Apple MacIntosh

Note: • Outside users are encouraged to bring any analysis programs they wish. Both VAX and IBM-PC environments are supported. The user's data is available on-line during the experimental run.

● AL ACTIVATION ● BEAM PROFILE ●

Camera: 100 -25 100

beam profile
2/12/88

Viewgraph 11

**Facilities for In-vivo and In-vitro
Radiation Biology**

by

F.A. Dilmanian

FACILITIES FOR IN-VIVO AND IN-VITRO
RADIATION BIOLOGY

F. Avraham Dilmanian
Medical Department

Slide 1

The design of the facility was influenced by the unique properties of HZE particles. The properties include:

a) the large variation of the ionization density with distance from the track of particles. The microdosimetric results for 600 MeV/amu ^{56}Fe ions passing through tissue-equivalent material shows a drop of the ionization density by 3 orders of magnitude at the distance 4 microns from the particle track.

Slide 2

b) Another unique property of the HZE particle is their sharp and enhanced Bragg peaks. This slide shows, among others, a 2 cm-spread depth-dose curve for 456 MeV/amu Ne ions passing through the water.

Slide 3

c) Still another important feature of the HZE particles is their fragmentation upon nuclear interaction with the target. The reaction produces a large multiplicity of nuclear fragments and other particles.

Slide 4

This slide shows one option for the design of the facility, which is comprised of three target rooms. In this option, target room A is dedicated to cell-culture studies; target room B, which has a very wide beam, for large-animal studies and for studies of large detectors; and target room C for small-animal studies. Each target room is connected through a mazed corridor to the Supply Facility, which includes preparation rooms and storage rooms. The corridors are wide enough to allow rigging equipment, such as fork-lifts, to enter the target rooms. Both the target rooms and the Support Facility will be air conditioned and humidity-controlled.

Slide 5

This slide shows the details of the Support Facility. In this facility two rooms are allocated to each target room. These rooms are labelled the "Ready Room" and the "Support Room". For example, for the target room C which is the small-animal room in this option, the Ready Room is used to prepare the subject for irradiation, while the Support Room is used as a storage room for small animals. The cell-culture Ready Room and the Support Room will be clean rooms, and will be over-pressurized. They will be also equipped with HEPA (High Efficacy Particulate Filter) air filtration.

Slide 6

The range of available beam widths is 0.5-10 cm for the cell-culture room, 5-100 cm for the wide-beam room, and 1-20 cm for the small-animal room. The basis for this design is that a dynamic range of 20:1 in the beam width can be reached with the beam optics equipment allocated for each beam line. The 1-cm minimum beam width for the small-animal room will allow unilateral irradiation of mouse and rat brains. The beam profiles will be square, flattened in both x and y directions using octupole magnets. It is estimated that the degree of beam profile non-uniformity left after the flattening is $\pm 10\%$. The profiles can be further smoothed to $\pm 5\%$ non-uniformity using beam wiggling motion at small amplitudes in both x and y directions.

In this option, Room C will be also used for shielding studies and detector calibration.

The future options for Room C which are not incorporated in the facility design at this time are microdosimetry, microbeam radiobiology which requires pencil beams or fan beams of 25 μm width, and particle spectrometry.

Slide 7

A major effort in design of the facility will be spent on features that allow production of clean beams on targets, free from unwanted components such as fragmentation products. For this purpose, beam parameters will be handled at the ion source, at the AGS Booster, or in the transfer lines with the help of the beam optics. These beam parameters are:

- Beam energy tuning
- Beam profile flattening
- Beam intensity adjustment, and
- Beam width adjustment

Maximum efforts will be spent to avoid use of beam absorbers and beam collimators upstream of the targets and downstream of the last dipole magnet. Also, efforts will be made to avoid irradiation of the subjects outside the specimen area, such as irradiation of the target holder, or irradiation of unintended parts of the target.

Slide 8

Another major effort will be spent to avoid scattered radiation from different sources to reach the target. The design features to alleviate this concern include: a) having only one target in a room (except for the cell-culture room in which several thin targets can be positioned in one rotating plate); b) to stop the beam at the machine at the switchboard, and not by beam stoppers positioned past the last dipole magnet; and c) to use beam dumps which are designed to avoid backscatter of particles to the room.

Slide 9

Computerized target positioning with options of high precision, laser-aided specimen positioning is included in the design. The design also includes use of videomonitors, including videomicroscopes, for real time

target visualization. Another feature included is videotaping of motions of the animal subjects, which can be used for off-line data correction and data analysis.

Slide 10

Dosimetry of the HZE particles is inherently difficult. The equipment presently put in the design for this purpose are segmented ionization chambers equipped with tissue-equivalent walls and/or a tissue-equivalent gas, and secondary-emission chambers.

Slide 11

Particle spectrometry has not been included in the design, but would be necessary to carry out comprehensive beam fragmentation studies. In the present options, Target Room C would be the choice for accommodating a small-size spectrometer. However, larger spectrometers such as HISS would require a dedicated room.

Slide 12

Much emphasis will be placed on efficient and convenient control of the experiment by the experimentalists themselves during the activation. For this purpose, besides the control room in the Support Facility that guides the beam at the switchboard and along the transport lines to individual target rooms, control consoles will be available in the Ready Rooms for the experimentalists to manipulate targets during experiments.

Slide 13

To have a source of low-LET radiation available at the Support Facility for concurrent specimen irradiation has been recommended. However, such an option has not been included in the design of the facility.

Slides 14-19

These slides list the major equipment that was included in the facility cost for the Ready Rooms and the Support Rooms in the present option.

MICRODOSIMETRY NEAR THE TRAJECTORY OF HIGH-ENERGY HEAVY IONS

N.F. Metting, H.H. Rossi, L.A. Braby, P.J. Kliauga, J. Howard,
M. Zaider, W. Schimmerling, M. Wong, and M. Rapkin

Radiation Research 116, 183-195, 1988

MICRODOSIMETRY OF HZE TRACKS

Comparison of the experimentally determined $(\bar{x}_b)_F$ and $\bar{x}_b$ with radial dose calculations based on two homogeneous track structure models.

600 MeV/amu ^{56}Fe ions

COMPARISON OF DIFFERENT RADIATION TYPES AND IRRADIATION GEOMETRIES IN STEREOTACTIC RADIOSURGERY

M.H. Phillips, K.A. Frankel, J.T. Lyman, J.I. Fabrikant, and R.P. Levy

In. J. Radiation Oncology Biol. Phys. Vol. 18, pp. 211-220, 1990

Depth dose curves for different radiation types. The depth dose curves for the following charged particle species are shown: protons (150 MeV, 2 cm spread Bragg peak), helium ions (150 MeV/amu, 2 cm spread Bragg peak), carbon ions (285 MeV/amu, 2 cm spread Bragg peak), and neon ions (456 MeV/amu, 2 cm spread Bragg peak). These are isoeffect curves-the physical dose has been modified by an LET-dependent RBE. Also shown is the depth dose curve for a 10×10 cm field of 8 MV linear accelerator-produced photons. All curves have been normalized to 1 at their peak dose. The curves are for absorption in water.

HZE PARTICLE FRAGMENTATION

1.2 GeV/AMU $^{56}\text{Fe} + ^{16}\text{O}$

- HEAVY FRAGMENTS
- PROTONS
- NEUTRONS
- PIONS
- GAMMA RAYS

Slide 5

T/
R/

ROOM	BEAM WIDTH*	APPLICATIONS	OPTIONS FOR FUTURE APPLICATIONS (NOT INCLUDED IN THE FACILITY COST ESTIMATE)
A	0.5-10 CM	- CELL CULTURE	
B	5-100 CM	- LARGE ANIMALS - DETECTOR TESTING	
C	1-20 CM	- SMALL ANIMALS - SHIELDING STUDIES - DETECTOR CALIBRATION	- MICRODOSIMETRY - MICROBEAM RADIOBIOLOGY - PARTICLE SPECTROMETRY

*BEAM PROFILES ARE FLATTENED BY OCTUPOLE MAGNETS.

BEAMLINE FEATURES PLANNED FOR PROVIDING CLEAN BEAMS TO TARGETS

OPERATION	METHODS
BEAM ENERGY TUNING	<ul style="list-style-type: none"> - DONE AT THE MACHINE - NO NEED FOR ABSORBERS
BEAM PROFILE FLATTENING	<ul style="list-style-type: none"> - DONE WITH OCTUPOLE MAGNETS - POSSIBLY NO MECHANICAL BEAM TRIMMER PAST THE LAST DIPOLE
BEAM INTENSITY ADJUSTMENT	<ul style="list-style-type: none"> - DONE AT THE ION SOURCE, OR BY CHARGE-STATE SELECTION AT THE TRANSPORT LINE - MINIMUM MATERIAL PAST THE LAST DIPOLE
BEAM DIAMETER ADJUSTMENT	<ul style="list-style-type: none"> - DONE BY BEAMLINE OPTICS TO CONFINE BEAM TO THE SPECIMEN ONLY - POSSIBLY NO BEAM COLLIMATOR PAST THE LAST DIPOLE

TARGET-ROOM FEATURES PLANNED TO AVOID STRAY RADIATION FROM REACHING THE TARGET

- ONLY ONE TARGET AREA IN A ROOM**
- BENDING MAGNETS AT SWITCHYARD WILL
BE TURNED OFF TO STOP BEAM**
- MECHANICAL BEAM SHUTTER ONLY AS A
SAFETY DEVICE**
- BEAM DUMP DESIGN TO MINIMIZE
BACKSCATTER CONTAMINATION**

TARGET POSITIONING

- **COMPUTERIZED X-Y TRANSLATION**
- **LASER-AIDED POSITIONING**
- **VIDEO MONITORING, INCLUDING
VIDEOMICROSCOPY**
- **VIDEO TAPING OF THE ANIMALS DURING
IRRADIATION - OPTIONAL**

DOSIMETRY

- **TISSUE EQUIVALENT SEGMENTED IONIZATION CHAMBERS**
- **SECONDARY EMISSION CHAMBERS**

PARTICLE SPECTROMETRY

- TO CARRY OUT HEAVY ION FRAGMENTATION STUDIES, A PARTICLE SPECTROMETER WOULD BE NECESSARY.**
- THE SPECIFICATIONS HAVE NOT BEEN STUDIED.**
- IF SUCH A SPECTROMETER IS TO BE ACCOMMODATED IN ONE OF THE THREE ROOMS, ROOM C WOULD BE THE MOST SUITABLE. ROOM C MAY HAVE TO BE ENLARGED.**
- THE CURRENT DESIGN DOES NOT INCLUDE A SPECTROMETER OPTION.**

BEAM CONTROLS

- **THE AGS/BOOSTER CONTROL ROOM WILL HANDLE THE BEAM IN THE BOOSTER, AND ALSO EXTRACTION OF THE BEAM FROM THE BOOSTER.**
- **A SECOND CONTROL ROOM IN THE SUPPORT FACILITY WILL CONTROL BEAMS AT THE SWITCHYARD AND TOWARDS THE TARGET ROOMS.**
- **CONTROL CONSOLES WILL BE AVAILABLE IN THE READY ROOMS TO MANIPULATE TARGETS DURING EXPERIMENTS.**

CONCURRENT LOW-LET IRRADIATION

- A ¹³⁷Cs SOURCE IS BEING CONSIDERED
- HAS NOT BEEN INCLUDED IN THE FACILITY DESIGN
- MAY BE POSITIONED IN A NEARBY ROOM WITHIN THE SUPPORT FACILITY

TARGET ROOM A - CELL CULTURE

FEATURES AND EQUIPMENT

- CLEAN ROOM**
- TARGET WHEEL - OPTIONAL**
- TARGET POSITIONER (X,Y) - OPTIONAL**
- EXTRACTOR TUBE - OPTIONAL**
- VIDEO SYSTEM**

READY ROOM AND SUPPORT A CELL CULTURE EQUIPMENT

- SINK/COUNTER**
- LAMINAR FLOW HOOD**
- REFRIGERATOR**
- DUAL CHAMBER INCUBATOR**
- MICROSCOPES**
- CELL COUNTER**
- MAGNETIC STIRRER**
- GAS MANIFOLD**
- FREEZER (-20°)**
- CENTRIFUGE**
- PH METER**
- HOMOGENIZER**
- SPECTROPHOTOMETER**
- MYLAR-BOTTOM DISH PREPARATION**

TARGET ROOM B

LARGE ANIMALS/LARGE DETECTORS

EQUIPMENT

- SPECIAL ANIMAL POSITIONING APPARATUS
- TARGET POSITIONER (X,Y)
- LASER POSITIONING - VIDEO SYSTEM
- ANESTHESIA EQUIPMENT

READY ROOM AND SUPPORT ROOM B

LARGE ANIMALS/LARGE DETECTORS

EQUIPMENT

- SINK/COUNTER**
- HOOD**
- REFRIGERATOR**
- EQUILIBRATION AREA**
- GAS MANIFOLD**
- DOG CAGES**
- CAT CAGES**
- PRIMATE CAGES**
- CAGES RACKS**

TARGET ROOM C

SMALL ANIMALS/SHIELDING AND CALIBRATION

EQUIPMENT

- TARGET POSITIONER (X,Y)
- LASER POSITIONING
- VIDEO SYSTEM
- SPECIAL ANIMAL HOLDERS

READY ROOM AND SUPPORT ROOM C

SMALL ANIMALS/SHIELDING AND CALIBRATION

EQUIPMENT

- SINK/COUNTER
- REFRIGERATOR
- HOOD
- HOOD
- RAT CAGES
- MICE CAGES
- CAGE RACKS

**Animal Care Facilities at the
Medical Department**

by

D.D. Joel

The Laboratory Animal Facility at Brookhaven is located on the ground floor of the Medical Department immediately adjacent to a block of well-equipped laboratories (see Illustration 1). All warm-blooded vertebrates are housed in this core facility. Animals may be transported to other on-site facilities such as the National Synchrotron Light Source but they are not allowed to be maintained at these facilities for more than 24 hours.

Brookhaven's Animal Care and Use Program has been fully accredited by the American Association for Accreditation of Laboratory Animal Care since 1966. The Program is also in compliance with Federal and State Statutes and has an Animal Welfare Assurance on file with the National Institutes of Health's Office for Protection from Research Risks (Illustration 2). The institutional procedures currently in effect are in accord with the policies and regulations of each of these agencies including the establishment of an Institutional Animal Care and Use Committee (IACUC) to semiannually review the Program as well as all research protocols involving the use of animals at Brookhaven.

The lines of authority for administering the Institutional Animal Care and Use Program at BNL are shown in Illustration 3. The Associate Director for Life Sciences is the chief administrative official with overall responsibility for the animal care program including the appointing of members to the IACUC. The Associate Director reports directly to the Laboratory Director. Implementation of the animal care program is the responsibility of the Staff Veterinarian, who is a full-time staff member in the Medical Department.

Research protocols initiated by Principal Investigators are transmitted to the IACUC for review via their respective Department Chairmen. Off-site investigators (facility users) submit protocols directly to the Associate Director for Life Sciences. These protocols are also reviewed by the

Brookhaven IACUC even though they may have already been reviewed and approved by the investigator's 'home' institutional IACUC.

The total net function space of the core facility is approximately 14,000 square feet. A total of 34 rooms are devoted to animal housing of which 28 rooms are on a clean/dirty corridor system (Illustration 4). The facility can house 25-30,000 adult mice or 5-6000 adult rats (up to 500 grams). Pen/run units provide housing for at least 75 dogs and, although only 7 primates are presently being maintained, with some minor modifications additional primate space could be made available. Currently the core facility is about 40% occupied.

Located within the core facility are several support areas devoted to the animal care program (see Illustration 5).

Of particular interest to the anticipated animal studies with heavy ion beams are facilities for long-term (life-long) housing of rodents. Rooms 9-272, 9-280, 9-282, and 9-284 (see Illustration 5) are self-contained units each with a shower-entry for personnel and a double-doored transit port. Each of these units will house about 2000 mice. Rooms 11-147 A-C also comprise an isolation suite equipped with shower-in entry and a pass-through autoclave. This unit is capable of housing about 4000 mice. Room 9-274 is a complete barrier facility with a high-vacuum pass-through autoclave. A laminar flow room with a capacity for housing up to 500 mice is available for maintaining highly susceptible animals such as 'nude' mice.

The animal care facilities at the Booster Biomedical Facility will be operationally a part of the existing accredited Brookhaven Animal Care and Use Program (see Illustration 6). The required institutional policies and programs of animal and veterinary care are already in place. To have the animal facilities at the Booster function independently would not only be costly but

fraught with regulatory problems. The holding units will be designed and constructed according to specifications that will permit animal housing at the Booster Facility for extended period of time, i.e., duration of exposure.

Off-site users may bring animals to the Laboratory for radiation exposures, however, a two-week period of quarantine will be required prior to transit to the Booster. However, if no other animal studies are in progress, outside animals may be brought directly to the Booster.

Long-term, post-exposure housing will be in the Central Animal Facility in the Medical Department or, in case of off-site users, at other institutions.

bwa

Illustration 1

REGULATORY AGENCIES

A. American Association for Accreditation of Laboratory Animal Care (AAALAC).

- Comprehensive on-site review of the entire animal care and use program, once every three years.
- BNL has been fully accredited since 1966.

B. United States Department of Agriculture (USDA).

- Unannounced site inspections by veterinary medical officers.
- Review compliance with the Animal Welfare Act.

C. Public Health Service; Office for Protection from Research Risks (OPRR).

- Conduct site visits in cases of apparent violation of PHS Policy
- Unannounced random inspections of Awardee Institutions.
- Written reports required annually.
- Brookhaven has an Animal Welfare Assurance on file with OPRR.

D. New York State Department of Health.

- Certificate of Approval for the use of animals in research.
- Annual inspections by a veterinary medical officer.

BROOKHAVEN NATIONAL LABORATORY

ORGANIZATION FOR THE INSTITUTIONAL ANIMAL CARE AND USE PROGRAM

Illustration 3

ANIMAL FACILITIES

A. Space for Housing Animals.

- Total functional space of ~ 14,000 sq. ft.
- 34 Rooms; 28 on clean/dirty corridor
- Capacity ~ 25-30,000 adult mice
 - or ~ 5-6,000 adult rats or guinea pigs
 - ~ 75 dogs
 - ~ ? primates

B. Support Areas.

- Receiving
- Quarantine/Isolation
- Surgery
- Necropsy
- Radiography
- Machine cage and rack washing
- Autoclaves (high vacuum)
- Incineration
- Clinical Pathology Laboratories

C. Special Facilities.

- Barrier room
- Isolation (semi-barrier) suites
- Laminar flow room

BROOKHAVEN NATIONAL LABORATORY
AAALAC File No. 000048

BLOCK 11 VETERINARY SERVICES

REACT

1 inch = 25 feet

Illustration 5

GENERAL OPERATIONAL PLAN FOR ANIMAL STUDIES
AT THE BOOSTER FACILITY

- A. The animal facilities at the Booster will be a part of the accredited BNL Program Unit.
- Institutional policies
 - Animal care
 - Veterinary care
- B. Animal Housing at the Booster Facility.
- Duration of exposure period
 - Care by truck transport from the core facility (racks, cages, food, etc.)
 - Off-site users
- C. Long-Term, Post-Exposure Housing.
- Central animal facility, Medical Department
 - Other institutions

**The BNL Medical Department and
Heavy Ion Radiobiology**

by

A.D. Chanana

Radiation biology research has a distinguished record of accomplishments both in Biology and Medical Departments at Brookhaven National Laboratory. Even though the current research emphasis in Biology and Medical Departments is in molecular and structural biology and medical applications of nuclear technology and health effects of energy-related agents in Biology and Medical Departments respectively, the efforts in radiation biology research are significant in both these departments (Figure 1).

The mission of the Medical Department as described in the U.S. Department of Energy approved Institutional Plan for Brookhaven National Laboratory is shown in Figure 2 and the Brookhaven facilities and resources utilized to accomplish this mission are shown in Figure 3.

The major DOE and NIH supported research programs in the Medical Department are shown in Figure 4. It is quite obvious that radiation biology, both basic and applied, constitutes a significant part of our current research effort.

We have no doubt that our current research efforts and the proposed NASA supported research at the Heavy Ion Beam Facility would be very compatible. The management and the scientific staff of the Medical Department therefore have no hesitation to state that the Medical Department would be willing to host a NASA supported core research program designed to elucidate the health effects of heavy ions. It is understood, however, that additional scientific staff will have to be recruited to supplement the current capabilities. We are developing radiation biology training programs for the radiation oncology residents and fellows who will be assigned at the BNL-SUNY Radiation Therapy Facility at the Medical Department. In addition to this new BNL-University interaction, the staff of the Medical Department has had a long standing collaborative effort in radiation biology with the staff of the RARAF facility of the Columbia University (Figure 5).

BIOLOGY DEPARTMENT

MEDICAL DEPARTMENT

CONTINUING MISSION

RADIATION BIOLOGY

CURRENT EMPHASIS

BIOLOGY DEPARTMENT

MOLECULAR BIOLOGY

STRUCTURAL BIOLOGY

MEDICAL DEPARTMENT

MEDICAL APPLICATIONS OF NUCLEAR TECHNOLOGY

HEALTH EFFECTS OF ENERGY-RELATED AGENTS

(INCLUDING IONIZING RADIATION)

BNL-AUI

Figure 1

MEDICAL DEPARTMENT

MISSION

- 1. DEVELOP MEDICALLY USEFUL RADIONUCLIDES AND RADIOPHARMACEUTICALS.**
- 2. DEVELOP NEW NUCLEAR MEDICINE AND RADIATION THERAPY PROCEDURES.**
- 3. STUDY THE BIOLOGICAL EFFECTS OF EXPOSURE TO IONIZING RADIATION AND OTHER ENERGY-RELATED AGENTS.**

BNL-AUI

BNL FACILITIES AND RESOURCES FOR BIOMEDICAL RESEARCH

- 1. BROOKHAVEN MEDICAL RESEARCH REACTOR**
- 2. HIGH FLUX BEAM REACTOR**
- 3. 200 MeV PROTON ACCELERATOR (DEDICATED BEAMLINE
FOR ISOTOPE PRODUCTION)**
- 4. NATIONAL SYNCHROTRON LIGHT SOURCE (BEAMLINE FOR
MEDICAL RESEARCH)**
- 5. CYCLOTRONS AND PET SCANNERS (CHEMISTRY
DEPARTMENT)**
- 6. IN VIVO WHOLE BODY AND PARTIAL BODY NEUTRON
ACTIVATION AND ANALYSIS FACILITIES**
- 7. INHALATION EXPOSURE FACILITY**
- 8. ACCREDITED CLINICAL RESEARCH CENTER**
- 9. ACCREDITED LABORATORY ANIMAL FACILITY**

BNL-AUI

Figure 3

MAJOR PROGRAMS: MEDICAL DEPARTMENT

1. NUCLEAR MEDICINE RESEARCH

SPECT (Single Photon Emission Computed Tomography) Brain, Heart, lungs

PET (Positron Emission Tomography: Chem. Dept.): Brain

2. RADIONUCLIDE/RADIOPHARMACEUTICAL RESEARCH

Radiolabeled Monoclonal Antibodies

3. MEDICAL APPLICATIONS OF SYNCHROTRON RADIATION

Coronary Angiography, Multiple Energy Computed Tomography for Neuroradiology, Microbeam Radiation Therapy, Photon Activation Therapy

4. MEDICAL APPLICATIONS OF THERMAL AND FAST NEUTRONS

In Vivo Body Composition Studies (K, Ca, N, C)

5. MEDICAL APPLICATION OF THERMAL AND EPITHERMAL NEUTRONS

Boron Neutron Capture Therapy of Brain and Eye Tumors

6. RADIATION BIOLOGY: Low and High LET Radiation

Carcinogenesis, Leukemogenesis, Genomic Damage

7. HUMAN HEALTH EFFECTS OF FALL-OUT RADIATION

Marshall Islands Medical Program

8. RADIATION ONCOLOGY

BNL-State University of New York at Stony Brook Joint Radiation Therapy Facility at the Medical Department

BNL-AUI

Figure 4

RADIATION HEALTH RESEARCH HEAVY ION BEAM FACILITY

- 1. CURRENT RESEARCH IN MEDICAL DEPARTMENT AND
NASA MISSION.**
- 2. NASA SUPPORTED CORE PROGRAM IN MEDICAL
DEPARTMENT
(ADDITIONAL STAFF RECRUITMENT).**
- 3. UNIVERSITY INTERACTIONS
BNL-SUNY RADIATION THERAPY FACILITY AT
THE MEDICAL DEPARTMENT
RADIATION BIOLOGY TRAINING (RESIDENTS
AND FELLOWS)**

COLUMBIA-RARAF

BNL-AUI

Figure 5

Heavy Ion Radiation Biology Research Goals
by
V.P. Bond

BNL PARTICIPATING INVESTIGATORS

M. BENDER

V. BOND

J. CODERRE

E. CRONKITE

D. JOEL

A. DILMANIAN

L. SCHAIRER

D. SLATKIN

12/21/90

Notes on View Graphs

V. P. Bond

The first graph is self explanatory; the second and third refer to earlier experiences with biological systems in space. The experiments involving Tradescantia plant cells and with human lymphocytes in vitro were designed to test for possible synergism between microgravity and relatively high doses of radiation delivered by the isotopic sources indicated. Two individuals involved in these experiments (M. Bender and L. Schairer) are still at the Laboratory. The frequency of aberrations in the blood of astronauts was within normal limits.

The exquisite "sensitivity" of the cells of the stamen hairs of Tradescantia to a mutational event is shown in graph 4. Graph 5 refers to early deuteron microbeam work done by Dr. Curtis in the Biology Department, showing that neurons, although extremely resistant to beams of cellular dimensions, are killed indirectly at much lower doses by wider beams that destroy supportive vascular and other cells.

In graph 6 are summarized large-scale studies on the leukemic and other responses of cells exposed to radiations spanning a wide range of LET's, combined with precision microdosimetry. Although quite accurate RBE values will derive from this work, the chief purpose is to obtain a cell response function required for an "inverse target theory" approach to evaluating the risk of exposure to "low-level" radiation, in mixed fields.

In graph 7, upper equation, is shown the meaning of the currently used absorbed dose D, in cellular terms. D at the cell level is a compound and therefore confounding quantity, the product of the "quantity factor" (N_H) and

the "quality factor" ($\bar{z}$), which vary independently. The lower "cross section" equation is that of the classical target theory approach to evaluating risk, which will yield a geometrically correct σ only in the rare case in which the number of responding cells (N_q) is equal to N_H . Thus, only an "action" cross section or probability is obtainable. Also, the approach is useable only if the field is quite well characterized in terms of the Φ for each ion species and energy, and only if a large number of values of σ are known.

The inverse target approach uses microdosimetry, but not in the usual way. A microdosimetric proportional counter is used to simulate the genome-containing target gross sensitive volume, the cell nucleus. When placed in a low-level field, the instrument yields not only the quantity factor N_H (the number of hits on an exposed cell), but the quality factor in the form of a series of normalized distributions of z (graph 8) which overlap but show increasing z with LET. One can then ignore which radiation type is responsible for any given z and develop a cell-response function, shown in graph 8 as an HSEF (hit size effectiveness function). Folding of this curve with the distributions, even in a markedly mixed field, yields a smaller distribution. The area under this distribution yields the number of hit cells that respond quantally. When the number of hits are scaled up from that on the single phantom cell to that for the number of real cells actually exposed, one obtains what is the radiobiological goal as far as risk is concerned, N_q/N_E (i.e., the true product of the effect of quantity and quality, not obtainable from either D or Φ). This approach in principle could replace the present absorbed dose-RBE-Q-dose equivalent method. Its application does not require a characterization of the physics of the exposure field.

Present work on this system is done with "monoenergetic" fast neutrons of different energies, as well as with low-LET radiation. Although in principle the method can be extended to include HZE particles (graph 9),

additional biological and microdosimetric investigative work would have to be done. Dr. L. Braby of Battelle Northwest is quite interested in the approach, and in carrying out the necessary microdosimetric investigations.

Graph 10 lists a number of proposed studies, mainly on damage to neurons, that are largely self explanatory. The $^{13}\text{C}/^{12}\text{C}$ method involves using food with different isotopic ratios for the very young versus older animals. The fan or microbeam work would resemble that done earlier by Curtis, but with beams of HZE particles. The last item refers to methods of evaluating, in each individual cell, the amount of DNA or histone damage resulting from the passage of one or more HZE particles. The continuation of graph 10 on graph 11 indicates first a possible method of evaluating, by means of vital drugs, the number of damaged cells in an in vitro system. The last item refers to an extremely sensitive technique for detecting functional changes in animals after head irradiation with HZE particles.

NASA - RELEVANT BIOMEDICAL RESEARCH

**V.P. BOND
MEDICAL DEPARTMENT
BROOKHAVEN NATIONAL LABORATORY**

**SUBJECTS COVERED IN THIS
DOCUMENT ARE:**

- **EARLIER BNL EXPERIENCE**
- **CURRENT NASA - RELEVANT
RESEARCH AT BNL**
- **ADAPTATION OF THE ONGOING
PROGRAMS TO NASA NEEDS**
- **PROPOSED NEW NASA-ORIENTED
STUDIES**

BNL - AUI

EARLIER BNL EXPERIENCE

A. BIOLOGICAL SYSTEMS IN SPACE

A-1. BIOSATELITE III, 1967.

- TRADESCANTIA CELL MUTATIONS.
- RADIATION-MICROGRAVITY SYNERGISM?
- ⁸⁵Sr SOURCE ALOFT.

**A-2. GEMINI 3, 1965; GEMINI 11,
1966**

O IN VITRO

- HUMAN LYMPHOCYTES,
CHROMOSOME ABERRATIONS**
- RADIATION-
MICROGRAVITY
SYNERGISM?**
- ³²P SOURCE ALOFT**

O IN VIVO

- BLOOD FROM ENTIRE
CREW, GEMINI 2
THROUGH MOST OF
APOLLO**
- CHROMOSOME
ABERRATIONS,
LYMPHOCYTES**

Graph 4

B. SPACE-RELATED STUDIES

SIMULATION OF HZE PARTICLE TRACKS IN RODENT BRAIN, USING DEUTERON MICROBEAMS

CURRENT NASA-RELEVANT RESEARCH AT BNL

- DETERMINATION OF LET-DEPENDENCE OF CELLULAR RESPONSES, INCLUDING TRADESCANTIA MUTATIONS, CHROMOSOME ABERRATIONS AND MICRONUCLEI, USING FAST NEUTRONS
- DETERMINATION OF LET-DEPENDENCE OF MOUSE LEUKEMOGENESIS, USING FAST "MONOENERGETIC" NEUTRONS
- PRECISION MICRODOSIMETRIC MEASUREMENTS AS AN INTEGRAL PART OF THE ABOVE STUDIES.
- USE OF RESULTS OF THE ABOVE STUDIES TO TEST AN INVERSE TARGET THEORY APPROACH TO COMPLEMENT DOSE, Q AND DOSE EQUIVALENT.

$$D = \bar{Z} \frac{N_H}{N_E}$$

D = TISSUE DOSE

$\bar{Z}$ = MEAN "CELL DOSE"

N_H = NO. OF HIT AND INJURED CELLS

N_E = NO. OF EXPOSED CELLS

$$\frac{N_H}{N_E} = \Phi \sigma$$

Φ = FLUENCE

σ = CROSS SECTION

Graph 8

ADAPTATION OF ONGOING PROGRAMS TO NASA NEEDS

- **EXTEND ABOVE-LISTED STUDIES TO INCLUDE HZE PARTICLES.**
- **EXTEND MICRODOSIMETRIC STUDIES TO INCLUDE THE HZE RANGE.**
- **EXTEND THE INVERSE TARGET THEORY APPROACH TO PERMIT ACCURATE ASSESSMENT OF RISK FROM HZE PARTICLE EXPOSURE.**
- **EXTEND TRADESCANTIA STUDIES FOR USE IN SPACE WITH MICRODOSIMETERS CURRENTLY BEING FLOWN**

PROPOSED NEW NASA- ORIENTED STUDIES

- 0 IMPAIRMENT OF CNS CELL FUNCTION BY GALACTIC PARTICLES, USING RECENTLY-DEVELOPED CULTURES OF HUMAN NEURONS.
- 0 DNA $^{13}\text{C}/^{12}\text{C}$ RATIO STUDIES TO ESTIMATE THE RATE OF DNA TURNOVER IN HZE-IRRADIATED CEREBELLAR GRANULAR NEURONS.
- 0 IRRADIATION OF CNS TISSUE WITH NARROW FAN BEAMS OF HZE PARTICLES, TO DISTINGUISH DIRECT CNS PARENCHYMAL DAMAGE FROM DAMAGE SECONDARY TO VASCULAR IMPAIRMENT.
- 0 USE OF THE DNA-UNWINDING FLUORESCENCE TECHNIQUE AND SOPHISTICATED SINGLE-CELL MICROELECTROPHORESIS TECHNIQUES, TO EVALUATE QUANTITATIVELY CNS CELL DAMAGE FROM HZE PARTICLES.

- **DIRECT IN VIVO VISUALIZATION OF CELLS IN THE RABBIT CORNEA (ENDOTHELUM AND EPITHELIUM), TO QUANTIFY DAMAGE TO INDIVIDUAL CELLS CAUSED BY HZE PARTICLES.**
- **ASSESSMENT OF INTEGRATED NEUROLOGIC FUNCTION IN IRRADIATED ANIMALS USING A VIDEO ACTIVITY MONITOR AND COMPUTER ANALYZER.**

BNL PARTICIPATING INVESTIGATORS

M. BENDER

V. BOND

J. CODERRE

E. CRONKITE

D. JOEL

A. DILMANIAN

L. SCHAIRER

D. SLATKIN

Shielding-related Research
by
C.L. Snead

**BNL RESEARCH PROGRAM IN SPACE
RADIATION EFFECTS;
SHIELDING-RELATED RESEARCH**

C. L. Snead

Introduction:

The primary mission of BNL is the construction and operation of large, sophisticated facilities for scientific research. These facilities are available to a wide community of users including academia, other government labs and agencies, and industry. It is, therefore, appropriate that unique facilities for the investigation of space radiation effects be constructed at BNL. Likewise, there has always been a strong programmatic interest among several departments in radiation effects as a consequence of in-house use of these facilities. The interest of the Medical and Biology Departments in developing radiobiological research programs using the proposed Booster Applications Facility is outlined elsewhere in this report. In mounting an ambitious manned exploration of space an expanded program in space radiation effects is required. Along with radiobiology other significant radiation issues are identified. Many of these directly couple to radiobiological issues while most others are complementary to "Life Sciences" concerns. Herein I outline some of these research areas where BNL expertise could contribute to a comprehensive space radiation effects program.

Viewgraphs:

SPACE RADIATION EFFECTS PROGRAM

The bullets list a chronological order of some of the key elements of folding radiation effects research into mission planning. "Characterizing the radiation environment" is the umbrella under which most of the experimental and theoretical work proposed to be achieved through in-house efforts is covered. This effort mainly involves establishment of an evaluated high-energy charged-particle data base, using the Radiation Effects Facility and the Booster Applications Facility to provide experimental cross-sections to that data base, and establish transport-code capability to employ the data base for shielding-type calculations.

SHIELDING CONCERNS SUMMARY

The primary source of radiation in space is due to two major components; high-energy high-Z particles and energetic protons. From these primaries the secondary components can be determined. For some space applications consideration of neutron and gamma flux coming from nuclear sources such as reactors for power or for propulsion must be included.

AREAS OF POTENTIAL SEI APPLICATION AT BNL

Herein are detailed some of the specific experimental topics. There are questions of survivability of sensors and detectors operating in a space radiation environment. A key asset to a versatile facility complex as proposed is the ability to calibrate charged-particle detectors over a wide range of energies. Radiobiological concerns are itemized here, and are treated in depth in other presentations. The development of the required data bases and shielding studies based upon transport-code modeling are complementary efforts in conjunction with the radiobiology research in a complete Life Sciences program.

The transport-code calculations will incorporate the cross sections, primary radiation that penetrates through whatever comprises the enclosure and secondary particles produced in the enclosure through interaction with the primaries, in defining the complete radiation threat to humans and materials inside the enclosure. Existing codes must be upgraded in their ability to handle the full range of particle species and their energy ranges. In a continuing program the codes must be further upgraded to account for three-dimensional irradiation: current capability is only one dimensional. Microdosimetric calculations will be available in the sense of calculating specific doses to various parts and organs of the body.

In order to pull these kinds of results together it is proposed to employ the methods of Probabilistic Risk Assessment, currently being successfully used for systems analysis in areas such as nuclear power plants, to assess probable health risks, probable system performance and reliability, and to predict the probability of mission success.

UNIQUE CAPABILITIES AT BNL THAT SUPPORT SEI

The National Nuclear Data Center is the international repository of nuclear cross section data. The extension of this data base and the resulting user code support thereby provided supports the transport-code calculational work most efficiently. The group's many years of compiling evaluated data bases and distributing it to a wide community of users make this effort a natural. The NNDC is a Division of the Department of Nuclear Energy at BNL.

The REF is a proton irradiation user facility that has been in operation for six years. It provides protons from 100 to 200 MeV in dose and dose rates that assure simulation fidelity for almost any test where effects of magnetically trapped or solar-flare protons are at issue. The measurement of (p, fragment) cross sections for protons up to 200 MeV is accomplished ideally at this facility. Other radiation/materials issues are also easily addressed there. A Radiobiology program with AFRRI as the user has been in progress

at the REF for several years. Irradiations of rats and mice along with cell-culture irradiations have been performed. Plans for irradiations by AFRRI in FY91 include work with ferrets, exposures to analine for dosimetry development, in vitro irradiation of C3H10T(1/2) mammalian cells, and human-hamster hybrid AL cells.

Much of the proposed experimental work is, of course, based upon the expectation of there being the Booster Applications Facility becoming an active facility in FY94.

The Medical Department provides two key ingredients to a successful program being mounted at the Booster Applications Facility. The first is a completely equipped Medical Facility including extensive animal handling facilities that provide superb support to a large user program. Secondly, in-house staff are well suited to expand the existing life sciences programs, making use of the new Booster capabilities.

Likewise, the Safety and Risk Evaluation Division will extend its expertise to the new area of risk analysis for space missions.

PROGRAM ELEMENTS ADDRESSED AT BNL

These two viewgraphs spell out the activities that are proposed to be included in the "Shielding" studies that are included in a comprehensive space radiation characterization. These can be seen as and outline of a statement of work, with the timelines included. Work would begin immediately on compilation of the high-energy data base. Additions to the data base begin with cross-section measurements made at the REF for proton energies up to 200 MeV. Higher-energy cross sections would be obtained for specific reactions using activation techniques and using the higher-energy beam at the Alternating Gradient Synchrotron. As the booster facility becomes available, the cross section data base for heavy-ion fragmentation will begin to be accumulated. A requirement for this important phase of the experimental data-base generation is the availability of a high-precision particle spectrometer as part of the Facility. Plans for the provision of this spectrometer should be part of the construction planning.

As the data base is being developed, benchmark experiments will be designed and carried out to test the adequacy of the data base in predicting flux and spectra of radiation in complex environments. The codes themselves will be going through a continuing upgrade to allow first for higher-energy components than are currently included, and later extending the code capability from current one-dimension to the required three dimensions. One aspect of the transport-code work is to perform sensitivity studies on model systems to determine the need for cross-section data at energies higher than 1.5 GeV/nucleon. These data can be obtained using the Alternating Gradient Synchrotron, but these experiments are likely to be complicated and expensive relative to the similar

work at the Booster Facility, so careful prior work is required to maximize the information gain and minimize the costs. The goal of the calculational effort is to model proposed spacecraft and habitats so that predictions of the radiation threat can be made with a high degree of assurance. Having this capability, one can then parametrize the shielding configurations to develop a maximally shielded environment.

A proposal to initiate and carry forward this program is currently being drafted by a BNL/NASA collaborative team, and will be ready for submission early in calendar year 1991.

SPACE RADIATION-EFFECTS PROGRAM

- Characterize the radiation environment
- Improve radiation dosimetry and detection technology
- Assess the biological effects to the crew of mission radiation exposures
- Assess radiation degradation effects to electronics, sensors, etc.
- Incorporate results into mission planning and habitat designs
- Optimize designs based upon Risk/Reliability Assessment addressing:
 - A. Health Effects
 - B. System Behavior

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SHIELDING CONCERNS SUMMARY

PRIMARY SOURCES

1. Natural radiation

- HZE particles (Galactic Cosmic)
- Protons
 - Solar Flares
 - High-Earth orbit trapped

2. On-board nuclear

- Habitat Power
- Propulsion

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AREAS OF POTENTIAL SEI APPLICATION AT BNL

A. Experimental Studies/Verification/Testing: Proton and Heavy-Ion Radiation Effects

- Sensors, detectors
- Data bases
- Shielding studies
- Radiobiology
 1. LET, dose, and dose-rate studies
 2. Dosimetry
 3. Benchmarks

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AREAS OF POTENTIAL SEI APPLICATION AT BNL

B. Code Calculations

- Define radiation threat in various environments: travel, space station, lunar and Mars bases
- Secondary-particle flux from protons and heavy-ions
- Damage production from primaries and secondaries in extended objects (LDEF, Habitats)
- Microdosimetric calculations for life sciences

C. Other Shielding Schemes

- Electrostatic
- Magnetic

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AREAS OF POTENTIAL SEI APPLICATION AT BNL

D. Integrated Risk/Reliability Assessment: Analyze Design Tradeoffs
Between

- Health Effects
- System Reliability/Mission Success Probability
- Cost (Mass,...etc.)

Note: These are potentially competing attributes

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UNIQUE CAPABILITIES AT BNL THAT SUPPORT SEI

- National Nuclear Data Center (NNDC)
 - Evaluated nuclear cross-section data base
 - With intermediate-energy cross sections provides basis for required transport-code work
- Radiation Effects Facility (REF)
 - Experimental user facility for protons 100–200 MeV
 - Time-of-flight capability for precision (p,n) work
 - Wide experience in electronics, materials, systems, and Life Sciences tests

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UNIQUE CAPABILITIES AT BNL THAT SUPPORT SEI

- Heavy Ion Booster Applications Facility (proposed)
 - Uses BNL Booster to provide required range of ions to 1.6 GeV/nucleon
 - Provides doses and dose rates adequate for required programs.
 - Provides “clean” beams in target areas tailored to programmatic needs
 - A User facility to meet needs of a comprehensive Space Radiation Effects Program
- Medical Department
 - Provides facilities and technical expertise sufficient to support an aggressive User Program at HIREF
 - Active in-house Life Sciences program to support SEI concerns

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UNIQUE CAPABILITIES AT BNL THAT SUPPORT SEI

- Safety and Risk Evaluation Division (DNE)
 - Integrate risk-assessment into the optimization of habitat design
 - PRA for human risk and system failures

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Graph 4b

PROGRAM ELEMENTS ADDRESSED AT BNL

- Transport Calculations
 - Adapt codes to extended data base incorporating necessary intermediate-energy channels (yrs 1–)
 - Perform sensitivity studies of proposed experiments and applications to determine data areas of principal importance (yrs 1–)
 - Develop a benchmark experiment(s) for testing of the data libraries for transport calculation use. (yrs 1–)
 - Transport calculations for model habitats (yrs 3–)
- Develop and Evaluate Alternative Shielding Schemes

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PROGRAM ELEMENTS ADDRESSED AT BNL

- Compile and evaluate (p,x) and (HZE,x) cross-section data into comprehensive data base to 10 GeV (NNDC, yrs 1,2)
- Experimental Studies:
 - Supply missing (p,x) cross sections to data base (REF to 200 MeV, yrs 1,2)
 - Cross sections (p,x) and (HZE,x) to 1.6 GeV to data base (Booster, yrs 3–)
 - Benchmark testing for code validations (REF, Booster, yrs 1–)

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**Molecular Quantitation of DNA Damage
and Repair in Humans: Methods and Facilities**

by

B.M Sutherland and J.C. Sutherland

DNA Damage and Repair in Human Tissues:
Quantitation by Gel Electrophoresis and Electronic Imaging

Betsy M. Sutherland and John C. Sutherland
Biology Department, Brookhaven National Laboratory
Upton NY 11973

(516) 282-3293/3380 FTS 666-3293/3380 FAX (516) 282-3407

Background Ionizing radiation damages human tissues, and a critical target for long term effects is DNA. Humans have several pathways for repairing damage to DNA, which have mainly been studied in human cells in culture. However, repair of non-ionizing radiation damage to human cells in culture is different from that in human tissues--fewer paths are present, and repair is much slower, thus leading to an underestimate of resistance to such radiation. Thus, it is important to determine the actual levels of ionizing radiation damage and repair rates in human tissues.

Method We have developed a method using gel electrophoresis and electronic imaging for quantitating DNA lesions (Transparency 2), including single strand breaks, double strand breaks, alkali-labile sites and base alterations (Transparency 3), in nanogram quantities of non-radioactive DNA, such as that from irradiated human tissues (Freeman et al., 1986, *Analyt. Biochem.* 158:119-129). Human volunteers or human tissues are exposed to radiation, DNA is digested, and electrophoresed on agarose gel (along with molecular length standards) under appropriate conditions for detection of the lesion of interest (Transparency 4). The DNA on the gel is stained with ethidium bromide, destained, and a quantitative electronic image obtained using a charge-coupled device camera system invented at BNL by J. Sutherland (Sutherland et al., 1987, *Analyt. Biochem.* 163:446-457.) (Transparency 5). The molecular lengths of the irradiated and unirradiated DNAs are determined, and the frequency of lesions determined. The current limit of detection is about 1 lesion per 2 million bases. Each assay uses about 50 nanograms of non-radioactive DNA. Transparency 6 shows an example of an electronic image of such a gel: human cells were irradiated with 254 nm radiation ($0-3 \text{ J/m}^2$), treated (lanes shown as +) or not treated with the pyrimidine dimer-specific endonuclease from *Micrococcus luteus*, and electrophoresed on alkaline agarose along with molecular length standards (lanes shown as L). An exposure of 0.2 J/m^2 induces about 1 dimer per million bases.

Results Similar gels were used to determine the cross-section as a function of wavelength (action spectrum) for pyrimidine dimer formation in DNA in skin of human volunteers irradiated in situ (Freeman et al., 1989, *Proc. Natl. Acad. Sci.*, 86:5605-5609.) (Transparency 7). Each point in the figure represents the slope of the dose-response line for one volunteer at one wavelength, obtained from at least three doses, with each point on the dose-response line derived from triplicate independent gels. The circled points represent multiple identical values. The solid lines in the figure represent solar spectra at the surface under today's conditions of stratospheric ozone (dotted line) and under conditions of 50% depletion (as found in the Antarctic ozone hole). Our data allow the calculation of increased risk of damage to DNA resulting from a specific level of ozone depletion.

We have also extended the technique to the measurement of single- and double-strand breaks induced by ionizing radiation (Chen and Sutherland, 1989, Electrophoresis 10:315-317). Transparency 8 shows the scheme for direct measurement of single strand breaks (left gel) and double-strand breaks (right gel).

Using the gel method, we have studied DNA damage and repair in human skin irradiated in situ with ultraviolet light (Sutherland et al., 1980, Cancer Res. 40:3181-3185). Transparency 9 shows some recent results (Hacham et al., 1990, submitted) on repair in human skin: first, UV induces substantial levels of pyrimidine dimers in human skin; second, excision repair can be quite rapid, with Volunteer 138 removing about 2/3 of the initial level of dimers in 30 min.; third, there is substantial variability in rates of excision among apparently normal humans (Vol. 139 has removed only about 10% of the dimers in 30 min.); fourth, photorepair is a major process in dimer removal in human skin.

We have also developed micro-methods for studying repair of specific genes in human skin irradiated in situ (Our experiments use about 100 ng DNA/lane, compared with the 10 ug/lane used in studies of cells in culture.) Transparency 10 shows excision repair results for the c-myc gene in the dermis and epidermis of a volunteer; in contrast to the results obtained in cells in culture, the rate of dimer removal is approximately the same for genomic DNA and for the c-myc gene.

These results point out several important qualitative and quantitative differences in repair of UV damage between human skin in situ and human skin cells in culture (Transparency 11): (1) in skin, additional repair paths are present; (2) excision can be much more rapid, with half the dimers removed in about 30 min. (cf. 12-24 hr. in cultured human cells); (3) the strategy for repair of specific genes seems to differ significantly--both repair of genomic DNA and of the gene c-myc occur at similar rates; and (4) results from cultured human cells underestimate the capacity of humans to repair UV damage to DNA in their skin. It would be intriguing to determine whether repair of damage induced by other kinds of radiation is similarly more rapid in human tissues than in cultured human cells.

● Gel Electrophoresis Method for ● Quantitation of Damage in Genomic DNA

- non-radioactive DNA
- about 50 nanograms DNA / assay
- current limit of sensitivity:
~ 1 lesion / 2 million bases
- measures several lesion types

Lesions measured by the Gel Method

Lesions convertible to breaks

alkali-labile sites

non-dimer pyrimidine damage

pyrimidine dimers

Frank breaks

single strand breaks

double strand breaks

Measurement of lesions Convertible to Strand Breaks

Schematic Diagram of Electronic Imaging System

MODIFY ## BUILD

L 0- 0+ .2- .2+ .5- .5+ UV dose J/sq 254 nm 1- 1+ 2- 2+ 3- 3+

L = Length Standards +/- = With/Without Endonuclease

QUANTITATION OF PYRIMIDINE DINERS IN HUMAN DNA

Wavelength Dependence of Dimer Formation in Human Skin irradiated in situ

Measurement of Single- and Double strand breaks

1. Schematic diagram of the gel electrophoresis assay for single- and double-strand breaks induced by γ -rays. The top portion of the figure shows a double-stranded segment of DNA being subjected to γ -radiation (---). Energetic electrons (—) and free radicals ($R^\bullet$) generated by the γ -rays produce both frank single-strand breaks (x), alkali-labile sites (o) and base damage that does not lead to strand breaks (not shown). The center portion of the figure shows how the irradiated molecule would be divided into several shorter double-stranded molecules in neutral buffer and into a larger number of single-stranded molecules in alkaline buffer. The bottom portion of the figure shows how ensembles of such molecules will appear respectively on alkaline and neutral agarose gels after electrophoresis in comparison with lanes containing otherwise identical but unirradiated samples as well as lanes containing DNA length standards.

Dimer Repair in Human Epidermis

302 nm Dose	Sample	Dimer Vol. 138	Level Vol. 139
0	No UV	0.2	1.6
2 MED	0 Time	127.7	152.0
2 MED	30 min dark	41.7	141.2
2 MED	30 min light	5.0	10.9
0	30 min light	1.4	1.4

Repair of Genomic DNA and c-myc gene

Sample	Genomic ESS/Mb	% Repair	c-myc ESS/Mb	% Repair
Dermis				
No UV	0	----	0	----
2 MED, 0'	228	----	186	----
2 MED, 35'	100	56	96	48
Epidermis				
No UV	0	----	0	----
2 MED, 0'	282.	----	262	----
2 MED, 35'	77.6	72	72*, 96*	72, 63

* duplicate determinations

● Repair in Humans differs qualitatively and ● and quantitatively from cultured human cells

- Additional paths present
- Rate much faster
- Specific gene repair strategy differs
- cell culture results
UNDERESTIMATE
human repair capacity

**Summary of Estimated Construction
Costs and Schedule
by
H. Foelsche**

COST AND SCHEDULE

The cost and schedule baseline estimate is presented for a facility encompassing three experimental areas, fully equipped and ready for commissioning by the last quarter of FY 1994. Scenarios and cost profiles stretching the schedule for completion to later years, or for a facility of reduced scope can be derived from this baseline information, and are discussed in the Introduction to this report.

The baseline cost estimate for a full facility completed in FY 1994 is 28.5 M\$ (at year \$), including 94.2 manyears of BNL manpower. This includes a contingency allowance for most systems of 25% for materials, 35% for personnel, and 15% for the conventional facilities. NOTE: This cost estimate is lower than the one presented at the NASA design review on 12/10/90, reflecting the review committee's suggestion to eliminate a substantial contingency allowance for the Tandem MP6 voltage upgrade.

The cost estimate summarized in these pages is based on detailed cost and manpower analyses of similar systems constructed and/or purchased by BNL in the recent past. More detailed backup information extending to lower levels of the Work Breakdown Structure is provided in Appendix II (Cost Estimate Details).

The salary rates assumed in the detailed manpower analyses represent averages paid to BNL personnel in FY 1991 (see attached tabulation), and include an appropriate allowance for fringe benefits. The salary rates in the summary for each system represent averages which reflect the relative weight of the skills devoted to each.

It is assumed that BNL will charge a reduced overhead rate of 5% which is customary for construction projects, and that there are no other interagency overhead charges to NASA.

Cost escalation factors for the outlying years are based on the most recent inflation rates assumed by the Department of Energy, the same as those assumed for the Relativistic Heavy Ion Collider Project (RHIC). The cost extensions to "at year dollars" make the assumption that planned commitments for purchased materials are made uniformly over a given year and are expensed with an average delay of 6 months, and that the contractors' prices will reflect this delay. Salaries, on the other hand, are committed and fully expensed in the same year.

The schedule leading to project completion in FY 1994 is outlined in the attached tables. It assumes a small amount of early funding in FY 1991 for the purpose of proceeding with in-house Title I Engineering and soliciting an Architect/Engineer firm for Title II design of conventional facilities, as well as for starting detailed engineering of long-lead accelerator systems. With this early start the project should be ready for detailed design reviews in the first half of FY 1992. The modification of the Booster tunnel must be coordinated with a machine shutdown in the summer of 1992. The major cost commitments can be made in FY 1992 and FY 1993. Installation can then start early in FY 1994, with beam commissioning beginning in the last quarter of FY 1994.

COST SUMMARY
 CONSTRUCTION AND OUTFITTING COSTS
 BOOSTER APPLICATIONS FACILITY
 BASELINE ESTIMATE, COMPLETION FY 1994

TOTAL COST	28.5 M\$ (AT YEAR \$)	Revised 1/12/91
	25.9 M\$ (FY 91 \$)	Revised 1/12/91

MATERIALS	21.8 M\$ (AT YEAR \$)	Revised 1/12/91
BNL LABOR	6.7 M\$ (94.2 MANYEARS)	Revised 1/12/91

INCLUDING: CONTINGENCY

MATERIALS	25 %
LABOR	35 %

BNL OVERHEAD 5 %

ESCALATION (FY 91 = 1.000)
 CUMULATIVE (DOE)

FY 92	1.045	Revised 1/12/91
FY 93	1.098	Revised 1/12/91
FY 94	1.160	Revised 1/12/91

Figure 1

BNL SALARY RATES (FY 91)
Including Fringe Benefits

CLASSIFICATION	CODE	MONTHLY SALARY
Senior Scientist	1	7500
Junior Scientist	2	5000
Senior Engineer, Electrical	3	7000
Junior Engineer, Electrical	4	5500
Senior Engineer, Mechanical	5	7000
Junior Engineer, Mechanical	6	5500
Senior Engineer, Contract	7	4500
Junior Engineer, Contract	8	3500
Senior Computer Analyst	9	6000
Junior Computer Analyst	10	5000
Senior Designer	11	5500
Junior Designer	12	4500
Senior Designer, Contract	13	4200
Junior Designer, Contract	14	3300
Senior Technician, Electrical	15	5000
Junior Technician, Electrical	16	3500
Senior Technician, Mechanical	17	5000
Junior Technician, Mechanical	18	3500
Senior Technician, Electro-mechanical	19	5000
Junior Technician, Electro-mechanical	20	3500
Senior Technician, Contract Labor	21	2700
Junior Technician, Contract Labor	22	2000
Senior Administrative	23	6250
Junior Administrative	24	4200
Senior Clerical/Support	25	3000
Junior Clerical/Support	26	2500
Building Trades	27	6353
Central Shops	28	7303
Staff Shop	29	5126
Davis Bacon Labor	30	6400

Figure 2

WBS #	DESCRIPTION	MATERIALS				PROJECT M&S		BHL LABOR SUMMARY				PROJECT TOTAL K\$
		qty	unit	unit cost \$	cost basis \$	inventory M&S K\$	PROJECT M&S K\$	Net Project Months	Rate \$/month	AVAILABLE LABOR K\$	PROJECT LABOR K\$	
1.	: NASA BOOSTER AREA PROJECT COST (AT YEAR \$) 30.3 M\$:											
1.1	CONSTRUCTION (WITH CONTINGENCY)	1	LOT	7363200		0.0	7363.2	0.0	0	0.0	0.0	7363.2
1.2	EXTRACTION COMPONENTS	1	LOT	55300		0.0	55.3	62.6	4910	0.0	307.2	362.5
1.3	TRANSFER MAGNETS	1	LOT	920741		67.0	853.7	87.1	4782	0.0	416.5	1270.3
1.4	EXTRACTION POWER SUPPLIES	1	LOT	241200		0.0	241.2	72.1	4803	0.0	346.5	587.7
1.5	TRANSFER POWER SUPPLIES	1	LOT	335000		0.0	335.0	21.6	5185	0.0	112.0	447.0
1.6	COLLIMATORS, STRIPPERS, STOPS	1	LOT	858510		0.0	858.5	47.3	4033	0.0	190.7	1049.2
1.7	VACUUM SYSTEM	1	LOT	366380		31.6	334.8	56.3	5971	0.0	336.1	670.9
1.8	CONTROLS	1	LOT	434400		0.0	434.4	117.0	5204	0.0	608.9	1043.3
1.9	BEAM INSTRUMENTATION	1	LOT	374000		0.0	374.0	33.5	5448	0.0	182.5	556.5
1.10	EXPERIMENTAL AREA OUTFITTING	1	LOT	944800		0.0	944.8	50.7	4338	0.0	219.8	1164.6
1.11	UTILITIES & SERVICES	1	LOT	430000		0.0	430.0	11.0	6529	0.0	71.8	501.8
1.12	TANDEM & BEAM MODIFICATIONS	1	LOT	4562950		50.0	4513.0	148.5	5357	0.0	795.5	5308.4
1.13	INSTALLATION	1	LOT	871434		0.0	871.4	85.9	4560	101.7	421.6	1293.0
1.14	GENERAL SYSTEM SUPPORT	1	LOT	250000		85.0	165.0	73.0	5606	0.0	409.3	574.3
1.15	CONTINGENCY (1.2 to 1.14)	25%	OF	10411115			2602.8	303.3	= 35%	35.6	1546.4	4149.2
1.16	BNL OVERHEAD	5%	OF	ABOVE			1018.9				298.2	1317.1
	SUBTOTAL (FY 1991 K\$)					233.6	21395.9	1169.8	MAN MONTHS	137.2	6262.9	27658.9
	ESCALATION (FY92 to FY94)						1998.6				665.3	2603.9
	T O T A L (AT YEAR K\$)					233.6	23394.5	97.5	MAN YEARS	137.2	6868.2	30262.8

H. Foelsche

Figure 3

12/07/98

BOOSTER APPLICATIONS FACILITY

SCHEDULE

NASA REVIEW OF PHASE II REPORT	12/90
NASA FUNDING AND DOE APPROVAL FOR ENGINEERING	start 1/91
IN-HOUSE TITLE I ENGINEERING CONVENTIONAL CONSTRUCTION	complete 4/91
SOLICIT ARCHITECT ENGINEER FOR TITLE II DESIGN	complete 8/91
NASA FUNDING APPROVAL	9/91
ENGINEERING OF COMPONENTS	complete 10/91
DETAILED DESIGN, REVIEW	complete 4/92
CIVIL CONSTRUCTION	start 8/92 complete 12/93
COMPONENT FABRICATION	complete 12/93
COMPONENT INSTALLATION	complete 3/94
OPERATION	start 6/94

Figure 4

BOOSTER APPLICATIONS FACILITY

SCHEDULE

Figure 5

WBS #	DESCRIPTION	MATERIALS COMMITMENT PROFILE (ANNUAL K\$)						LABOR COMMITMENT & EXPENSE PROFILE (ANNUAL K\$)					
		FY 1991	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996	FY 1991	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996
		INITIAL	40%	50%	10%	0%	0%	INITIAL	25%	45%	30%	0%	0%
1.	: NASA BOOSTER AREA PROJECT												
1.1	CONSTRUCTION (WITH CONTINGENCY)	500.00	6863.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.2	EXTRACTION COMPONENTS	0.00	22.12	27.65	5.53	0.00	0.00	0.00	76.79	138.22	92.15	0.00	0.00
1.3	TRANSFER MAGNETS	0.00	341.50	426.87	85.37	0.00	0.00	0.00	104.13	187.43	124.95	0.00	0.00
1.4	EXTRACTION POWER SUPPLIES	0.00	96.48	120.60	24.12	0.00	0.00	0.00	86.62	155.91	103.94	0.00	0.00
1.5	TRANSFER POWER SUPPLIES	0.00	134.00	167.50	33.50	0.00	0.00	0.00	28.00	50.40	33.60	0.00	0.00
1.6	COLLIMATORS, STRIPPERS, STOPS	0.00	343.40	429.26	85.85	0.00	0.00	0.00	47.68	85.82	57.21	0.00	0.00
1.7	VACUUM SYSTEM	0.00	133.91	167.39	33.48	0.00	0.00	0.00	84.03	151.25	100.83	0.00	0.00
1.8	CONTROLS	0.00	173.76	217.20	43.44	0.00	0.00	0.00	152.23	274.01	182.67	0.00	0.00
1.9	BEAM INSTRUMENTATION	0.00	149.60	187.00	37.40	0.00	0.00	0.00	45.63	82.13	54.75	0.00	0.00
1.10	EXPERIMENTAL AREA OUTFITTING	0.00	377.92	472.40	94.48	0.00	0.00	0.00	54.94	98.89	65.73	0.00	0.00
1.11	UTILITIES & SERVICES	0.00	172.00	215.00	43.00	0.00	0.00	0.00	17.96	32.32	21.55	0.00	0.00
1.12	TANDEM & BEAM MODIFICATIONS	0.00	1805.18	2256.48	451.30	0.00	0.00	0.00	198.87	357.97	238.64	0.00	0.00
1.13	INSTALLATION	0.00	0.00	697.15	174.29	0.00	0.00	0.00	0.00	105.40	316.20	0.00	0.00
1.14	GENERAL SYSTEM SUPPORT	0.00	66.00	82.50	16.50	0.00	0.00	250.00	39.81	71.66	47.78	0.00	0.00
1.15	CONTINGENCY (1.2 to 1.14)	0.00	953.97	1366.75	282.06	0.00	0.00	87.50	327.83	626.99	504.07	0.00	0.00
1.16	BNL OVERHEAD	25.0	581.7	341.7	70.5	0.0	0.0	16.9	63.2	120.9	97.2	0.0	0.0
	SUBTOTAL (FY 1991 K\$)	525.0	12214.7	7175.4	1480.8	0.0	0.0	354.4	1327.7	2539.3	2041.5	0.0	0.0
	ESCALATION (FY92 to FY94)	11.25	833.48	881.87	271.99	0.00	0.00	0.00	56.90	237.72	310.69	0.00	0.00
1.	TOTAL (AT YEAR K\$)	536.3	13048.2	8057.3	1752.8	0.0	0.0	354.4	1384.6	2777.0	2352.2	0.0	0.0
	INFLATION FACTORS ::	1.00	1.045	1.098	1.160	1.226	1.296 *	1.00	1.045	1.098	1.160	1.226	1.296 *

H. Foelsche

12/07/90

Figure 6

WBS #	DESCRIPTION	MATERIALS			PROJECT		BNL LABOR SUMMARY				PROJECT		
		Qty	unit	unit cost \$	cost basis \$	INVENTORY M&S K\$	M&S K\$	Net Project Months	Rate \$/month	AVAILABLE LABOR K\$	LABOR K\$	TOTAL K\$	
COST ESTIMATE IN FY 1991 \$DOLLARS													
1.	NASA BOOSTER AREA					233.60	20377.09	1169.8	101.65	5964.68		26341.77	
1.1	CONSTRUCTION (WITH CONTINGENCY)												
1.1.1	BEAM TUNNELS	1 LOT		7363200		0.00	7363.20			0.00	0.00	7363.20	
1.1.2	SUPPORT BUILDING	1 LOT		1122188		0.00	1122.19			0.00	0.00	1122.19	
1.1.3	EXPERIMENTAL AREAS	1 LOT		1129503		0.00	1129.50			0.00	0.00	1129.50	
1.1.4	SITE WORK	1 LOT		1722350		0.00	1722.35			0.00	0.00	1722.35	
1.1.5	CONTINGENCY (1.1.1 - 1.1.4)	1 LOT		418950		0.00	418.95			0.00	0.00	418.95	
1.1.6	FIELD SUPERVISION & OVERHEAD	25% of		4392990		0.00	1098.25			0.00	0.00	1098.25	
1.1.7	CONTRACTOR PROFIT & OVERHEAD	6% of		5491238		0.00	329.47			0.00	0.00	329.47	
1.1.8	ENGINEERING & ADMINISTRATION	15% of		5820712		0.00	873.11			0.00	0.00	873.11	
		10% of		6693819		0.00	669.38			0.00	0.00	669.38	
1.2	EXTRACTION COMPONENTS												
1.2.1	SEPTUM MAGNET	1 LOT		55300		0.00	55.30	62.56	4910	0.00	307.15	362.45	
1.2.2	ELECTROSTATIC SEPTUM	1 UNIT		34800		0.00	34.80	31.68	4966	0.00	157.31	192.11	
		1 UNIT		20500		0.00	20.50	30.88	4852	0.00	149.84	170.34	
1.3	TRANSFER MAGNETS												
1.3.1	QUADRUPOLES	1 LOT		920741		67.00	853.74	87.11	4782	0.00	416.51	1270.25	
1.3.2	H DIPOLE	25 UNITS		18780		0.00	489.49	32.00	4460	0.00	142.71	612.20	
1.3.3	C DIPOLE	2 EACH		75386		29.00	121.77	9.00	5357	0.00	48.22	169.99	
1.3.4	OCTUPOLES	2 EACH		95638		28.00	163.28	25.00	5189	0.00	129.72	292.99	
1.3.5	TRIM DIPOLES	6 EACH		9867		0.00	59.20	12.92	4893	0.00	63.22	122.42	
		16 EACH		3125		10.00	40.00	8.19	3989	0.00	32.65	72.65	
1.4	EXTRACTION POWER SUPPLIES												
1.4.1	SEPTUM MAGNET POWER SUPPLY	1 LOT		241200		0.00	241.20	72.13	4803	0.00	346.48	587.68	
1.4.2	E/S SEPTUM POWER SUPPLY	1 UNITS		35900		0.00	35.90	39.33	4690	0.00	184.48	220.38	
1.4.3	SEXTUPOLE POWER SUPPLY	1 UNITS		22300		0.00	22.30	20.13	4751	0.00	95.66	117.96	
1.4.4	EXTRACTION BUMP POWER SUPPLY	2 EACH		10000		0.00	20.00	2.53	5395	0.00	13.67	33.67	
1.4.5	SPILL SERVO	8 EACH		20000		0.00	160.00	8.27	5242	0.00	43.33	203.33	
		1 EACH		3000		0.00	3.00	1.87	5000	0.00	9.33	12.33	
1.5	TRANSFER POWER SUPPLIES												
1.5.1	QUADRUPOLE POWER SUPPLY	1 LOT		335000		0.00	335.00	21.60	5185	0.00	112.00	447.00	
1.5.2	DIPOLE POWER SUPPLY	25 EACH		5000		0.00	125.00	8.67	5115	0.00	44.33	169.33	
1.5.3	OCTUPOLE POWER SUPPLY	4 EACH		35000		0.00	140.00	3.07	5326	0.00	16.33	156.33	
1.5.4	TRIM DIPOLE POWER SUPPLIES	6 EACH		5000		0.00	30.00	3.60	5278	0.00	19.00	49.00	
		16 EACH		2500		0.00	40.00	6.27	5160	0.00	32.33	72.33	
1.6	COLLIMATORS, STRIPPERS, STOPS												
1.6.1	ADJUSTABLE COLLIMATOR	1 LOT		858510		0.00	858.51	47.29	4033	0.00	190.71	1049.22	
1.6.2	STRIPPER	8 ea		7045		0.00	56.36	30.29	3454	0.00	104.61	160.97	
1.6.3	BEAM STOPS	2 ea		6075		0.00	12.15	12.00	5719	0.00	68.61	80.76	
1.6.4	COLLIMATOR CONTROL POWER	3 ea		260000		0.00	780.00	0.00	0	0.00	0.00	780.00	
		10 ea		1000		0.00	10.00	5.00	3500	0.00	17.50	27.50	
1.7	VACUUM SYSTEM												
1.7.1	INLINE COMPONENTS	1 LOT		366380		31.60	334.78	56.29	5971	0.00	336.11	670.89	
1.7.2	ION PUMPS & P.S.	1 lot		154460		31.60	122.86	33.57	6889	0.00	231.27	354.13	
1.7.3	ROUGHING STATIONS	1 lot		41520		0.00	41.52	6.60	4409	0.00	29.10	70.62	
1.7.4	VACUUM INSTRUM. & CONTROL	4 ea		24000		0.00	96.00	0.21	5000	0.00	1.07	97.07	
		1 lot		74400		0.00	74.40	15.91	4694	0.00	74.67	149.07	
1.8	CONTROLS	1 LOT		434400		0.00	434.40	117.00	5204	0.00	608.90	1043.30	

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Figure 7

WBS #	DESCRIPTION	MATERIALS				PROJECT				BNL LABOR SUMMARY				PROJECT	PROJECT
		QTY	unit	unit cost \$	cost basis	INVENTORY	M&S	M&S	K\$	Net Project Months	Rate \$/month	AVAILABLE LABOR	K\$	LABOR	TOTAL
1.8.1	TIMING SYSTEM	1	lot	9500		0.00	9.50			5.00	4300	0.00	21.50		31.00
1.8.2	CONTROL ROOM	1	lot	113500		0.00	113.50			14.00	4357	0.00	61.00		174.50
1.8.3	NETWORK	1	lot	37600		0.00	37.60			5.00	5300	0.00	26.50		64.10
1.8.4	SOFTWARE DEVELOPMENT	1	lot	17000		0.00	17.00			18.00	5000	0.00	90.00		107.00
1.8.5	TVOG PROCESS CONTROLS	1	lot	26500		0.00	26.50			17.00	5735	0.00	97.50		124.00
1.8.6	BOOSTER EXTRACTION CONTROLS	1	lot	24200		0.00	24.20			14.00	4800	0.00	84.00		108.20
1.8.7	BEAM PROCESS CONTROLS	1	lot	50100		0.00	50.10			24.00	4850	0.00	116.40		166.50
1.8.8	INTERLOCK SYSTEM	1	lot	120000		0.00	120.00			6.00	5000	0.00	30.00		150.00
1.8.9	CONTROL SYSTEM INTEGRATION	1	lot	36000		0.00	36.00			14.00	5857	0.00	82.00		118.00
1.9	BEAM INSTRUMENTATION	1	LOT	374000		0.00	374.00			33.50	5448	0.00	182.50		556.50
1.9.1	BEAM PROFILE MONITOR	8	ea	33000		0.00	264.00			14.00	5857	0.00	82.00		346.00
1.9.2	SECONDARY EMISSION CHAMBERS	4	ea	1500		0.00	6.00			2.00	5000	0.00	10.00		16.00
1.9.3	FLAG SYSTEM	5	ea	10800		0.00	54.00			8.50	5353	0.00	45.50		99.50
1.9.4	DATA ACQUISITION & DISPLAY	1	lot	50000		0.00	50.00			9.00	5000	0.00	45.00		95.00
1.10	EXPERIMENTAL AREA OUTFITTING	1	LOT	944800		0.00	944.80			50.66	4338	0.00	219.77		1164.57
1.10.1	TARGET AREA A (CELL CULTURE)	1	lot	231000		0.00	231.00			10.00	4025	0.00	40.25		271.25
1.10.2	TARGET AREA B (LARGE BEAM)	1	lot	144000		0.00	144.00			9.50	4053	0.00	38.50		182.50
1.10.3	TARGET AREA C	1	lot	88000		0.00	88.00			8.00	4156	0.00	33.25		121.25
1.10.4	READY ROOM A	1	lot	43200		0.00	43.20			5.16	4606	0.00	23.77		66.97
1.10.5	READY ROOM B	1	lot	45200		0.00	45.20			5.00	4550	0.00	22.75		67.95
1.10.6	READY ROOM C	1	lot	36500		0.00	36.50			5.00	4550	0.00	22.75		59.25
1.10.7	SUPPORT LAB EQUIPMENT	1	lot	356900		0.00	356.90			8.00	4813	0.00	38.50		395.40
1.11	UTILITIES & SERVICES	1	LOT	430000		0.00	430.00			11.00	6529	0.00	71.82		501.82
1.11.1	ELECTRICAL POWER DISTRIBUTION	1	LOT	130000		0.00	130.00			3.00	6569	0.00	19.71		149.71
1.11.2	COOLING WATER SYSTEM	1	LOT	300000		0.00	300.00			8.00	6515	0.00	52.12		352.12
1.12	TANDEM & BEAM MODIFICATIONS	1	LOT	4562950		50.00	4512.95			148.50	5357	0.00	795.48		5308.43
1.12.1	MP6 TANDEM UPGRADE	1	LOT	2730600		0.00	2730.60			55.35	5353	0.00	306.27		3036.87
1.12.2	BEAM BYPASS	1	LOT	1832350		50.00	1782.35			93.15	5252	0.00	489.21		2271.56
1.13	INSTALLATION	1	LOT	871434		0.00	871.43			85.91	4560	101.65	421.60		1293.03
1.13.1	CABLE	1	lot	794910		0.00	794.91			29.87	5505	0.00	164.43		959.34
1.13.2	TRAY	4000	ft	15		0.00	60.00					0.00	0.00		60.00
1.13.3	COOLING WATER HOSE	1	lot	11024		0.00	11.02			5.73	5591	0.00	32.06		43.08
1.13.4	MISCELLANEOUS PARTS	1	lot	5000		0.00	5.00			1.00	6353	0.00	6.35		11.35
1.13.5	STAGING	1	lot	500		0.00	0.50			1.00	6353	0.00	6.35		6.85
1.13.6	RIGGING	1	lot	0		0.00	0.00			11.60	6353	0.00	73.69		73.69
1.13.7	SURVEY	1	lot	0		0.00	0.00			3.32	6353	0.00	21.09		21.09
1.13.8	HOOKUP	1	lot	0		0.00	0.00			28.93	3526	0.00	102.03		102.03
1.13.9	RUN & TEST	1	lot	0		0.00	0.00			4.45	0	100.72	15.59		15.59
1.13.10	INSTALLATION SUPPORT	1	LOT	36000		20.00	16.00			15.33	5519	4.87	83.43		99.43
1.14	GENERAL SYSTEM SUPPORT	1	LOT	250000		85.00	165.00			73.00	5606	0.00	409.25		574.25
1.14.1	MANUFACTURING SUPPORT	1	LOT	210000		85.00	125.00			31.00	5145	0.00	159.50		284.50
1.14.2	DESIGN SUPPORT	1	LOT	15000		0.00	15.00			12.00	5500	0.00	66.00		81.00
1.14.3	ADMINISTRATION & MANAGEMENT	1	LOT	25000		0.00	25.00			30.00	6125	0.00	183.75		208.75
1.15	CONTINGENCY	25%	OF 10411115				2602.78			303.29	=	35%	1546.40		4149.18

H. Foetsche

12/07/90

Figure 8

BNL

BOOSTER - AGS - RHIC

SCHEDULES

BOOSTER CONSTRUCTION

COMPLETE 1990

COMMISSIONING PROTONS	FY 1991
COMMISSIONING HEAVY IONS	FY 1991-2
RESEARCH FACILITY CONSTRUCTION	FY 1992-3
SLOW BEAM SPILL	1993
PULSE TO PULSE SWITCHING	1993
TANDEM MP-6 UPGRADES	1993
OPERATION	1994

RELATIVISTIC HEAVY ION COLLIDER (RHIC)

CONSTRUCTION START	FY 1991
COMMISSIONING START	FY 1997

Figure 9

Operation Cost Estimates
by
D. Lowenstein

The operating costs summarized on the following page are based on 26 weeks of continuous shared operation per year. This corresponds to approximately 4368 hours of BAF operation and an hourly cost of \$1830. It was assumed that for this number of hours per year a full-time staff, fully dedicated to this facility would be required.

If instead, only 2000 hours were used many of the required services could be provided on a part-time basis and Booster personnel could be shared accordingly. This scenario is explored in the executive summary (section III of this report) and leads to an hourly cost of \$1950.

Please note that, following discussions with the NASA Panel, it was concluded that the full cost surcharge of 24.5% shown on the next page may not apply. For this reason the numbers presented in the executive summary do not contain this surcharge.

NASA FACILITY YEARLY OPERATIONS COSTS
(FY1990\$)

	MPWR	Labor*	Purchases* etc.	Power (@ \$70/MWH)		
	(FTE)	(M\$)	(M\$)	(M\$)	(MW)	(Weeks.^)
A.Tandem	18	1.8	0.4	0.3	1.0	26
<i>Linac</i>	<i>13</i>	<i>1.3</i>	<i>1.0</i>	<i>0.8</i>	<i>2.5</i>	<i>26</i>
B.Booster	15	1.5	1.2	0.9	3.0	26
C.Additional						
Pulsing				0.3	0.8	26
Extraction (33% DF)				0.5	1.5	26
Beamline	5	0.4	0.4	0.3	0.8	26
D.Experimental						
Areas	12	1.2	0.5	0.2	0.2	52

Proposed Charging Algorithm

Subtotal= .5(A+B)+C+D 3.2 1.7 1.5 = 6.4
(Assume concurrent 26 week operation for DOE and NASA.)

Full Cost
Surcharges(24.5%) 0.8 0.4 0.4 = 1.6

TOTAL 4.0 2.1 1.9 = 8.0

* Includes 48.5% G&A
^ 1 Week = 168 Hours

D.I.L
11/27/90

Figure 1

APPENDIX 1

by

P. Thieberger

Compatibility of Primary and Time-Sharing Beams for the Booster Applications Facility

Introduction

The BNL Booster, now nearing completion, was designed to inject protons and heavy ions into the Alternating Gradient Synchrotron (AGS) for further acceleration. In the future, ion beams from the AGS will in turn be further accelerated in the Relativistic Heavy Ion Collider (RHIC). Given the wide range of ion masses, energies and beam intensities the Booster will generate, other important applications should be considered. Dedicated use of the Booster for such applications may be possible during limited periods. However shared use would be preferable from the points of view of availability and cost.

While heavy ions of a given isotope are injected into the AGS, the same or other ion species from the Booster could be simultaneously delivered to a new irradiation area for radiobiological research, shielding studies, detector calibrations or other applications and research. To generate two different beam species, ion sources on both Tandem accelerators would be used; one for AGS injection and the other one for a time-sharing application. Since the beam transport from the Tandems to the Booster can not be rapidly adjusted, it will be necessary to select beams of identical magnetic rigidity. The present study was performed to determine to what extent this compatibility requirement imposes limitations on the available ion species, energies and/or intensities.

Description of the Tables.

The tables on the following pages summarize the results of this study for a selection of the available beam species. In the first two tables, heavy ion beam parameters are listed for dedicated use. For these cases the accelerating voltages and the selected charge-states can be optimized without the restriction of a given magnetic rigidity.

In the remaining tables, all the typical primary beams listed in the Booster Design Manual are considered, except protons which will not originate at the Tandem and will not be transported through the heavy ion transfer line. The deuteron injection energy has been changed from 30 MeV to 15 MeV which will be required due to radiation safety considerations. For each of these primary beams, possible time-sharing beams are listed having identical magnetic rigidity in the transfer line. The terms used in the tables are explained below:

Q_{TANDEM} : The selected charge-state accelerated in the Tandem.
 V_{TANDEM} : The accelerating voltage of the Tandem in mega volts.
 E_{HITL} : The energy (in mega electron volts) of the beam in the Heavy Ion Transfer Line.
 Q_{HITL} : The charge-state of the ions in the transfer line.
 Q_{BOOSTER} : The charge-state of the ions accelerated in the Booster.
 E_{MAX} : The maximum Booster accelerated beam energy in mega electron volts per atomic mass unit.

For each beam species in each table, the first or only entry corresponds to choosing charge-states as close as possible to the most abundant ones resulting in the highest possible intensities. For those species listed more than once, subsequent entries show examples of how intensity can be traded off for higher energies. Twenty turn injection was assumed for all beams.

The intensities were estimated adopting a nominal ion-source output of 100 μA for all beams except for iron for which an ion-source output of 8 μA was assumed. In several of these cases there is no experience for pulsed ion-source operation and those estimates are based on DC performance. For some of the beams intensities as high as 200 μA have been produced and it is probable that even higher intensities will result from recent ion-source developments. In addition to the intensity reductions due to stripper efficiencies an overall transmission of 25% was assumed, which includes the Tandem, the transfer line, capture, acceleration, extraction and beam transport to the target.

In all cases, whether solid or gas stripping is used, it was assumed that the stripper thickness is optimized. This can be accomplished for gas strippers by changing the pressure in the stripper canal and for foil strippers by providing a sufficient selection of thicknesses in the foil changer. In those cases for which $Q_{\text{BOOSTER}} > Q_{\text{HITL}}$ a stripper is required close to the Booster injection point. If this stripper is not adequate for the primary beam it will have to be moved in and out of the beam for each cycle. This will be easy to accomplish in time available between pulses.

The "worst-case" combinations of primary and time-sharing beams from the points of view of energy and of intensity have been selected from all the studied cases. A comparison of these worst-case combinations and dedicated-use beams is shown on the last table. Note that no drastic limitations are encountered and that worst case combinations will seldom if ever have to be used. For example in the case of Fe beams the worst primary beam would be Au_{33+} but the most likely candidate for AGS and RHIC use is Au_{13+} .

Conclusions

Comparing ion beam energies and intensities in the "dedicated use" and the "time sharing" tables one finds surprisingly few, and surprisingly minor differences. All pairs of beams are compatible and it is always possible to find charge-state and voltage combinations, in the shared mode, which yield energies and intensities which are not very different from the best possible values. For proton operation of the Booster it will be possible to deliver time-sharing heavy ion beams identical to the ones characterized in the "dedicated use" tables.

The main difference between both operating modes has to do with the available pulse repetition rates. In the dedicated mode, periods as short as 0.8 sec. are possible in principle for some beams, while AGS requirements will lead to periods between 1.6 and 3.5 sec. in the shared mode.

Some of the lighter ions, require Tandem terminal voltages which are below 10 MV. Those beams could be produced in the shared mode before upgrading the first Tandem (MP6). However, the majority of beams requires higher voltages and their shared acceleration must await the upgrading of MP6.

A significant technical development which will be required to achieve shared mode operation is the implementation of pulse to pulse parameter switching for the Booster. It should be pointed out that such systems have been successfully operated for decades at other accelerators. Our modern control system based on much more powerful computers is already designed with this capability in mind and should make the development of such a system relatively straightforward.

This study has shown that shared operation will not only be feasible but that it can be accomplished with great flexibility and without significant compatibility restrictions.

P.Thieberger January 2, 1991

Booster Beams - Dedicated Use

BEAM	Q _{TANDEN}	V _{TANDEN} (MV)	E _{INIT} (MEV)	Q _{INIT}	Q _{BOOSTER}	E _{max} (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
${}^6\text{C}^{12}$	5	8	48	6	6	1500	99
${}^8\text{O}^{16}$	5	8	48	8	8	1500	71
${}^9\text{F}^{19}$	6	8.6	60	9	9	1500	70
${}^{14}\text{Si}^{28}$	7	8.7	70	12	12	1500	44
${}^{15}\text{P}^{31}$	9	14	140	14	14	1500	29
${}^{16}\text{S}^{32}$	9	15	150	15	15	1500	29
${}^{17}\text{Cl}^{35}$	9	15	150	15	15	1500	28
${}^{26}\text{Fe}^{56}$	10	15	165	21	21	1248	1.5
${}^{29}\text{Cu}^{63}$	11	15	180	22	22	1127	19
${}^{29}\text{Cu}^{63}$	11	15	180	24	24	1277	6

P. Thieberger January 2, 1991

Booster Beams - Dedicated Use

BEAM	Q _{TANDEN}	V _{TANDEN} (MV)	E _{HITL} (MEV)	Q _{HITL}	Q _{BOOSTER}	E _{MAX} (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$^{32}\text{Ge}^{70}$	11	15	180	24	24	1097	15
$^{32}\text{Ge}^{70}$	11	15	180	26	26	1231	2.8
$^{35}\text{Br}^{79}$	11	15	180	24	24	917	19
$^{35}\text{Br}^{79}$	12	15	195	27	27	1092	2.5
$^{53}\text{I}^{127}$	12	15	195	30	30	620	12
$^{53}\text{I}^{127}$	12	15	195	33	33	722	2.1
$^{79}\text{Au}^{197}$	12	15	195	33	33	350	12
$^{79}\text{Au}^{197}$	13	15	210	38	38	445	1.1
$^{79}\text{Au}^{197}$	12	15	195	33	33		5.8
$^{79}\text{Au}^{197}$	13	15	210	38	38		0.7

P. Thieberger January 2, 1991

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beams: 90 MeV ${}^6\text{C}^{12}$ $Q_{\text{HITL}} = 6$ $B_{\text{RHITL}} = 0.7896$
 15 MeV ${}^1\text{H}^2$ $Q_{\text{HITL}} = 1$ $B_{\text{RHITL}} = 0.7896$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
${}^6\text{C}^{12}$	5	15.0	90.0	6	6	1500	57
${}^8\text{O}^{16}$	6	9.7	67.6	6	8	1500	71
${}^9\text{F}^{19}$	6	8.1	57.0	6	9	1500	66
${}^{14}\text{Si}^{28}$	7	6.6	52.7	7	11	1334	42
${}^{14}\text{Si}^{28}$	7	6.6	52.7	7	13	1500	8.7
${}^{15}\text{P}^{31}$	7	6.0	47.6	7	12	1306	37
${}^{15}\text{P}^{31}$	8	6.9	62.1	8	14	1500	3.3
${}^{16}\text{S}^{32}$	7	5.8	46.1	7	12	1249	41
${}^{16}\text{S}^{32}$	8	6.7	60.2	8	14	1500	7.7
${}^{17}\text{Cl}^{35}$	7	5.3	42.1	7	12	1097	39
${}^{17}\text{Cl}^{35}$	9	14.5	145.4	13	16	1500	6.5
${}^{26}\text{Fe}^{56}$	10	14.1	155.2	17	17	916	1.8

P.Thieberger January 2, 1991

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beams: 90 MeV ${}^{12}\text{C}$ $Q_{\text{HITL}} = 6$ $B_{\text{PHITL}} = 0.7896$
 15 MeV ${}^2\text{H}$ $Q_{\text{HITL}} = 1$ $B_{\text{PHITL}} = 0.7896$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{MAX} (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
${}^{63}\text{Cu}$	11	14.4	172.3	19	19	907	17
${}^{63}\text{Cu}$	12	14.7	190.9	20	25	1353	1.1
${}^{70}\text{Ge}$	11	14.3	171.9	20	20	836	18
${}^{70}\text{Ge}$	11	14.3	171.9	20	25	1164	1.7
${}^{79}\text{Br}$	12	14.2	184.3	22	22	804	12
${}^{79}\text{Br}$	12	14.2	184.3	22	26	1033	1.6
${}^{127}\text{I}$	12	14.3	185.8	28	28	555	13
${}^{127}\text{I}$	13	14.2	199.3	29	31	654	1.2
${}^{197}\text{Au}$	10	13.4	146.9	31	31	314	12
${}^{197}\text{Au}$	13	14.9	209.2	37	37	426	2.9
${}^{197}\text{Au}$	10	13.4	146.9	31	31		4.7
${}^{197}\text{Au}$	13	14.9	209.2	37	37		1.8

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 150 MeV $^{32}_{16}\text{S}$ $Q_{\text{HITL}} = 14$ $B_{\text{RHITL}} = 0.7126$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$^{12}_6\text{C}$	5	8.5	51.0	5	6	1500	82
$^{16}_8\text{O}$	6	7.9	55.1	6	8	1500	63
$^{19}_9\text{F}$	6	6.6	46.4	6	9	1500	50
$^{28}_{14}\text{Si}$	9	12.6	125.9	12	12	1500	21
$^{31}_{15}\text{P}$	9	13.3	133.4	13	13	1462	20
$^{32}_{16}\text{S}$	9	15.0	149.9	14	14	1500	24
$^{35}_{17}\text{Cl}$	9	13.7	137.1	14	14	1368	28
$^{35}_{17}\text{Cl}$	10	14.3	157.3	15	15	1500	17
$^{56}_{26}\text{Fe}$	11	14.6	174.9	20	20	1277	1.3

P. Thieberger January 2, 1991

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 150 MeV $^{32}_{16}\text{S}$ $Q_{\text{HITL}} = 14$ $V_{\text{HITL}} = 0.7126$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$^{63}_{29}\text{Cu}$	11	14.3	171.5	21	21	1053	16
$^{63}_{29}\text{Cu}$	11	14.3	171.5	21	24	1277	1.2
$^{70}_{32}\text{Ge}$	12	14.2	185.1	23	23	1031	12
$^{70}_{32}\text{Ge}$	12	14.2	185.1	23	25	1164	1.8
$^{79}_{35}\text{Br}$	11	14.9	178.6	24	24	917	19
$^{79}_{35}\text{Br}$	11	14.9	178.6	24	26	1033	2.2
$^{127}_{53}\text{I}$	11	14.5	173.7	30	30	621	11
$^{197}_{79}\text{Au}$	5	10.1	60.3	22	22	170	22
$^{197}_{79}\text{Au}$	10	12.3	135.6	33	33	350	2.8
$^{197}_{79}\text{Au}$	5	10.1	60.3	22	22		3.8
$^{197}_{79}\text{Au}$	10	12.3	135.6	33	33		1.4

P. Thieberger January 2, 1991

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 180 MeV ^{63}Cu $Q_{\text{MITL}} = 21$ $V_{\text{MITL}} = 0.7297$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{MITL} (MEV)	Q_{MITL}	Q_{BOOSTER}	E_{max} (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$^{12}_6\text{C}$	5	8.9	53.5	5	6	1500	97
$^{16}_8\text{O}$	6	8.3	57.8	6	8	1500	66
$^{19}_9\text{F}$	6	7.0	48.7	6	9	1500	54
$^{28}_{14}\text{Si}$	8	14.7	132.0	12	12	1500	32
$^{31}_{15}\text{P}$	9	14.0	139.9	13	13	1461	20
$^{32}_{16}\text{S}$	10	14.3	157.1	14	14	1500	12
$^{35}_{17}\text{Cl}$	10	15.0	164.9	15	15	1500	18
$^{56}_{26}\text{Fe}$	10	15.0	165.5	19	19	1081	1.5
$^{63}_{29}\text{Cu}$	11	15.0	179.8	21	21	1053	16
$^{63}_{29}\text{Cu}$	11	15.0	179.8	21	24	1500	1.4

F. Thieberger January 2, 1991

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 180 MeV ^{63}Cu $Q_{\text{HITL}} = 21$ $B_{\text{HITL}} = 0.7297$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} (MeV/AMU) (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
^{70}Ge	11	14.8	177.6	22	22	965	15
^{70}Ge	11	14.8	177.6	22	25	1164	1.6
^{79}Br	12	14.4	187.3	24	24	917	13
^{79}Br	12	14.4	187.3	24	26	1033	1.7
^{127}I	12	15.0	194.5	31	31	654	9.0
^{127}I	12	15.0	194.5	31	33	722	0.3
^{197}Au	9	8.2	81.6	25	25	214	19
^{197}Au	10	12.9	142.1	33	33	350	7.2
^{197}Au	10	12.9	142.1	33	33		3.6

P. Thieberger January 2, 1991

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 210 MeV $^{127}_{53}\text{I}$ $Q_{\text{HITL}} = 29$ $B_{\text{PMIL}} = 0.8103$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$^{12}_6\text{C}$	5	11.0	65.9	5	6	1500	84
$^{16}_8\text{O}$	6	10.2	71.2	6	8	1500	71
$^{19}_9\text{F}$	6	8.6	60.0	6	9	1500	70
$^{28}_{14}\text{Si}$	8	8.0	72.4	8	12	1500	23
$^{31}_{15}\text{P}$	7	6.3	50.1	7	12	1306	40
$^{31}_{15}\text{P}$	9	8.3	82.8	9	14	1500	4.2
$^{32}_{16}\text{S}$	7	6.1	48.5	7	13	1398	28
$^{32}_{16}\text{S}$	8	7.0	63.4	8	14	1500	9.0
$^{35}_{17}\text{Cl}$	7	5.6	44.4	7	13	1232	23
$^{35}_{17}\text{Cl}$	8	6.4	57.9	8	15	1500	3.4
$^{56}_{26}\text{Fe}$	10	14.8	163.4	17	17	916	1.6

P Thieberger January 2, 1991

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 210 MeV $^{127}_{53}\text{I}$ $Q_{\text{HITL}} = 29$ $B_{\text{PHITL}} = .8103$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{MAX} (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$^{63}_{29}\text{Cu}$	11	15.2	181.8	19	19	907	17
$^{63}_{29}\text{Cu}$	11	15.2	181.8	19	23	1202	3.5
$^{70}_{32}\text{Ge}$	11	15.1	181.0	20	20	836	17
$^{70}_{32}\text{Ge}$	11	15.1	181.0	20	24	1097	3.7
$^{79}_{35}\text{Br}$	12	14.9	194.1	22	22	804	14
$^{79}_{35}\text{Br}$	12	14.9	194.1	22	25	975	3.2
$^{127}_{53}\text{I}$	13	15.0	209.9	29	29	587	10
$^{127}_{53}\text{I}$	13	15.0	209.9	29	31	654	1.6
$^{197}_{79}\text{Au}$	11	12.9	154.7	31	31	314	13
$^{197}_{79}\text{Au}$	13	14.9	208.6	36	36	407	4.6
$^{197}_{79}\text{Au}$	11	12.9	154.7	31	31		5.2
$^{197}_{79}\text{Au}$	13	14.9	208.6	36	36		3.0

P. Thieberger January 2, 1991

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 210 MeV ^{197}Au $Q_{\text{HITL}} = 33$ $B_{\text{HITL}} = 0.88695$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{MAX} (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$^{12}_6\text{C}$	5	13.2	78.9	5	6	1500	69
$^{16}_8\text{O}$	6	12.2	85.3	6	8	1500	70
$^{19}_9\text{F}$	6	10.3	71.9	6	9	1500	73
$^{28}_{14}\text{Si}$	8	9.6	86.7	8	12	1500	29
$^{31}_{15}\text{P}$	8	8.7	78.4	8	13	1459	29
$^{31}_{15}\text{P}$	9	9.9	99.1	9	15	1500	3.4
$^{32}_{16}\text{S}$	8	8.4	75.9	8	14	1500	20
$^{32}_{16}\text{S}$	9	9.6	96.0	9	15	1500	7.1
$^{35}_{17}\text{Cl}$	8	7.7	69.4	8	14	1365	24
$^{35}_{17}\text{Cl}$	9	8.8	87.8	9	16	1500	2.1
$^{56}_{26}\text{Fe}$	11	14.5	173.4	16	16	836	1.3

P. Thieberger January 2, 1991

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 210 MeV ^{197}Au $Q_{\text{HITL}} = 33$ $B_{\text{HITL}} = 0.88695$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{MAX} (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$^{63}\text{Cu}_{29}$	11	14.5	174.1	17	17	763	17
$^{63}\text{Cu}_{29}$	11	14.5	174.1	17	22	1125	4.6
$^{70}\text{Ge}_{32}$	12	15.1	195.7	19	19	771	12
$^{70}\text{Ge}_{32}$	12	15.1	195.7	19	24	1095	2.9
$^{79}\text{Br}_{35}$	12	14.8	192.2	20	20	692	13
$^{79}\text{Br}_{35}$	12	14.8	192.2	20	25	973	3.0
$^{127}\text{I}_{53}$	12	14.4	186.9	25	25	460	13
$^{127}\text{I}_{53}$	12	14.4	186.9	25	30	620	2.3
$^{197}\text{Au}_{79}$	13	15.0	210.0	33	33	350	9.1
$^{197}\text{Au}_{79}$	16	14.7	250.0	36	36	407	1.3
$^{197}\text{Au}_{79}$	13	15.0	210.0	33	33		4.6
$^{197}\text{Au}_{79}$	16	14.7	250.0	36	36		0.8

P. Thieberger January 2, 1991

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 210 MeV $^{79}\text{Au}^{197}$ $Q_{\text{HITL}} = 13$ $B_{\text{RHITL}} = 2.2515$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{MAX} (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$_{6}^{12}\text{C}$	1	10.2	20.4	1	6	1500	56
$_{8}^{16}\text{O}$	1	7.6	15.3	1	6	1248	52
$_{8}^{16}\text{O}$	1	7.6	15.3	1	7	1500	45
$_{9}^{19}\text{F}$	1	6.4	12.9	1	7	1217	54
$_{9}^{19}\text{F}$	1	6.4	12.9	1	8	1469	11
$_{14}^{28}\text{Si}$	2	11.7	35.0	2	10	1164	37
$_{14}^{28}\text{Si}$	2	11.7	35.0	2	12	1500	10
$_{15}^{31}\text{P}$	2	10.5	31.6	2	11	1154	38
$_{15}^{31}\text{P}$	2	10.5	31.6	2	13	1462	2.5
$_{16}^{32}\text{S}$	2	10.2	30.6	2	11	1101	42
$_{16}^{32}\text{S}$	2	10.2	30.6	2	13	1398	4.6
$_{17}^{35}\text{Cl}$	2	9.3	28.0	2	11	965	46
$_{17}^{35}\text{Cl}$	2	9.3	28.0	2	13	1232	7.6

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 210 MeV $^{79}\text{Au}^{197}$ $Q_{\text{HIL}} = 13$ $B_{\text{PHIL}} = 2.2515$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HIL} (MEV)	Q_{HIL}	Q_{BOOSTER}	E_{MAX} (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
^{56}Fe	4	14.0	69.9	4	17	916	2.3
^{63}Cu	4	12.4	62.2	4	18	835	28
^{63}Cu	4	12.4	62.2	4	20	980	5.7
^{70}Ge	5	14.6	87.4	5	21	900	21
^{70}Ge	5	14.6	87.4	5	23	1031	3.6
^{79}Br	5	12.9	77.5	5	21	748	24
^{79}Br	5	12.9	77.5	5	23	860	4.6
^{127}I	8	13.7	123.3	8	26	491	18
^{127}I	8	13.7	123.3	8	29	588	4.2
^{197}Au	13	15.0	210.0	13	34	369	9.1
^{197}Au	13	15.0	210.0	13	38	445	1.1
^{197}Au	13	15.0	210.0	13	34		4.6
^{197}Au	13	15.0	210.0	13	38		0.7

COMPARISON OF DEDICATED USE AND WORST-CASE SHARED USE

B E A M	DEDICATED USE		SHARED WORST-CASE ENERGIES			SHARED WORST-CASE INTENSITIES		
	ENERGY (MeV/AMU)	INTENSITY $\times 10^8$ FPP	ENERGY (MeV/AMU)	INTENSITY $\times 10^8$ FPP	PRIMARY BEAM	ENERGY (MeV/AMU)	INTENSITY $\times 10^8$ FPP	PRIMARY BEAM
${}^6\text{C}^{12}$	1500	99	1500	56	Au ${}^{13+}$	1500	56	Au ${}^{13+}$
${}^8\text{O}^{16}$	1500	71	1500	52	Au ${}^{13+}$	1500	52	Au ${}^{13+}$
${}^9\text{F}^{19}$	1500	70	1217	54	Au ${}^{13+}$	1500	50	S
${}^{14}\text{Si}^{28}$	1500	44	1164	37	Au ${}^{13+}$	1500	21	S
${}^{15}\text{P}^{31}$	1500	29	1154	38	Au ${}^{13+}$	1500	20	S
${}^{16}\text{S}^{32}$	1500	29	1249	41	C	1500	12	Cu
${}^{17}\text{Cl}^{35}$	1500	28	965	46	Au ${}^{13+}$	1500	18	Cu
${}^{26}\text{Fe}^{56}$	1248	1.5	836	1.3	Au ${}^{33+}$	836	1.3	Au ${}^{33+}$
${}^{29}\text{Cu}^{63}$	1127	19	763	17	Au ${}^{33+}$	1053	16	S
${}^{32}\text{Ge}^{70}$	1097	15	771	12	Au ${}^{33+}$	771	12	Au ${}^{33+}$
${}^{35}\text{Br}^{79}$	917	19	692	13	Au ${}^{33+}$	804	12	C
${}^{53}\text{I}^{127}$	620	12	460	13	Au ${}^{33+}$	654	9.0	Cu
${}^{79}\text{Au}^{197}$	350	12	170	22	S	350	12	Au ${}^{33+}$

P. Thieberger January 2, 1991

APPENDIX 2

by

H. Foelsche, P. Thieberger, and T. Robinson

APPENDIX 2

**COST ESTIMATE DETAILS
AND
LATEST SCHEDULE AS OF FEBRUARY 1991**

BOOSTER APPLICATIONS FACILITY

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

Upton, Long Island, New York 11973

Department of Physics

(516) 282-4581
FTS 666

February 28, 1991

Donald E. Robbins, Ph.D.
Chairman, NASA Facilities Panel
Lyndon B. Johnson Space Center
Houston, Texas 77058

Dear Dr. Robbins,

Thank you for your letter of February 8 and for the information regarding NASA's estimated requirements for the use of a radiation ground facility. Our proposed Booster Applications Facility would amply satisfy these requirements with one or perhaps two minor exceptions:

- 1) Even assuming an almost immediate start of the project, beam could only be delivered to the new experimental areas toward the end of 1994. This would allow sufficient time for thorough commissioning and testing but probably not for extensive use of the facility during 1994. Full two-cave operation, for the required number of hours, could start in 1995 and three-cave operation in 1997 as you require.
- 2) The maximum energies for all beams up to and including Cl^{35} will be well in excess of the required 1 GeV/nucleon. In fact these energies are all equal or close to 1.5 GeV/nucleon regardless of any other time sharing beam. For Fe^{56} , the maximum energy is 1.248 GeV/nucleon but rigidity matching requirements will, on occasion, lower this maximum energy to 0.916 GeV/nucleon. Some scheduling restrictions may apply to those Fe^{56} runs for which 0.916 GeV/nucleon is not sufficient. Much higher energies (up to ~ 14 GeV/nucleon) and much heavier ions (up to Au^{197}) will be available on the AGS floor, should such beams ever be required for special experiments or tests.

We have further refined our preliminary cost estimates. According to your requirements, we have studied a scenario in which two experimental areas are built and equipped as fast as possible (full operation in 1995) while the third one is built one year later and equipped two years later (full operation in 1997). This schedule and the corresponding commitment and expense profiles are summarized on one of the enclosed pages. Cost estimate details are also appended.

The operating costs have been recalculated for your estimated 2250 hours per year. A DOE mandated "full cost recovery factor for other federal agencies" of 1.032 has now been included in these calculations. Additional operation of the facility for other users is expected, and would of course lower the hourly cost.

Please let me know if you require additional information or if I can be of assistance in any other way.

Sincerely,

Peter Thieberger, Ph.D.

Head, Brookhaven Booster
Applications Facility Task Force

**Proposed Commitment and Expense Profiles
for the
Design, Construction, and Installation
of the
BNL Boster Applications Facility**

	Rooms B+C built and equipped	MP6 Tandem upgraded + connected	Room A built	Room A equipped	Commitment (at year K\$)	Expense (at year K\$)
1991					461	361
1992					12698	6887
1993					8132	11097
1994	✓	✓			5662	6952
1995			✓		1573	2752
1996				✓	412	889
1997						

TOTAL : 28,973

2/26/91

BOOSTER APPLICATIONS FACILITY OPERATIONS COST

The Booster Applications Facility (BAF) is expected to supply 2250 hours of ion beams yearly to NASA supported radiobiological and physics experiments. The funds necessary to support this endeavor will be supplied by NASA to BNL to provide for machine and beamline operations. We consider here the concurrent operations mode of the Booster. This assumes that the BAF program will share with other programs, such as high energy and nuclear physics, the operating time of the Booster. Note that the calculated costs are in FY1991 dollars and that the present DOE guidance for Booster and Tandem operations funding is assumed. The BAF costs will be reviewed on a yearly basis and be modified in response to changes in the DOE funding guidance and projected power costs.

For this concurrent running case we expect, for the near term future, to run the Booster approximately 26 weeks per year. An operational week is 168 hours, with a 36 hour maintenance period every 3 weeks, and a machine availability uptime of greater than 90%. We assume, for the NASA supported BAF program, that the Booster will supply beam for 24 hours per day, 7 days per week, except for maintenance periods. This results in approximately 14 weeks of elapsed time per year to acquire 2250 hours. In our cost calculation, we assume that most of the machine and personnel costs to provide beam is covered in the fractional base cost of items A and B in Table 1. The costs in Table 1 are broken down into labor (including fringe and overhead costs), purchases of materials and services (including overhead) and power costs (no overhead applied). We assume that the 14 weeks of operations are contiguous and are run concurrently with the AGS physics program. The determination of the fraction of the base costs is based upon the rationale that BAF requires 1/2 the Booster resources when it is operational, which in turn is just greater than 1/2 the available Booster operating time. We thus arrive at a fraction of $0.27(A+B)$. In addition to this base cost are the BAF specific items that are not covered under the base Booster operation costs. These are identified as items C and D in Table 1. Item C identifies those costs related to Booster pulsing, extraction and external beamline operations. Item D identifies those costs related to experimental area operations. Included here are the incremental power costs, purchases for materials and services, and the cost of

additional personnel that are not presently available. The additional personnel include professional support, such as for dosimetry, optics, life science liaison, and engineering liaison, and the additional technical support to maintain the extensive machine, beamline and experimental area equipment. We have not identified the costs for animal care. We note that the shift operator and administrative support is included in the fractional base costs of A+B. In addition, we also note that the costs to be incurred by NASA, on a yearly basis, would be reduced if other programs, yet to be identified, were to use the BAF and thus share the costs. We have identified as a separate item the 3.2% DOE full cost recovery factor surcharge for other Federal agencies such as NASA. The present projection of hourly costs is \$1825 for 2250 hours per year. Should the desired number of operations hours be otherwise, then the fraction of A+B costs and power costs in C+D would scale accordingly. The labor costs in C+D would not change and the purchase costs in C+D would vary slowly.

BOOSTER APPLICATIONS FACILITY YEARLY OPERATIONS COSTS
(FY1991\$)

Proposed Charging Algorithm for 2250 hours of shared use

* Includes 48.5% G&A

WBS #	DESCRIPTION	MATERIALS			PROJECT M&S		BNL LABOR SUMMARY				PROJECT TOTAL	
		qty	unit	unit cost \$	cost basis M&S K\$	M&S K\$	Net Project Months	Rate \$/month	AVAILABLE LABOR K\$	LABOR K\$	TOTAL K\$	TOTAL K\$
1.	: NASA BOOSTER AREA PROJECT COST (AT YEAR \$) 28.9 M\$:											
1.1	CONSTRUCTION (WITH CONTINGENCY)	1 LOT		6414879	0.0	6414.9	0.0 0.0	0	0.0	0.0	6414.9	
1.2	EXTRACTION COMPONENTS	1 LOT		55300	0.0	55.3	62.6 0.0	4910	0.0	307.2	362.5	
1.3	TRANSFER MAGNETS	1 LOT		983156	67.0	916.2	92.4 0.0	4708	0.0	435.2	1351.3	
1.4	EXTRACTION POWER SUPPLIES	1 LOT		241200	0.0	241.2	76.1 0.0	4840	0.0	368.5	609.7	
1.5	TRANSFER POWER SUPPLIES	1 LOT		335000	0.0	335.0	21.6 0.0	5185	0.0	112.0	447.0	
1.6	COLLIMATORS, STRIPPERS, STOPS	1 LOT		858510	0.0	858.5	47.3 0.0	4033	0.0	190.7	1049.2	
1.7	VACUUM SYSTEM	1 LOT		366380	31.6	334.8	56.3 0.0	5971	0.0	336.1	670.9	
1.8	CONTROLS	1 LOT		434400	0.0	434.4	117.0 0.0	5204	0.0	608.9	1043.3	
1.9	BEAM INSTRUMENTATION	1 LOT		374000	0.0	374.0	33.5 0.0	5448	0.0	182.5	556.5	
1.10	EXPERIMENTAL AREA OUTFITTING	1 LOT		1094800	150.0	944.8	50.7 0.0	4338	0.0	219.8	1164.6	
1.11	UTILITIES & SERVICES	1 LOT		430000	0.0	430.0	11.0 0.0	6529	0.0	71.8	501.8	
1.12	TANDEM & BEAM MODIFICATIONS (with contingency)	1 LOT		4181252	50.0	4131.3	154.4 0.0	5334	0.0	823.3	4954.5	
1.13	INSTALLATION	1 LOT		1232434	20.0	1212.4	129.8 0.0	4680	4.9	605.7	1818.2	
1.14	GENERAL SYSTEM SUPPORT	1 LOT		250000	85.0	165.0	73.0 0.0	5606	0.0	409.3	574.3	
1.15	CONTINGENCY (1.2 to 1.14)	25% OF		6301580		1575.4	269.9	=	35%	1346.7	2922.1	
1.16	BNL/DOE OVERHEAD	6.3% OF ABOVE				1160.7				379.1	1539.8	
	SUBTOTAL (FY 1991 K\$)				403.6	19583.8	1195.6	MAN MONTHS	6.6	6396.7	25980.4	
	ESCALATION (FY92 to FY96)					2176.8				780.9	2957.7	
1.	TOTAL (AT YEAR K\$)				403.6	21750.5	99.6	MAN YEARS	6.6	7177.6	28938.1	

H. Foelsche

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VBS #	DESCRIPTION	PROJECT TOTAL K\$	TOTAL COMMITMENT PROFILE (ANNUAL K\$)						
			FY 1991	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996	
1.	-----								

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VBS #	DESCRIPTION	PROJECT TOTAL K\$	TOTAL EXPENSE PROFILE (ANNUAL K\$)					
			FY 1991	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996
1.1	CONSTRUCTION (WITH CONTINGENCY)	6414.9	75.0	2869.9	2794.9	337.5	337.5	0.0
1.2	EXTRACTION COMPONENTS	362.5	0.0	206.4	149.8	6.3	0.0	0.0
1.3	TRANSFER MAGNETS	1351.3	0.0	389.9	589.1	224.9	134.7	12.8
1.4	EXTRACTION POWER SUPPLIES	609.7	0.0	300.7	285.3	23.7	0.0	0.0
1.5	TRANSFER POWER SUPPLIES	447.0	0.0	176.5	187.2	35.0	48.3	0.0
1.6	COLLIMATORS, STRIPPERS, STOPS	1049.2	0.0	335.5	368.1	194.2	144.4	7.0
1.7	VACUUM SYSTEM	670.9	0.0	151.0	301.9	201.3	16.7	0.0
1.8	CONTROLS	1043.3	0.0	173.9	447.8	378.2	43.4	0.0
1.9	BEAM INSTRUMENTATION	556.5	0.0	64.3	213.0	223.1	56.1	0.0
1.10	EXPERIMENTAL AREA OUTFITTING	1164.6	0.0	0.0	331.2	451.2	166.9	215.3
1.11	UTILITIES & SERVICES	501.8	0.0	104.0	225.8	150.5	21.5	0.0
1.12	TANDEM & BEAM MODIFICATIONS (with contingency)	4954.5	0.0	1127.5	2316.1	1349.8	161.1	0.0
1.13	INSTALLATION	1818.2	0.0	0.0	443.1	979.2	227.9	168.0
1.14	GENERAL SYSTEM SUPPORT	574.3	265.0	75.1	111.0	103.0	20.3	0.0
1.15	CONTINGENCY (1.2 to 1.14) (except 1.12)	2922.1	0.0	224.9	740.6	980.9	733.3	242.4
1.16	BHL/DOE OVERHEAD	1539.8	21.4	390.6	598.8	355.2	133.1	40.7
	SUBTOTAL (FY 1991 K\$)	25980.4	361.4	6590.1	10103.7	5993.8	2245.2	686.2
	ESCALATION (FY92 to FY96)	2957.7	0.0	296.6	993.1	757.8	507.2	203.0
1.	TOTAL (AT YEAR K\$)	28938.1	361.4	6886.7	11096.8	6951.6	2752.4	889.2
	CUMULATIVE		361.4	7248.1	18344.9	25296.6	28048.9	28938.1

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WBS #	DESCRIPTION	MATERIALS COMMITMENT PROFILE (ANNUAL K\$)						LABOR COMMITMENT & EXPENSE PROFILE (ANNUAL K\$)					
		FY 1991	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996	FY 1991	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996
		INITIAL	40%	50%	10%	0%	0%	INITIAL	25%	45%	30%	0%	0%
1.	: NASA BOOSTER AREA PROJECT	150.0	5589.9	0.0	675.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.1	CONSTRUCTION (WITH CONTINGENCY)	0.0	42.7	12.6	0.0	0.0	0.0	0.0	185.0	122.2	0.0	0.0	0.0
1.2	EXTRACTION COMPONENTS	0.0	642.4	95.3	152.9	25.6	0.0	0.0	68.8	220.3	100.8	45.4	0.0
1.3	TRANSFER MAGNETS	0.0	233.9	7.3	0.0	0.0	0.0	0.0	183.8	164.7	20.1	0.0	0.0
1.4	EXTRACTION POWER SUPPLIES	0.0	265.0	0.0	70.0	0.0	0.0	0.0	44.0	54.7	0.0	13.3	0.0
1.5	TRANSFER POWER SUPPLIES	0.0	527.0	54.4	263.0	14.1	0.0	0.0	72.0	77.4	35.4	5.8	0.0
1.6	COLLIMATORS, STRIPPERS, STOPS	0.0	133.9	167.4	33.5	0.0	0.0	0.0	84.0	151.2	100.8	0.0	0.0
1.7	VACUUM SYSTEM	0.0	43.4	304.1	86.9	0.0	0.0	0.0	152.2	274.0	182.7	6.0	0.0
1.8	CONTROLS	0.0	37.4	224.4	112.2	0.0	0.0	0.0	45.6	82.1	54.8	0.0	0.0
1.9	BEAM INSTRUMENTATION	0.0	0.0	636.6	0.0	308.2	0.0	0.0	0.0	12.8	132.8	12.8	61.3
1.10	EXPERIMENTAL AREA OUTFITTING	0.0	172.0	215.0	43.0	0.0	0.0	0.0	18.0	32.3	21.5	0.0	0.0
1.11	UTILITIES & SERVICES	0.0	2123.0	1686.0	322.3	0.0	0.0	0.0	66.0	411.6	345.6	0.0	0.0
1.12	TANDEM & BEAM MODIFICATIONS (with contingency)	0.0	0.0	740.4	292.5	147.0	32.5	0.0	0.0	72.9	462.8	8.1	62.0
1.13	INSTALLATION	30.0	40.5	54.0	40.5	0.0	0.0	250.0	39.8	63.7	55.7	0.0	0.0
1.14	GENERAL SYSTEM SUPPORT	0.0	274.8	581.2	450.7	198.7	70.0	0.0	87.5	312.6	464.9	408.6	73.1
1.15	CONTINGENCY (1.2 to 1.14) (except 1.12)	11.3	637.9	301.1	160.2	43.7	6.5	15.8	65.9	129.3	124.6	31.1	12.4
1.16	BNL/DOE OVERHEAD	191.3	10763.8	5079.8	2702.6	737.3	108.9	265.8	1112.6	2181.9	2102.6	525.2	208.6
	SUBTOTAL (FY 1991 K\$)	4.3	771.2	655.5	521.2	192.3	32.2	0.0	50.1	214.5	336.0	118.7	61.7
	ESCALATION (FY92 to FY96)	195.6	11535.0	5735.3	3223.8	929.6	141.2	265.8	1162.7	2396.4	2438.6	643.9	270.4
1.	T O T A L (AT YEAR K\$)	1.000	1.045	1.098	1.160	1.226	1.296	1.000	1.045	1.098	1.160	1.226	1.296 *
	INFLATION FACTORS ::												

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WBS #	DESCRIPTION	MATERIALS EXPENSE PROFILE (ANNUAL K\$)					LABOR COMMITMENT & EXPENSE PROFILE (ANNUAL K\$)						
		FY 1991	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996	FY 1991	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996
1.1	CONSTRUCTION (WITH CONTINGENCY)	75.0	2869.9	2794.9	337.5	337.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.2	EXTRACTION COMPONENTS	0.0	21.4	27.7	6.3	0.0	0.0	0.0	185.0	122.2	0.0	0.0	0.0
1.3	TRANSFER MAGNETS	0.0	321.2	368.8	124.1	89.3	12.8	0.0	68.8	220.3	100.8	45.4	0.0
1.4	EXTRACTION POWER SUPPLIES	0.0	117.0	120.6	3.7	0.0	0.0	0.0	183.8	164.7	20.1	0.0	0.0
1.5	TRANSFER POWER SUPPLIES	0.0	132.5	132.5	35.0	35.0	0.0	0.0	44.0	54.7	0.0	13.3	0.0
1.6	COLLIMATORS, STRIPPERS, STOPS	0.0	263.5	290.7	158.7	138.5	7.0	0.0	72.0	77.4	35.4	5.8	0.0
1.7	VACUUM SYSTEM	0.0	67.0	150.7	100.4	16.7	0.0	0.0	84.0	151.2	100.8	0.0	0.0
1.8	CONTROLS	0.0	21.7	173.8	195.5	43.4	0.0	0.0	152.2	274.0	182.7	0.0	0.0
1.9	BEAM INSTRUMENTATION	0.0	18.7	130.9	168.3	56.1	0.0	0.0	45.6	82.1	54.8	0.0	0.0
1.10	EXPERIMENTAL AREA OUTFITTING	0.0	0.0	318.3	318.3	154.1	154.1	0.0	0.0	12.8	132.8	12.8	61.3
1.11	UTILITIES & SERVICES	0.0	86.0	193.5	129.0	21.5	0.0	0.0	18.0	32.3	21.5	0.0	0.0
1.12	TANDEM & BEAM MODIFICATIONS (with contingency)	0.0	1061.5	1904.5	1004.1	161.1	0.0	0.0	66.0	411.6	345.6	0.0	0.0
1.13	INSTALLATION	0.0	0.0	370.2	516.5	219.8	106.0	0.0	0.0	72.9	462.8	8.1	62.0
1.14	GENERAL SYSTEM SUPPORT	15.0	35.3	47.3	47.3	20.3	0.0	250.0	39.8	63.7	55.7	0.0	0.0
1.15	CONTINGENCY (1.2 to 1.14) (except 1.12)	0.0	137.4	428.0	516.0	324.7	169.3	0.0	87.5	312.6	464.9	408.6	73.1
1.16	BNL/DOE OVERHEAD	5.7	324.6	669.5	230.6	101.9	28.3	15.8	65.9	129.3	124.6	31.1	12.4
	SUBTOTAL (FY 1991 K\$)	95.7	5477.6	7921.8	3691.2	1719.9	477.6	265.8	1112.6	2181.9	2102.6	525.2	208.6
	ESCALATION (FY92 to FY96)	0.0	246.5	778.7	621.8	388.5	141.3	0.0	50.1	214.5	336.0	118.7	61.7
	TOTAL (AT YEAR K\$)	2176.8	5724.1	8700.5	4513.0	2108.5	618.8	265.8	1162.7	2396.4	2438.6	643.9	270.4
1.	INFLATION FACTORS ::	1.00	1.045	1.098	1.160	1.226	1.296 *	1.00	1.045	1.098	1.160	1.226	1.296 *
			1.045	1.051	1.056	1.057	1.057 *		1.045	1.051	1.056	1.057	1.057 *

WBS #	DESCRIPTION	MATERIALS				PROJECT		BNL LABOR SUMMARY				PROJECT TOTAL K\$
		Qty	unit	unit cost \$	cost basis \$	INVENTORY M&S K\$	M&S K\$	Net Project Months	Rate \$/month	AVAILABLE LABOR K\$	LABOR K\$	
COST ESTIMATE IN FY 1991 \$DOLLARS												
1.	NASA BOOSTER AREA					403.60	18423.11	1195.6	4.87	6017.57		24440.68
1.1	CONSTRUCTION (WITH CONTINGENCY)	1 LOT		6414879		0.00	6414.88		0.00	0.00		6414.88
1.1.1	BEAM TUNNELS	1 LOT		1057018		0.00	1057.02		0.00	0.00		1057.02
1.1.2	SUPPORT BUILDING	1 LOT		810303		0.00	810.30		0.00	0.00		810.30
1.1.3	EXPERIMENTAL AREAS	1 LOT		1693755		0.00	1693.76		0.00	0.00		1693.76
1.1.4	SITE WORK	1 LOT		425600		0.00	425.60		0.00	0.00		425.60
1.1.5	CONTINGENCY (1.1.1 - 1.1.4)	20% of		3986675		0.00	797.34		0.00	0.00		797.34
1.1.6	FIELD SUPERVISION & OVERHEAD	6% of		4784010		0.00	287.04		0.00	0.00		287.04
1.1.7	CONTRACTOR PROFIT & OVERHEAD	15% of		5071051		0.00	760.66		0.00	0.00		760.66
1.1.8	ENGINEERING & ADMINISTRATION	10% of		5831708		0.00	583.17		0.00	0.00		583.17
1.2	EXTRACTION COMPONENTS	1 LOT		55300		0.00	55.30	62.56	4910	0.00	307.15	362.45
1.2.1	SEPTUM MAGNET	1 UNIT		34800		0.00	34.80	31.68	4966	0.00	157.31	192.11
1.2.2	ELECTROSTATIC SEPTUM	1 UNIT		20500		0.00	20.50	30.88	4852	0.00	149.84	170.34
1.3	TRANSFER MAGNETS	1 LOT		983156		67.00	916.16	92.44	4708	0.00	435.18	1351.33
1.3.1	QUADRUPOLES	25 UNITS		18780		0.00	469.49	32.00	4460	0.00	142.71	612.20
1.3.2	H DIPOLE	3 EACH		70553		29.00	182.66	10.00	5232	0.00	52.32	234.98
1.3.3	C DIPOLE	1 EACH		112804		28.00	84.80	24.00	5234	0.00	125.61	210.41
1.3.4	OCTUPOLES	6 EACH		9867		0.00	59.20	12.92	4893	0.00	63.22	122.42
1.3.5	TRIM DIPOLES	16 EACH		3125		10.00	40.00	8.19	3989	0.00	32.65	72.65
1.3.6	WOBLER	2 EACH		40000		0.00	80.00	5.33	3500	0.00	18.67	98.67
1.4	EXTRACTION POWER SUPPLIES	1 LOT		241200		0.00	241.20	76.13	4840	0.00	368.48	609.68
1.4.1	SEPTUM MAGNET POWER SUPPLY	1 UNITS		35900		0.00	35.90	39.33	4690	0.00	184.48	220.38
1.4.2	E/S SEPTUM POWER SUPPLY	1 UNITS		22300		0.00	22.30	20.13	4751	0.00	95.66	117.96
1.4.3	SEXTUPOLE POWER SUPPLY	2 EACH		10000		0.00	20.00	2.53	5395	0.00	13.67	33.67
1.4.4	EXTRACTION BUMP POWER SUPPLY	8 EACH		20000		0.00	160.00	8.27	5242	0.00	43.33	203.33
1.4.5	SPILL SERVO	1 EACH		3000		0.00	3.00	5.87	5341	0.00	31.33	34.33
1.5	TRANSFER POWER SUPPLIES	1 LOT		335000		0.00	335.00	21.60	5185	0.00	112.00	447.00
1.5.1	QUADRUPOLE POWER SUPPLY	25 EACH		5000		0.00	125.00	8.67	5115	0.00	44.33	169.33
1.5.2	DIPOLE POWER SUPPLY	4 EACH		35000		0.00	140.00	3.07	5326	0.00	16.33	156.33
1.5.3	OCTUPOLE POWER SUPPLY	6 EACH		5000		0.00	30.00	3.60	5278	0.00	19.00	49.00
1.5.4	TRIM DIPOLE POWER SUPPLIES	16 EACH		2500		0.00	40.00	6.27	5160	0.00	32.33	72.33
1.6	COLLIMATORS, STRIPPERS, STOPS	1 LOT		858510		0.00	858.51	47.29	4033	0.00	190.71	1049.22
1.6.1	ADJUSTABLE COLLIMATOR	8 ea		7045		0.00	56.36	30.29	3454	0.00	104.61	160.97
1.6.2	STRIPPER	2 ea		6075		0.00	12.15	12.00	5719	0.00	68.61	80.76
1.6.3	BEAM STOPS	3 ea		260000		0.00	780.00	0.00	0	0.00	0.00	780.00
1.6.4	COLLIMATOR CONTROL POWER	10 ea		1000		0.00	10.00	5.00	3500	0.00	17.50	27.50
1.7	VACUUM SYSTEM	1 LOT		366380		31.60	334.78	56.29	5971	0.00	336.11	670.89
1.7.1	INLINE COMPONENTS	1 lot		154460		31.60	122.86	33.57	6889	0.00	231.27	354.13
1.7.2	ION PUMPS & P.S.	1 lot		41520		0.00	41.52	6.60	4409	0.00	29.10	70.62
1.7.3	ROUGHING STATIONS	4 ea		24000		0.00	96.00	0.21	5000	0.00	1.07	97.07
1.7.4	VACUUM INSTRUM. & CONTROL	1 lot		74400		0.00	74.40	15.91	4694	0.00	74.67	149.07

H. Foelsche

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WBS #	DESCRIPTION	MATERIALS				PROJECT				BNL LABOR SUMMARY				PROJECT TOTAL K\$
		Qty	unit	unit cost \$	cost basis	INVENTORY	M&S	M&S	K\$	Net Project Months	Rate \$/month	AVAILABLE LABOR	LABOR K\$	
1.8	CONTROLS	1 LOT	434400	0.00	0.00	0.00	434.40			117.00	5204	0.00	608.90	1043.30
1.8.1	TIMING SYSTEM	1 lot	9500	0.00	0.00	0.00	9.50			5.00	4300	0.00	21.50	31.00
1.8.2	CONTROL ROOM	1 lot	113500	0.00	0.00	0.00	113.50			14.00	4357	0.00	61.00	174.50
1.8.3	NETWORK	1 lot	37600	0.00	0.00	0.00	37.60			5.00	5300	0.00	26.50	64.10
1.8.4	SOFTWARE DEVELOPMENT	1 lot	17000	0.00	0.00	0.00	17.00			18.00	5000	0.00	90.00	107.00
1.8.5	TVDG PROCESS CONTROLS	1 lot	26500	0.00	0.00	0.00	26.50			17.00	5735	0.00	97.50	124.00
1.8.6	BOOSTER EXTRACTION CONTROLS	1 lot	24200	0.00	0.00	0.00	24.20			14.00	6000	0.00	84.00	108.20
1.8.7	BEAM PROCESS CONTROLS	1 lot	50100	0.00	0.00	0.00	50.10			24.00	4850	0.00	116.40	166.50
1.8.8	INTERLOCK SYSTEM	1 lot	120000	0.00	0.00	0.00	120.00			6.00	5000	0.00	30.00	150.00
1.8.9	CONTROL SYSTEM INTEGRATION	1 lot	36000	0.00	0.00	0.00	36.00			14.00	5857	0.00	82.00	116.00
1.9	BEAM INSTRUMENTATION	1 LOT	374000	0.00	0.00	0.00	374.00			33.50	5448	0.00	182.50	556.50
1.9.1	BEAM PROFILE MONITOR	8 ea	33000	0.00	0.00	0.00	264.00			14.00	5857	0.00	82.00	346.00
1.9.2	SECONDARY EMISSION CHAMBERS	4 ea	1500	0.00	0.00	0.00	6.00			2.00	5000	0.00	10.00	16.00
1.9.3	FLAG SYSTEM	5 ea	10800	0.00	0.00	0.00	54.00			8.50	5353	0.00	45.50	99.50
1.9.4	DATA ACQUISITION & DISPLAY	1 lot	50000	0.00	0.00	0.00	50.00			9.00	5000	0.00	45.00	95.00
1.10	EXPERIMENTAL AREA OUTFITTING	1 LOT	1094800	0.00	0.00	150.00	944.80			50.66	4338	0.00	219.77	1164.57
1.10.1	TARGET AREA B (CELL CULTURE)	1 lot	281000	0.00	0.00	50.00	231.00			10.00	4025	0.00	40.25	271.25
1.10.2	TARGET AREA A (LARGE BEAM)	1 lot	194000	0.00	0.00	50.00	144.00			9.50	4053	0.00	38.50	182.50
1.10.3	TARGET AREA C	1 lot	138000	0.00	0.00	50.00	88.00			8.00	4156	0.00	33.25	121.25
1.10.4	READY ROOM B	1 lot	43200	0.00	0.00	0.00	43.20			5.16	4606	0.00	23.77	66.97
1.10.5	READY ROOM A	1 lot	45200	0.00	0.00	0.00	45.20			5.00	4550	0.00	22.75	67.95
1.10.6	READY ROOM C	1 lot	36500	0.00	0.00	0.00	36.50			5.00	4550	0.00	22.75	59.25
1.10.7	SUPPORT LAB EQUIPMENT	1 lot	356900	0.00	0.00	0.00	356.90			8.00	4813	0.00	38.50	395.40
1.11	UTILITIES & SERVICES	1 LOT	430000	0.00	0.00	0.00	430.00			11.00	6529	0.00	71.82	501.82
1.11.1	ELECTRICAL POWER DISTRIBUTION	1 LOT	130000	0.00	0.00	0.00	130.00			3.00	6569	0.00	19.71	149.71
1.11.2	COOLING WATER SYSTEM	1 LOT	300000	0.00	0.00	0.00	300.00			8.00	6515	0.00	52.12	352.12
1.12	TANDEM & BEAM MODIFICATIONS	1 LOT	4181252	0.00	0.00	50.00	4131.25			154.35	5334	0.00	823.29	4954.54
1.12.1	MP6 TANDEM UPGRADE	1 LOT	2220002	0.00	0.00	0.00	2220.00			45.00	5533	0.00	249.00	2469.00
1.12.2	BEAM BYPASS	1 LOT	1961250	0.00	0.00	50.00	1911.25			109.35	5252	0.00	574.29	2485.54
1.13	INSTALLATION	1 LOT	1232434	0.00	0.00	20.00	1212.43			129.80	4680	4.87	605.75	1818.18
1.13.1	CABLE	1 lot	794910	0.00	0.00	0.00	794.91			29.87	5505	0.00	164.43	959.34
1.13.2	TRAY	4000 ft	15	0.00	0.00	0.00	60.00			0.00	0.00	0.00	0.00	60.00
1.13.3	COOLING WATER HOSE	1 lot	11024	0.00	0.00	0.00	11.02			5.73	5591	0.00	32.06	43.08
1.13.4	MISCELLANEOUS PARTS	1 lot	5000	0.00	0.00	0.00	5.00			1.00	6353	0.00	6.35	11.35
1.13.5	STAGING	1 lot	500	0.00	0.00	0.00	0.50			1.00	6353	0.00	6.35	6.85
1.13.6	RIGGING	1 lot	0	0.00	0.00	0.00	0.00			11.60	6353	0.00	73.69	73.69
1.13.7	SURVEY	1 lot	0	0.00	0.00	0.00	0.00			3.32	6353	0.00	21.09	21.09
1.13.8	HOOKUP	1 lot	0	0.00	0.00	0.00	0.00			28.93	3526	0.00	102.03	102.03
1.13.9	RUN & TEST	1 lot	0	0.00	0.00	0.00	0.00			33.01	3523	0.00	116.31	441.31
1.13.10	INSTALLATION SUPPORT	1 LOT	36000	0.00	0.00	20.00	16.00			15.33	5519	4.87	83.43	99.43
1.14	GENERAL SYSTEM SUPPORT	1 LOT	250000	0.00	0.00	85.00	165.00			73.00	5606	0.00	409.25	574.25
1.14.1	MANUFACTURING SUPPORT	1 LOT	210000	0.00	0.00	85.00	125.00			31.00	5145	0.00	159.50	284.50
1.14.2	DESIGN SUPPORT	1 LOT	15000	0.00	0.00	0.00	15.00			12.00	5500	0.00	66.00	81.00
1.14.3	ADMINISTRATION & MANAGEMENT	1 LOT	25000	0.00	0.00	0.00	25.00			30.00	6125	0.00	183.75	208.75
1.15	CONTINGENCY	25% OF	6301580				1575.39			269.95	=	35%	1346.66	2922.06

H. Foelsche

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WBS #	DESCRIPTION	MATERIALS				PROJECT INVENTORY		BNL LABOR SUMMARY				PROJECT	PROJECT			
		Qty	unit	unit cost \$	cost Basis	M&S K\$	M&S K\$	Quant	Time	Unit	Man of Months	Net Project Months	Code Rate \$/month	AVAILABLE LABOR K\$	LABOR K\$	TOTAL K\$
1.1	CONSTRUCTION (WITH CONTINGENCY)	1 LOT		6414879		0.00	6414.88								6414.88	
1.1.1	BEAM TUNNELS	1 LOT		1057018		0.00	1057.02								1057.02	
1.1.1.1	Sheet Piling	2000 sf		25	625		50.00									
1.1.1.2	Concrete Tunnel/Headwalls	625 cy		350			218.75									
1.1.1.3	Access Halls, Entrances	100 cy		350			35.00									
1.1.1.4	Corrugated Tunnel	390 ft		300	400		117.00									
1.1.1.5	Emergency Exits	4 ea		30000			120.00									
1.1.1.6	Slab	170 cy		200	250		34.00									
1.1.1.7	Backfill	22000 cy		10	20000		220.00									
1.1.1.8	Mech. & Electr. Services	33% of		794750			262.27									
1.1.2	SUPPORT BUILDING	1 LOT		810303		0.00	810.30								810.30	
1.1.2.1	Retaining Walls	375 cy		350			131.25									
1.1.2.2	Slab on Ground	200 cy		200	250		40.00									
1.1.2.3	Labs, Offices etc	6000 sf		65	4000		390.00									
1.1.2.3	Support Building	1200 sf		40			48.00									
1.1.2.4	Mech. & Electr. Services	33% of		609250			201.05									
1.1.3	EXPERIMENTAL AREAS	1 LOT		1693755		0.00	1693.76								1693.76	
1.1.3.1	Structural Steel Trusses	0 ton		2000			0.00									
1.1.3.2	Structural Concrete	2750 cy		350			962.50									
1.1.3.3	Special Doors	2 ea		20000			40.00									
1.1.3.4	Misc. Metals, Pipes	1 lot		41000			41.00									
1.1.3.5	Water Proofing	25000 sf		2			50.00									
1.1.3.6	Painting all Areas	50000 sf		0.50			25.00									
1.1.3.7	Backfill	15500 cy		10			155.00									
1.1.3.8	Mech. & Electr. Services	33% of		1273500			420.26									
1.1.4	SITE WORK	1 LOT		425600		0.00	425.60								425.60	
1.1.4.1	Demolition & Clearing	3 wks		10000			30.00									
1.1.4.2	Excavation & Grading	1 lot		35000			35.00									
1.1.4.3	Sanitary & Storm	1 lot		20000			20.00									
1.1.4.4	Paving	3000 sy		20			60.00									
1.1.4.5	Power & Electrical	1 lot		30000			30.00									
1.1.4.6	Substation	1 lot		125000			125.00									
1.1.4.7	Top Soil & Seed	2 acres		10000			20.00									
1.1.4.8	Misc	33% of		320000			105.60									
1.1.5	CONTINGENCY (1.1.1 - 1.1.4)	20% of		3986675			797.34								797.34	
1.1.6	FIELD SUPERVISION & OVERHEAD	6% of		4784010			287.04								287.04	
1.1.7	CONTRACTOR PROFIT & OVERHEAD	15% of		5071051			760.66								760.66	
1.1.8	ENGINEERING & ADMINISTRATION	10% of		5831708			583.17								583.17	

VBS #	DESCRIPTION	MATERIALS			PROJECT		BNL LABOR SUMMARY					PROJECT			
		QTY	unit	cost \$	cost basis \$	INVENTORY M&S K\$	M&S K\$	Quant	Time	Unit of Time	Man Months	Code \$/month	Rate AVAILABLE LABOR K\$	LABOR K\$	TOTAL K\$
1.2	EXTRACTION COMPONENTS	1	LOT	55300		0.00	55.30		MONTH	62.56	62.56	4910	0.00	307.15	362.45
1.2.1	SEPTUM MAGNET	1	UNIT	34800		0.00	34.80	1	31.68 MONTHS	31.68	31.68	4966	0.00	157.31	192.11
1.2.1.1	Coil	2	ea	1250		0.00	2.50	2	0.61 MONTH	1.23	1.23	2700	0.00	3.31	5.81
1.2.1.1.1	Conductor	2	lot	100			0.20	2	20 hr	0.27	0.27	2700		0.72	
1.2.1.1.2	Downfeed	1	lot	100			0.10	1	20 hr	0.13	0.13	2700		0.36	
1.2.1.1.3	Macor Insulators	2	lot	200			0.40	2	40 hr	0.53	0.53	2700		1.44	
1.2.1.1.4	Power Connection	1	ea	1500			1.50	1	20 hr	0.13	0.13	2700		0.36	
1.2.1.1.5	Cleaning	1	fluid	100			0.10	1	8 hr	0.05	0.05	2700		0.14	
1.2.1.1.6	Bakeout	1	lot	0			0.00	1	0.000 hr	0.00	0.00	2700		0.00	
1.2.1.1.7	Other	2	lot	100			0.20	2	8 hr	0.11	0.11	2700		0.29	
1.2.1.2	Core	2	ea	8425		0.00	16.85	2	1.28 MONTH	2.56	2.56	4292	0.00	10.99	27.84
1.2.1.2.1	Laminations	5000	lams	0.50			2.50							0.00	
1.2.1.2.2	Punching Die (amortized)	1	die	10000			10.00							0.00	
1.2.1.2.3	Fixtures (amortized)	1	lct	2000			2.00							0.00	
1.2.1.2.4	Miscellaneous Parts	2	lot	1000			2.00							0.75	
1.2.1.2.5	Setup	2	unit	100			0.20	2	16 hr	0.21	0.21	3500		0.75	
1.2.1.2.6	Degrease	1	fluid	150			0.15	1	40 hr	0.27	0.27	3500		0.93	
1.2.1.2.7	Bakeout	1	lot	0			0.00	1	40 hr	0.93	0.93	3500		3.73	
1.2.1.2.8	Stacking	2	unit	0			0.00	2	80 hr	1.07	1.07	3500		3.89	
1.2.1.2.9	Welding	2	unit	0			0.00	2	40 hr	0.53	0.53	7303		3.89	
1.2.1.3	Vacuum Vessel	1	ea	6000		0.00	6.00	1	1.41 MONTH	1.41	1.41	6729	0.00	9.51	15.51
1.2.1.3.1	Material	1	lot	1500			1.50	1	140 hr	0.93	0.93	7303		6.82	
1.2.1.3.2	Cutting & Machining	1	lot	0			0.00							0.00	
1.2.1.3.3	Flanges	10	ea	50			0.50	1	40 hr	0.27	0.27	7303		1.95	
1.2.1.3.4	Welding	1	lot	0			0.00							0.00	
1.2.1.3.5	Valves	1	ea	2000			2.00							0.00	
1.2.1.3.6	Ion Pump & Supply		see Vacuum				0.00							0.00	
1.2.1.3.7	Bellows	1	lot	1000			1.00							0.00	
1.2.1.3.8	Gaskets	1	lot	250			0.25							0.00	
1.2.1.3.9	Fasteners	1	lot	250			0.25							0.00	
1.2.1.3.10	Gauges	1	lot	500			0.50							0.00	
1.2.1.3.11	Leakcheck	1	ea	0			0.00	1	16 hr	0.11	0.11	3500		0.37	
1.2.1.3.12	Bakeout	1	lot	0			0.00	1	16 hr	0.11	0.11	3500		0.37	
1.2.1.4	Beam Tube	1	ea	2450		0.00	2.45	1	0.48 MONTH	0.48	0.48	5257	0.00	2.52	4.97
1.2.1.4.1	Tube	1	ea	1500			1.50							0.00	
1.2.1.4.2	Seal	1	ea	100			0.10							0.00	
1.2.1.4.3	Bellows	1	ea	500			0.50							0.00	
1.2.1.4.4	Welding	1	lot	0			0.00							1.95	
1.2.1.4.5	RF Treatment	1	lot	100			0.10							0.36	
1.2.1.4.6	Cleaning	1	fluid	150			0.15							0.07	
1.2.1.4.7	Bakeout	1	lot	0			0.00							0.07	
1.2.1.4.8	Other	1	lot	100			0.10							0.07	
1.2.1.5	Cable Termination	1	lot	2000			2.00							0.72	2.72
1.2.1.6	Base & Supports	1	ea	4400		0.00	4.40						0.00	1.57	5.97
1.2.1.6.1	Base Plate	1	lot	1500			1.50							0.36	
1.2.1.6.2	Clamps & Blocks	12	ea	50			0.60							0.00	
1.2.1.6.3	Internal Adjustment Jacks	4	ea	50			0.20							0.00	
1.2.1.6.4	External Support Girder	1	ea	1500			1.50							0.36	
1.2.1.6.5	Jacks	4	ea	50			0.20							0.36	

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WBS #	DESCRIPTION	MATERIALS				PROJECT		BNL LABOR SUMMARY							PROJECT		
		Qty	unit	unit cost \$	cost basis \$	INVENTORY	M&S	Quant	Time	Unit	Man	Net	Code	Rate	AVAILABLE	LABOR	LABOR
							K\$					Months	\$/month	K\$		K\$	K\$
1.2.1.6.6	Welding	1	lot	0			0.00	1	10 hr	0.07	0.07	0.07	28	7303		0.49	
1.2.1.6.7	Fasteners & Clamps	1	lot	400			0.40										
1.2.1.7	Magnet Assembly	1	lot	200			0.20	1	120 hr	0.80	0.80	0.80	20	3500		2.80	3.00
1.2.1.8	Bakeout	1	lot	200			0.20	1	40 hr	0.27	0.27	0.27	21	2700		0.72	0.92
1.2.1.9	Checkout	1	lot	0			0.00	1	80 hr	0.53	0.53	0.53	20	3500		1.87	1.87
1.2.1.10	Miscellaneous	1	lot	200			0.20	1	100 hr	0.67	0.67	0.67	21	2700		1.80	2.00
1.2.1.11	Septum Magnet Engineering	1	lot			0.00	0.00		MONTH	23.00	23.00	23.00		5283	0.00	121.50	121.50
1.2.1.11.1	Conceptual Design	1	lot				0.00		MONTH	1	1.00	1.00	5	7000		7.00	
1.2.1.11.2	Detailed Engineering	1	lot				0.00		MONTH	5	5.00	5.00	6	5500		27.50	
1.2.1.11.3	Detailed Design	1	lot				0.00		MONTH	8	8.00	8.00	12	4500		36.00	
1.2.1.11.4	Specify Parts	1	lot				0.00		MONTH	2	2.00	2.00	6	5500		11.00	
1.2.1.11.5	Bid & Award Parts	1	lot				0.00		MONTH	2	2.00	2.00	6	5500		11.00	
1.2.1.11.6	Supervision	1	lot				0.00	0.125	24 MONTH	3	3.00	3.00	6	5500		16.50	
1.2.1.11.7	Testing	1	lot				0.00		MONTH	1	1.00	1.00	6	5500		5.50	
1.2.1.11.8	Documentation	1	lot				0.00		MONTH	1	1.00	1.00	5	7000		7.00	
1.2.2	ELECTROSTATIC SEPTUM	1	UNIT	20500		0.00	20.50	1	30.88 MONTHS	30.88	30.88	30.88		4852	0.00	149.84	170.34
1.2.2.1	Electrodes	1	lot	7500		0.00	7.50	1	3.466 MONTH	3.47	3.47	3.47	21	2700		9.36	16.86
1.2.2.1.1	Cathode	1	lot	1300			2.00	1	200 hr	1.33	1.33	1.33	21	2700		3.60	
1.2.2.1.2	Anode	1	lot	2000			2.00	1	200 hr	1.33	1.33	1.33	21	2700		3.60	
1.2.2.1.3	Downfeed	1	lot	100			0.10	1	20 hr	0.13	0.13	0.13	21	2700		0.36	
1.2.2.1.4	Macro Insulators	1	lot	200			0.20	1	40 hr	0.27	0.27	0.27	21	2700		0.72	
1.2.2.1.5	Feedthrough	1	ea	3000			3.00	1	20 hr	0.13	0.13	0.13	21	2700		0.36	
1.2.2.1.6	Cleaning	1	fluid	100			0.10	1	24 hr	0.16	0.16	0.16	21	2700		0.43	
1.2.2.1.7	Bakeout	1	lot	0			0.00	1	8 hr	0.05	0.05	0.05	21	2700		0.14	
1.2.2.1.8	Other	1	lot	100			0.10	1	8 hr	0.05	0.05	0.05	21	2700		0.14	
1.2.2.3	Vacuum Vessel	1	ea	6000		0.00	6.00	1	1.41 MONTH	1.41	1.41	1.41		6729	0.00	9.51	15.51
1.2.2.3.1	Material	1	lot	1500			1.50									0.00	
1.2.2.3.2	Cutting & Machining	1	lot	0			0.00	1	140 hr	0.93	0.93	0.93	28	7303		6.82	
1.2.2.3.3	Flanges	10	ea	50			0.50									0.00	
1.2.2.3.4	Welding	1	lot	0			0.00	1	40 hr	0.27	0.27	0.27	28	7303		1.95	
1.2.2.3.5	Valves	1	ea	2000			2.00									0.00	
1.2.2.3.6	Ion Pump & Supply	1	see Vacuum				0.00									0.00	
1.2.2.3.7	Bellows	1	lot	1000			1.00									0.00	
1.2.2.3.8	Gaskets	1	lot	250			0.25									0.00	
1.2.2.3.9	Fasteners	1	lot	250			0.25									0.00	
1.2.2.3.10	Gauges	1	lot	500			0.50									0.00	
1.2.2.3.11	Leakcheck	1	ea	0			0.00									0.37	
1.2.2.3.12	Bakeout	1	lot	0			0.00									0.37	
1.2.2.5	Cable Termination	1	lot	2000			2.00									0.00	2.72
1.2.2.6	Base & Supports	1	ea	4400		0.00	4.40	1	0.47 MONTH	0.47	0.47	0.47	21	3358	0.00	1.57	5.97
1.2.2.6.1	Base Plate	1	lot	1500			1.50	1	20 hr	0.13	0.13	0.13	21	2700		0.36	
1.2.2.6.2	Clamps & Blocks	12	ea	50			0.60									0.00	
1.2.2.6.3	Internal Adjustment Jacks	4	ea	50			0.20									0.36	
1.2.2.6.4	External Adjustment Jacks	1	ea	1500			1.50									0.00	
1.2.2.6.5	Internal Support Girder	4	ea	50			0.20									0.36	
1.2.2.6.6	Jacks	4	ea	50			0.20									0.36	
1.2.2.6.6	Welding	1	lot	0			0.00	1	10 hr	0.07	0.07	0.07	28	7303		0.49	
1.2.2.6.7	Fasteners & Clamps	1	lot	400			0.40									0.30	

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WBS #	DESCRIPTION	MATERIALS			PROJECT		BNL LABOR SUMMARY						PROJECT			
		qt'y	unit	unit cost \$	cost basis	M&S K\$	Quant	Time	Unit of Time	Man Months	Net Project Months	Code	Rate \$/month	AVAILABLE LABOR K\$	LABOR K\$	TOTAL K\$
1.2.2.7	Septum Assembly	1	lot	200		0.20	1	120 hr	0.80	0.80	20	3500		2.80	3.00	
1.2.2.8	Bakeout	1	lot	200		0.20	1	40 hr	0.27	0.27	21	2700		0.72	0.92	
1.2.2.9	Checkout	1	lot	0		0.00	1	80 hr	0.53	0.53	20	3500		1.87	1.87	
1.2.2.10	Miscellaneous	1	lot	200		0.20	1	100 hr	0.67	0.67	21	2700		1.80	2.00	
1.2.2.11	E/S Septum Engineering	1	lot			0.00		MONTH	23.00	23.00		5283	0.00	121.50	121.50	
1.2.2.11.1	Conceptual Design	1	lot			0.00		MONTH	1	1.00	5	7000		7.00		
1.2.2.11.2	Detailed Engineering	1	lot			0.00		MONTH	5	5.00	6	5500		27.50		
1.2.2.11.3	Detailed Design	1	lot			0.00		MONTH	8	8.00	12	4500		36.00		
1.2.2.11.4	Specify Parts	1	lot			0.00		MONTH	2	2.00	6	5500		11.00		
1.2.2.11.5	Bid & Award Parts	1	lot			0.00		MONTH	2	2.00	6	5500		11.00		
1.2.2.11.6	Supervision	1	lot			0.00	0.125	24	MONTH	3	3.00	6	5500		16.50	
1.2.2.11.7	Testing	1	lot			0.00		MONTH	1	1.00	6	5500		5.50		
1.2.2.11.8	Documentation	1	lot			0.00		MONTH	1	1.00	5	7000		7.00		

VBS #	DESCRIPTION	MATERIALS			PROJECT		BML LABOR SUMMARY					PROJECT		
		Qt'y	unit	unit cost \$	cost basis \$	M&S K\$	Quant	Time Unit	Man Months	Met Project Months	Code \$/month	Rate AVAILABLE LABOR K\$	LABOR K\$	TOTAL K\$
1.3	TRANSFER MAGNETS	1	LOT	983156	67.00	916.16		MONTH	92.44	92.44	4708	0.00	435.18	1351.33
1.3.1	QUADRUPOLES	25	UNITS	18780	0.00	469.49	25	1.280 MONTH	32.00	32.00	4460	0.00	142.71	512.20
1.3.1.1	Coils	100	coils	2180	0.00	218.00								218.00
1.3.1.1.1	Tooling (amortized)	1	set	28000	0.00	28.00								
	Winding Fixture	1	ea	10000		10.00								
	Annealing Rack	1	ea	2000		2.00								
	Wrapping Fixture	1	ea	6000		6.00								
	Curing Fixture	1	ea	10000		10.00								
1.3.1.1.2	Copper Conductor	12000	lb	3.00		36.00								
1.3.1.1.3	Setup	100	coil	100.00		10.00								
1.3.1.1.4	Joint Brazing	0	joint	250.00		0.00								
1.3.1.1.5	Winding	500	turns	50.00		25.00								
1.3.1.1.6	End Fittings	200	ea	120.00		24.00								
1.3.1.1.7	Sandblasting	100	coil	50.00		5.00								
1.3.1.1.8	Annealing	100	coil	50.00		5.00								
1.3.1.1.9	Wrapping	100	coil	200.00		20.00								
1.3.1.1.10	Impregnation	100	coil	200.00		20.00								
1.3.1.1.11	Testing	100	coil	50.00		5.00								
1.3.1.1.12	Handling	100	coil	50.00		5.00								
1.3.1.1.13	Package	25	crate	200.00		5.00								
1.3.1.1.14	Supervision	100	coil	250.00		25.00								
1.3.1.1.15	Shipping	25	crate	200.00		5.00								
1.3.1.2	Cores	100	cores	1480		147.99								147.99
1.3.1.2.1	Laminations	79680	lam	0.67	0.00	53.72								
	Die (amortized)	1	die	15000	15.00	0.00								
	Steel	40850	lb	0.42		17.16								
	Slitting	40850	lb	0.20		8.17								
	Stamping	79680	lam	0.30		23.90								
	Package	40850	lb	0.03		1.23								
	Shipping	40850	lb	0.08		3.27								
1.3.1.2.2	Setup	100	core	100		10.00								
1.3.1.2.3	Degrease	100	core	40		4.00								
1.3.1.2.4	Stacking	100	core	40		4.00								
1.3.1.2.5	Misc Parts	100	lot	65		6.50								
1.3.1.2.6	Tie Bars	100	core	50		5.00								
1.3.1.2.7	End Plate	100	core	50		5.00								
1.3.1.2.8	Welding	100	core	100		10.00								
1.3.1.2.9	Painting	100	core	100		10.00								
1.3.1.2.10	Grating	25	sets	260		6.50								
1.3.1.2.11	Supervision	100	core	300		30.00								
1.3.1.2.12	Shipping	40850	lb	0.08		3.27								
1.3.1.3	Stand	25	unit	3100	0.00	77.50	25	0.12 MONTH	3	3	5000	0.00	15.00	92.50
1.3.1.3.1	Stand	25	stand	1200		30.00	25	10 hr	1.67	1.67	5000		8.33	
1.3.1.3.2	Jacks	100	Jack	450		45.00	100	2 hr	1.33	1.33	5000		6.67	
1.3.1.3.3	Miscellaneous	25	lot	100		2.50							0.00	
1.3.1.4	Miscellaneous Parts	25	lot	800	0.00	20.00						0.00	0.00	20.00
1.3.1.4.1	Fittings	25	set	50		1.25							0.00	
1.3.1.4.2	Coils Spacer Springs	25	set	100		2.50							0.00	
1.3.1.4.3	Coil Spacer Blocks	25	set	100		2.50							0.00	

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WBS #	DESCRIPTION	MATERIALS			PROJECT		BNL LABOR SUMMARY						PROJECT				
		qt'y	unit	cost \$	cost basis \$	INVENTORY	M&S	Quant	Time	Unit	Man	Net	Code	Rate	AVAILABLE	LABOR	TOTAL
							K\$				of Months	Project Months		\$/month	K\$	K\$	K\$
	Package	58364	lb	0.03			1.75										
	Shipping	58364	lb	0.08			4.67										
1.3.2.2.2	Setup	3	core	300			0.90										
1.3.2.2.3	Degrease	3	core	700			2.10										
1.3.2.2.4	Stacking	3	core	700			2.10										
1.3.2.2.5	Misc Parts	3	lot	300			0.90										
1.3.2.2.6	Tie Bars	3	core	400			1.20										
1.3.2.2.7	End Plate	6	ea	500			3.00										
1.3.2.2.8	Welding	3	core	200			0.60										
1.3.2.2.9	Painting	3	core	250			0.75										
1.3.2.2.10	Crating	3	core	250			0.75										
1.3.2.2.11	Supervision	3	core	700			2.10										
1.3.2.2.12	Shipping	58363	lb	0.08			4.67										
1.3.2.3	Stand	3	unit	3100			9.30			0.36	0.36			5000	0.00	1.80	11.10
1.3.2.3.1	Jacks	12	stand	1200			3.60			0.20	0.20			5000		1.00	
1.3.2.3.2	Miscellaneous	3	lot	450			5.40							5000		0.80	
1.3.2.3.3	Miscellaneous Parts	3	lot	800			2.40								0.00	0.00	2.40
1.3.2.4	Fittings	3	set	50			0.15								0.00	0.00	
1.3.2.4.1	Coils Spacer Springs	3	set	100			0.30								0.00	0.00	
1.3.2.4.2	Coil Spacer Blocks	3	set	100			0.30								0.00	0.00	
1.3.2.4.3	Water Manifold	3	ea	100			0.30								0.00	0.00	
1.3.2.4.4	Flow Meter	3	ea	200			0.60								0.00	0.00	
1.3.2.4.5	Interlock Harness	3	ea	200			0.60								0.00	0.00	
1.3.2.4.6	Other Parts	3	lot	50			0.15								0.00	0.00	
1.3.2.4.7	Dipole Tooling	1	lot	1000			1.00								0.00	0.00	0.00
1.3.2.5	Dipole Assembly	3	magnet	100			0.00			2.64	2.64			3987	0.00	10.52	10.82
1.3.2.6	Staging	3	ea	100			0.00			0.16	0.16			6353		1.02	
1.3.2.6.1	Assembly	3	ea	100			0.00			2.00	2.00			3500		7.00	
1.3.2.6.2	Welding	3	ea	100			0.00			0.08	0.08			6353		0.51	
1.3.2.6.3	Checkout	3	ea	100			0.00			0.40	0.40			5000		2.00	
1.3.2.6.4	Miscellaneous	3	lot	100			0.30								0.00	0.00	0.30
1.3.2.7																	
1.3.2.8	H Dipole Engineering	1	lot				0.00				7.00			5714	0.00	40.00	40.00
1.3.2.8.1	Conceptual Design	1	lot				0.00				0.0000			7000		0.00	
1.3.2.8.2	Detailed Engineering	1	lot				0.00				0.0000			5500		0.00	
1.3.2.8.3	Detailed Design	1	lot				0.00				0.0000			4500		0.00	
1.3.2.8.4	Specify Parts	1	lot				0.00				0.0000			5500		0.00	
1.3.2.8.5	Bid & Award Parts	1	lot				0.00				2			5500		0.00	
1.3.2.8.6	Supervision	1	lot				0.00			24	3			5500		16.50	
1.3.2.8.7	Testing	1	lot				0.00				1			5500		5.50	
1.3.2.8.8	Documentation	1	lot				0.00				1			7000		7.00	
1.3.3	C DIPOLE	1	EACH	112804			28.00				24.00			5234	0.00	125.61	210.41
1.3.3.1	Coils	4	coil	18648			28.00										46.59
	Tooling (amortized)	1	set	28000			28.00										
	Winding Fixture	1	ea	10000			10.00										
	Annealing Rack	1	ea	2000			2.00										
	Wrapping Fixture	1	ea	6060			6.00										

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WBS #	DESCRIPTION	MATERIALS			PROJECT		BHL LABOR SUMMARY					PROJECT		PROJECT TOTAL K\$	
		Qt'y	unit	cost \$	cost basis	M&S K\$	Quant	Time	Unit of Time	Man Months	Met Project Months	Code \$/month	AVAILABLE LABOR K\$		LABOR K\$
	Curing Fixture	1	ea	10000		10.00									
	Copper Conductor	2040	lb	3.00											
	Setup	4	coil	100.00											
	Joint Brazing	4	joint	250.00											
	Winding	16	turns	50.00											
	End Fittings	8	ea	120.00											
	Sandblasting	4	coil	50.00											
	Annealing	4	coil	50.00											
	Wrapping	4	coil	200.00											
	Impregnation	4	coil	200.00											
	Testing	4	coil	50.00											
	Handling	4	coil	50.00											
	Package	2	crate	200.00											
	Supervision	4	coil	250.00											
	Shipping	2	crate	200.00											
1.3.3.2	Cores	1	core	33112											
1.3.3.2.1	Laminations	3650	lb	7.24		0.00									33.11
	Die (amortized)	1	die	40000		0.00									
	Steel	23725	lb	0.42											
	Slitting	23725	lb	0.20											
	Stamping	3650	lb	0.30											
	Package	23725	lb	0.03											
	Shipping	23725	lb	0.08											
	Setup	1	core	300											
	Degrease	1	core	700											
	Stacking	1	core	700											
	Misc Parts	1	lot	300											
	Tie Bars	1	core	400											
	End Plate	2	ea	500											
	Welding	1	core	200											
	Painting	1	core	250											
	Crating	1	core	250											
	Supervision	1	core	700											
1.3.3.2.11	Shipping	23725	lb	0.08											
1.3.3.2.12	Stand	1	unit	3100		0.00									
1.3.3.3.1	Jacks	1	stand	1200											
1.3.3.3.2	Miscellaneous	4	jack	450											
1.3.3.3.3	Miscellaneous Parts	1	lot	100											
1.3.3.4	Fittings	1	lot	800		0.00									
1.3.3.4.1	Coils Spacer Springs	1	set	50											
1.3.3.4.2	Coil Spacer Blocks	1	set	100											
1.3.3.4.3	Water Manifold	1	set	100											
1.3.3.4.4	Flow Meter	1	ea	100											
1.3.3.4.5	Interlock Harness	1	ea	200											
1.3.3.4.6	Other Parts	1	ea	200											
1.3.3.4.7	Dipole Tooling	1	lot	50											
1.3.3.5	Dipole Assembly	1	lot	1000		0.00									
1.3.3.6	Staging	1	magnet	100		0.00									
1.3.3.6.1	Assembly	1	ea	100											
1.3.3.6.2	Welding	1	ea	100											
1.3.3.6.3		1	ea	100											

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WBS #	DESCRIPTION	MATERIALS			PROJECT		BNL LABOR SUMMARY					PROJECT			
		Qty	unit	cost \$	cost basis	INVENTORY M&S K\$	Quant	Time Unit of Time	Man Months	Met Project Months	Code \$/month	Rate \$	AVAILABLE LABOR K\$	LABOR K\$	TOTAL K\$
1.3.3.6.4	Checkout	1	ea			0.00	1	20 hr	0.13	0.13	17	5000		0.67	0.10
1.3.3.7	Miscellaneous	1	lot	100		0.10								0.00	
1.3.3.8	C Dipole Engineering	1	lot			0.00		MONTH	23.00	23.00		5283	0.00	121.50	121.50
1.3.3.8.1	Conceptual Design	1	lot			0.00		MONTH	1	1.00	5	7000		7.00	
1.3.3.8.2	Detailed Engineering	1	lot			0.00		MONTH	5	5.00	6	5500		27.50	
1.3.3.8.3	Detailed Design	1	lot			0.00		MONTH	8	8.00	12	4500		36.00	
1.3.3.8.4	Specify Parts	1	lot			0.00		MONTH	2	2.00	6	5500		11.00	
1.3.3.8.5	Bid & Award Parts	1	lot			0.00		MONTH	2	2.00	6	5500		11.00	
1.3.3.8.6	Supervision	1	lot			0.00	0.125	24 MONTH	3	3.00	6	5500		16.50	
1.3.3.8.7	Testing	1	lot			0.00		MONTH	1	1.00	6	5500		5.50	
1.3.3.8.8	Documentation	1	lot			0.00		MONTH	1	1.00	5	7000		7.00	
1.3.4	OCTUPOLES	6	EACH	9867		59.20	6	2.15 MONTH	12.92	12.92		4893	0.00	63.22	122.42
1.3.4.1	Coils	48	ea	400		19.20								0.00	19.20
1.3.4.2	Cores	6	ea	3000		18.00								0.00	18.00
1.3.4.3	Supports	6	ea	1000		6.00	6	18 hr	0.72	0.72	18	3500		2.52	8.52
1.3.4.4	Miscellaneous Parts	6	lot	300		1.80								0.00	1.80
1.3.4.5	Trim Magnet Tooling	1	ea	10000		10.00	6	80 hr	3.20	3.20	18	3500		11.20	10.00
1.3.4.6	Assembly & Checkout	6	ea	500		3.00								0.00	14.20
1.3.4.7	Miscellaneous	6	ea	200		1.20								0.00	1.20
1.3.4.8	Octupole Engineering					0.00		MONTH	9	9.00	6	5500		49.50	49.50
1.3.5	TRIM DIPOLES	16	EACH	3125		40.00	16	0.51 MONTH	8.19	8.19		3989	0.00	32.65	72.65
1.3.5.1	Coils	32	ea	400		12.80								0.00	12.80
1.3.5.2	Cores	16	ea	400		6.40								0.00	6.40
1.3.5.3	Supports	16	ea	500		8.00	16	18 hr	1.92	1.92	18	3500		6.72	14.72
1.3.5.4	Miscellaneous Parts	16	lot	100		1.60								0.00	1.60
1.3.5.5	Trim Magnet Tooling	1	ea	10000		10.00								0.00	0.00
1.3.5.6	Assembly & Checkout	16	ea	500		8.00	16	40 hr	4.27	4.27	18	3500		14.93	22.93
1.3.5.7	Miscellaneous	16	ea	200		3.20								0.00	3.20
1.3.5.8	Trim Magnet Engineering					0.00		MONTH	2	2.00	6	5500		11.00	11.00
1.3.6	WOBLER	2	EACH	40000		80.00	2	2.67 MONTH	5.33	5.33		3500	0.00	18.67	
1.3.6.1	Wobbler Magnet	2	ea	20000		40.00								9.33	49.33
1.3.6.2	Wobbler Power Supply	2	ea	20000		40.00								9.33	49.33

WBS #	DESCRIPTION	QTY	UNIT	MATERIALS unit cost \$	INVENTORY cost basis \$	PROJECT M&S K\$	Quant	Time	Unit	Man of Months	Net Project Months	Code	Rate \$/month	AVAILABLE LABOR K\$	PROJECT LABOR K\$	PROJECT TOTAL K\$
1.4	EXTRACTION POWER SUPPLIES	1	LOT	241200	0.00	241.20	1	39.33	MONTH	76.13	76.13		4840	0.00	368.48	609.68
1.4.1	SEPTUM MAGNET POWER SUPPLY	1	UNITS	35900	0.00	35.90	1	39.33	MONTH	39.33	39.33		4690	0.00	184.48	220.38
1.4.1.1	Transformer	1	ea	10000		10.00	1	80 hr		0.53	0.53	16	3500		1.87	11.87
1.4.1.2	Transistor Bank	1	ea	13600		13.60	1	4.80 MONTH		4.80	4.80		3056		14.67	28.27
1.4.1.2.1	Transistors	40	ea	200		8.00	40	2 hr		0.53	0.53	21	2700		1.44	
1.4.1.2.2	Connections	40	ea	10		1.00	40	2 hr		0.53	0.53	21	2700		1.44	
1.4.1.2.3	Resistor Assembly	1	ea	1000		1.00	1	40 hr		0.27	0.27	21	2700		0.72	
1.4.1.2.4	Enclosure	1	ea	3100		3.10	1	40 hr		0.27	0.27	21	2700		0.72	
1.4.1.2.5	Support Hardware	1	lot	500		0.50	1	40 hr		0.27	0.27	21	2700		0.72	
1.4.1.2.6	Voltage Divider	1	ea	200		0.20	1	40 hr		0.27	0.27	21	2700		0.72	
1.4.1.2.7	Oil	0.0000	lot	0		0.00	0.0000	16 hr		0.00	0.00	21	2700		0.00	
1.4.1.2.8	Miscellaneous	1	lot	400		0.40	1	80 hr		0.53	0.53	21	2700		1.44	
1.4.1.2.9	Assembly & Pretest	1	unit	1000		1.00	1	320 hr		2.13	2.13	16	3500		7.47	
1.4.1.3	Control Racks	1	ea	7000		7.00	1	160 hr		1.07	1.07	21	2700		2.88	3.88
1.4.1.4	Control System	1	ea	5000	0.00	5.00	1	2 MONTH		2.00	2.00	16	3500	0.00	7.00	14.00
1.4.1.4.1	Master Controller	1	ea	2000		2.00	1	60 hr		0.40	0.40	16	3500		5.60	
1.4.1.4.2	Trigger Unit	1	ea	3300	0.00	3.30	1	2 MONTH		2.00	2.00	16	3500	0.00	1.40	
1.4.1.6	Miscellaneous	1	lot	2000		2.00	1	80 hr		0.53	0.53	21	2700		5.40	8.70
1.4.1.6.1	Local Cabling	1	lot	0		0.00	1	80 hr		0.53	0.53	21	2700		1.44	
1.4.1.6.2	Cable Termination	1	lot	1000		1.00	1	80 hr		0.27	0.27	21	2700		0.72	
1.4.1.6.3	Input Power Distribution	1	lot	300		0.30	1	40 hr		0.67	0.67	21	2700		1.80	9.00
1.4.1.6.4	Misc	1	lot	1000		1.00	1	100 hr		1.60	1.60	15	5000		8.00	9.00
1.4.1.7	System Assembly	1	lot			0.00	1	240 hr		1.33	1.33	15	5000		6.67	6.67
1.4.1.8	System Pretest	1	lot			0.00	1	200 hr		1.33	1.33	15	5000		6.67	
1.4.1.9	Septum Power Engineering	1	lot		0.00	0.00		MONTH	26.00	26.00	26.00		5308	0.00	138.00	138.00
	Conceptual Design				0.00	0.00		MONTH	1	1.00	1.00	3	7000		7.00	
	Detailed Engineering				0.00	0.00		MONTH	5	5.00	5.00	4	5500		27.50	
	Specify Parts				0.00	0.00		MONTH	8	8.00	8.00	12	4500		36.00	
	Bid & Award Parts				0.00	0.00		MONTH	2	2.00	2.00	4	5500		11.00	
	Supervision				0.00	0.00	0.25	MONTH	2	2.00	2.00	4	5500		33.00	
	Testing				0.00	0.00		MONTH	6	6.00	6.00	4	5500		5.50	
	Documentation				0.00	0.00		MONTH	1	1.00	1.00	4	5500		7.00	
1.4.2	E/S SEPTUM POWER SUPPLY	1	UNITS	22300	0.00	22.30	1	20.13	MONTH	20.13	20.13		4751	0.00	95.66	117.96
1.4.2.1	HV Power Supply	1	ea	10000		10.00	1	80 hr		0.53	0.53	16	3500		1.87	11.87
1.4.2.3	Control Racks	1	ea	1000		1.00	1	160 hr		1.07	1.07	21	2700		2.88	3.88
1.4.2.4	Control System	1	ea	5000	0.00	5.00	1	1.6 MONTH		1.60	1.60	16	3500	0.00	5.60	10.60
1.4.2.4.1	Master Controller	1	ea	5000		5.00	1	240 hr		1.60	1.60	16	3500		5.60	
1.4.2.6	Miscellaneous	1	lot	5300	0.00	5.30	1	2 MONTH		2.00	2.00	21	2700	0.00	5.40	10.70
1.4.2.6.1	Local Cabling	1	lot	2000		2.00	1	80 hr		0.53	0.53	21	2700		1.44	
1.4.2.6.2	Cable Termination	1	lot	2000		2.00	1	80 hr		0.53	0.53	21	2700		0.72	
1.4.2.6.3	Input Power Distribution	1	lot	1000		1.00	1	40 hr		0.27	0.27	21	2700		1.80	9.00
1.4.2.6.4	Misc	1	lot	300		0.30	1	100 hr		0.67	0.67	21	2700		8.00	9.00
1.4.2.7	System Assembly	1	lot	1000		1.00	1	240 hr		1.60	1.60	15	5000		6.67	6.67
1.4.2.8	System Pretest	1	lot			0.00	1	200 hr		1.33	1.33	15	5000		6.67	

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WBS #	DESCRIPTION	MATERIALS				PROJECT		BIL LABOR SUMMARY					PROJECT			
		Qty	unit	unit cost \$	cost basis \$	inventory M&S K\$	M&S K\$	Quant	Time	Unit	Man of Months	Met Project Months	Code \$/month	AVAILABLE LABOR K\$	LABOR K\$	PROJECT TOTAL K\$
1.4.2.9	E/S Septum Power Engineering	1	lot			0.00	0.00		MONTH	12.00	12.00	5438	0.00	65.25	65.25	
	Conceptual Design					0.00	0.00		MONTH	0.5	0.50	3	7000	3.50		
	Detailed Engineering					0.00	0.00		MONTH	1.5	1.50	4	5500	8.25		
	Detailed Design					0.00	0.00		MONTH	3	3.00	12	4500	13.50		
	Specify Parts					0.00	0.00		MONTH	1	1.00	4	5500	5.50		
	Bid & Award Parts					0.00	0.00		MONTH	1	1.00	4	5500	5.50		
	Supervision					0.00	0.00	0.25	12 MONTH	3	3.00	4	5500	16.50		
	Testing					0.00	0.00		MONTH	1	1.00	4	5500	5.50		
	Documentation					0.00	0.00		MONTH	1	1.00	3	7000	7.00		
1.4.3	SEXTUPOLE POWER SUPPLY	2	EACH	10000		0.00	20.00	2	1.27 MONTH	2.53	2.53	5395	0.00	13.67	33.67	
1.4.3.1	Sextupole Power Supply	2	ea	10000			20.00	2	40 hr	0.53	0.53	15	5000	2.67	22.67	
1.4.3.2	Engineering Support					0.00	0.00		MONTH	2	2.00	4	5500	11.00	11.00	
1.4.4	EXTRACTION BUMP POWER SUPPLY	8	EACH	20000		0.00	160.00	8	1.03 MONTH	8.27	8.27	5242	0.00	43.33	203.33	
1.4.4.1	Bump Power Supply	8	ea	20000			160.00	8	80 hr	4.27	4.27	15	5000	21.33	181.33	
1.4.4.2	Engineering Support					0.00	0.00		MONTH	4	4.00	4	5500	22.00	22.00	
1.4.5	SPILL SERVO	1	EACH	3000		0.00	3.00	1	5.87 MONTH	5.87	5.87	5341	0.00	31.33	34.33	
1.4.5.1	Spill Servo Hardware	1	lot	3000			3.00	1	80 hr	0.53	0.53	15	5000	2.67	5.67	
1.4.5.2	Assembly & Test Labor	1	lot			0.00	0.00	1	200 hr	1.33	1.33	15	5000	6.67	6.67	
1.4.5.3	Engineering Support	1	lot			0.00	0.00		MONTH	4	4.00	4	5500	22.00	22.00	

WBS #	DESCRIPTION	MATERIALS			PROJECT		BNL LABOR SUMMARY					PROJECT				
		qt'y	unit	cost \$	cost basis	INVENTORY M&S K\$	Quant	Time	Unit of Time	Man Months	Net Project Months	Code	Rate \$/month	AVAILABLE LABOR K\$	LABOR K\$	TOTAL K\$
1.5	TRANSFER POWER SUPPLIES	1	LOT	335000		0.00			MONTH	21.60	21.60		5185	0.00	112.00	447.00
1.5.1	QUADRUPOLE POWER SUPPLY	25	EACH	5000		0.00		25	0.35 MONTH	8.67	8.67		5115	0.00	44.33	169.33
1.5.1.1	Quadrupole Power Supply	25	ea	5000		125.00		25	40 hr	6.67	6.67	15	5000		33.33	158.33
1.5.1.10	Engineering Support					0.00			MONTH	2	2.00	4	5500		11.00	11.00
1.5.2	DIPOLE POWER SUPPLY	4	EACH	35000		0.00		4	0.77 MONTH	3.07	3.07		5326	0.00	16.33	156.33
1.5.2.1	Dipole Power Supply	4	ea	35000		140.00		4	40 hr	1.07	1.07	15	5000		5.33	145.33
1.5.2.10	Engineering Support					0.00			MONTH	2	2.00	4	5500		11.00	11.00
1.5.3	OCTUPOLE POWER SUPPLY	6	EACH	5000		0.00		6	0.60 MONTH	3.60	3.60		5278	0.00	19.00	49.00
1.5.3.1	Octupole Power Supply	6	ea	5000		30.00		6	40 hr	1.60	1.60	15	5000		8.00	38.00
1.5.3.10	Engineering Support					0.00			MONTH	2	2.00	4	5500		11.00	11.00
1.5.4	TRIM DIPOLE POWER SUPPLIES	16	EACH	2500		0.00		16	0.39 MONTH	6.27	6.27		5160	0.00	32.33	72.33
1.5.4.1	Trim Supply	16	ea	2500		40.00		16	40 hr	4.27	4.27	15	5000		21.33	61.33
1.5.4.10	Engineering Support					0.00			MONTH	2	2.00	4	5500		11.00	11.00

WBS #	DESCRIPTION	MATERIALS			PROJECT		BNL LABOR SUMMARY						PROJECT				
		Qty	unit	unit cost \$	cost basis \$	INVENTORY M&S K\$	M&S K\$	Quant	Time	Unit of Time	Man Months	Net Project Months	Code	Rate \$/month	AVAILABLE LABOR K\$	LABOR K\$	TOTAL K\$
1.6	COLLINATORS, STRIPPERS, STOPS	1	LOT	858510		0.00	858.51		MONTH	47.29	47.29		4033	0.00	190.71	1049.22	
1.6.1	ADJUSTABLE COLLINATOR	8	ea	7045		0.00	56.36	8	3.786	MONTH	30.29	30.29	3454	0.00	104.61	160.97	
1.6.1.1	Materials	8	lot	1700		0.00	13.60									13.60	
	Brass	3760	lb	2.50			9.40										
	Aluminum Stock	1600	lb	2.00			3.20										
	Misc	8	lot	125			1.00										
1.6.1.2	Purchases	8	lot	4300			34.40									34.40	
	ACME Shafts	16	shaft	400			6.40										
	Rails & Bushings	32	rail	150			4.80										
	Bellows Weldments	16	ea	250			4.00										
	Belows & Seals	16	ea	700			11.20										
	Motors, Gears, Misc.	8	lot	1000			8.00										
1.6.1.3	Weldments	8	lot	100			0.80										
1.6.1.4	Stands	8	ea	845		0.00	6.76	8	0.586	MONTH	4.69	11.95	28	48.69	0.00	0.58	
	Aluminum Stock	2880	lb	2.00			5.76									34.28	
	Misc Materials	8	lot	125			1.00									0.00	
1.6.1.5	Assembly & Test	8	lot	100		0.00	0.80	8	120	hr	6.40	6.40	17	5000	0.00	34.28	
1.6.1.6	Collimator Engineering	8	lot	100			0.00									32.00	
	Conceptual Design	1	lot				0.00					1	7000		7.00	37.75	
	Detailed Engineering						0.00					1	5500		5.50		
	Specify Parts						0.00					4	4500		18.00		
	Bid & Award Parts						0.00					0.5	5500		2.75		
	Supervision						0.00					0.50	6	5500		2.75	
	Testing						0.00								0.00		
	Documentation						0.00					0.25	5	7000		1.75	
1.6.2	STRIPPER	2	ea	6075		0.00	12.15	2	6.00	MONTH	12.00	12.00		5719	0.00	68.61	80.76
1.6.2.1	Foil Holders	2	lot	2050		0.00	4.10										
	Foil	20	foils	100.00			2.00									5.60	9.70
	Holder	20	ea	100.00			2.00									2.67	
	Misc	2	lot	50.00			0.10									0.27	
1.6.2.2	Purchases	2	lot	3600			7.20										7.20
	ACME Shafts	2	shaft	400.00			0.80										
	Rails & Bushings	4	rail	150.00			0.60										
	Bellows Weldments	4	ea	250.00			1.00										
	Belows & Seals	4	ea	700.00			2.80										
	Motors, Gears, Misc.	2	lot	1000.00			2.00										
1.6.2.3	Weldments	2	lot	100.00			0.20										
1.6.2.4	Stands	2	ea	225		0.00	0.45	2	0.053	MONTH	2.99	2.99	28	7303	0.00	21.81	22.01
	Aluminum Stock	100	lb	2.00			0.20									0.78	1.23
	Misc Materials	2	lot	125.00			0.25									0.00	
1.6.2.5	Assembly & Test	2	lot	100.00			0.20									0.78	
1.6.2.6	Stripper Engineering	1	lot			0.00	0.00									2.67	2.87
	Conceptual Design						0.00									37.75	37.75
	Detailed Engineering						0.00									7.00	
	Specify Parts						0.00									5.50	
							0.00									18.00	
							0.00									2.75	

WBS #	DESCRIPTION	MATERIALS			PROJECT		BHL LABOR SUMMARY				PROJECT	
		qt'y	unit	cost basis \$	cost basis M&S K\$	PROJECT M&S K\$	Quant	Time of Time	Unit Man Months	Net Project Months	Code \$/month	AVAILABLE LABOR K\$
	Bid & Award Parts					0.00		MONTH	0.5	0.50	6	5500
	Supervision					0.00						2.75
	Testing					0.00						0.00
	Documentation					0.00		MONTH	0.25	0.25	5	7000
1.6.3	BEAM STOPS	3	ea	260000	0.00	780.00						
1.6.4	COLLINATOR CONTROL POWER	10	ea	1000		10.00	10	0.50 MONTH	5.00	5.00	8	3500
												17.50
												780.00
												27.50

WBS #	DESCRIPTION	MATERIALS			PROJECT		BIL LABOR SUMMARY					PROJECT			
		Qty	unit	cost \$	unit cost \$	INVENTORY M&S K\$	M&S K\$	Quant	Time Unit	Man Months	Net Project Months	Code \$/month	Rate AVAILABLE LABOR K\$	LABOR K\$	TOTAL K\$
1.7	VACUUM SYSTEM	1	LOT	366380		31.60	334.78		MONTH	56.29	56.29	5971	0.00	336.11	670.89
1.7.1	INLINE COMPONENTS	1	lot	154460		31.60	122.86	1	33.57 MONTH	33.57	33.57	6889	0.00	231.27	354.13
1.7.1.1	Magnet Vacuum Chambers	1	lot	37500		0.00	37.50	25	20 hr	5.73	5.73	7303	0.00	41.87	79.37
	Quadrupole Chamber	25	ea	500			12.50	3	20 hr	3.33	3.33	7303		24.34	
	H Dipole Chamber	3	ea	3500			10.50	1	20 hr	0.40	0.40	7303		2.92	
	C Dipole Chamber	1	ea	3500			3.50	1	20 hr	0.13	0.13	7303		0.97	
	Octupole Chamber	6	ea	500			3.00	6	20 hr	0.80	0.80	7303		5.84	
	Trim Magnet Chamber	16	ea	500			8.00	16	10 hr	1.07	1.07	7303		7.79	
1.7.1.2	Bellos Assemblies	102	ea	160			16.32	102	4 hr	2.72	2.72	7303	0.00	19.86	36.18
1.7.1.3	Tubes	1	lot	6500		0.00	6.50	20	3 hr	1.62	1.62	7303		11.83	18.33
	Short	20	ea	20			0.40	61	3 hr	0.40	0.40	7303		2.92	
	Long	61	ea	100			6.10	10	5 hr	1.22	1.22	7303		8.91	
1.7.1.4	Tees	10	ea	160			1.60			0.33	0.33	7303		2.43	
1.7.1.5	Flanges	1	lot	23140		0.00	23.14	1	MONTH	0.17	0.17	3500	0.00	0.58	34.58
	Flange (Chamber Transition)	102	ea	20			2.04	5	2 hr	0.07	0.07	3500		0.23	
	Flange (Tubes & Tees)	211	ea	100			21.10	5	2 hr	0.07	0.07	3500		0.23	
1.7.1.6	Valves	1	lot	34000			34.00	5	5 hr	0.03	0.03	3500		0.12	
	In-Line	5	ea	2200			11.00	1	1 hr	0.27	0.27	3500		0.93	
	Roughing	1	ea	12000			2.00	40							
1.7.1.7	All Metal Valve	40	ea	50		31.60	1.80								
1.7.1.8	Support Brackets (in-line)	1	lot	33400		23.00	0.00								
	Vacuum Tooling	1	lot	23000		7.00	0.00								
	Magnet Chambers	1	lot	7000		0.40	-0.00								
	Flanges	1	lot	400		0.60	0.00								
	Bellos	1	lot	600		0.60	0.00								
	Tee Assemblies	1	lot	600		0.00	0.60								
	Tubes	1	lot	600		0.00	0.60								
1.7.1.9	Tube Supports	1	lot	1200		0.00	1.20								
1.7.1.10	Ion Pump Support Brackets	1	lot			0.00	0.00								
	Assembly Manpower														
	In-Line System Engineering														
	Conceptual Design														
	Detailed Engineering														
	Specify Parts														
	Bid & Award Parts														
	Supervision														
	Testing														
	Documentation														
1.7.2	ION PUMPS & P.S.	1	lot	41520		0.00	41.52	1	6.60 MONTH	6.60	6.60	4409	0.00	29.10	70.62
1.7.2.1	Beam Line Ion Pumps	10	ea	2400			24.00	10	5 hr	0.33	0.33	3500		1.17	25.17
1.7.2.2	Special Extraction Ion Pumps	2	ea	8400			16.80	2	8 hr	0.11	0.11	3500		0.37	17.17
1.7.2.3	Pump Support Brackets	12	ea	60			0.72	12	2 hr	0.16	0.16	3500		0.56	10.50
1.7.2.4	Ion Pump Assembly Manpower						0.00								
1.7.2.5	Ion Pump Engineering						0.00								
1.7.3	ROUGHING STATIONS	4	ea	24000			96.00	4	0.053 MONTH	0.21	0.21	5000		1.07	97.07

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		qty	unit	cost \$	cost basis	INVENTORY M&S K\$	PROJECT M&S K\$	Quant	Time	Unit of Time	Man Months	Net Project Months	Code \$/month	Rate AVAILABLE LABOR K\$	LABOR K\$	PROJECT TOTAL K\$
1.7.4	VACUUM INSTRUM. & CONTROL	1	lot	74400		0.00	74.40	1	15.90	MONTH	15.91	15.91	4694	0.00	74.67	149.07
1.7.4.1	Penning Gaug's	8	ea	600		4.80		8	1	hr	0.05	0.05	18		0.19	4.99
1.7.4.2	PIG Controls w/IF Ports	8	ea	1800		14.40		8	4	hr	0.21	0.21	18		0.75	15.15
1.7.4.3	Ion Pump Control w/IF Ports	12	ea	1800		21.60		12	4	hr	0.32	0.32	18		1.12	22.72
1.7.4.4	Device Controllers	4	ea	6000		24.00		4	4	hr	0.11	0.11	18		0.37	24.37
1.7.4.5	TC w/Control & IF Port	4	ea	1200		9.60		8	4	hr	0.21	0.21	18		0.75	10.35
1.7.4.6	I & C Assembly Manpower	8	ea			0.00				MONTH	6	6.00	18		21.00	21.00
1.7.4.7	Vacuum I & C Engineering									MONTH	9	9.00	5		50.50	50.50
	Conceptual Design									MONTH	1	1.00	5		7.00	7.00
	Detailed Engineering									MONTH	1	1.00	6		5.50	5.50
	Detailed Design									MONTH	2	2.00	12		9.00	9.00
	Specify Parts									MONTH	1	1.00	6		5.50	5.50
	Bid & Award Parts									MONTH	1	1.00	5		7.00	7.00
	Supervision									MONTH	1	1.00	6		5.50	5.50
	Testing									MONTH	1	1.00	6		5.50	5.50
	Documentation									MONTH	1	1.00	6		5.50	5.50

WBS #	DESCRIPTION	MATERIALS			PROJECT		BNL LABOR SUMMARY					PROJECT			
		qt'y	unit	unit cost \$	cost basis \$	M&S K\$	M&S K\$	quant	Time	Unit of Months	Man Months	Code \$/month	Rate \$/month	AVAILABLE LABOR K\$	LABOR K\$
1.8	CONTROLS	1	LOT	434400		0.00	434.40	1	MONTH	117.00	117.00	5204	0.00	608.90	1043.30
1.8.1	TIMING SYSTEM	1	lot	9500		0.00	9.50	1	MONTH	5.00	5.00	4300	0.00	21.50	31.00
1.8.1.1	Decoder Chassis	2	ea	3100			6.20								
1.8.1.2	Timing Interface	3	ea	1100			3.30								
1.8.1.3	Timing Assembly	1	lot				0.00								
1.8.1.4	Timing Engineering	1	lot				0.00								
1.8.2	CONTROL ROOM	1	lot	113500		0.00	113.50	1	MONTH	14.00	14.00	4357	0.00	61.00	174.50
1.8.2.1	Console Computers	3	ea	6500			19.50								
1.8.2.2	Console Displays	2	ea	12000			24.00								
1.8.2.3	General Equipment	1	lot	70000			70.00								
1.8.2.4	Control Room Assembly	1	lot				0.00								
1.8.2.5	Control Room Engineering	1	lot				0.00								
1.8.3	NETWORK	1	lot	37600		0.00	37.60	1	MONTH	5.00	5.00	5300	0.00	26.50	64.10
1.8.3.1	Network Station	4	ea	7500			30.00								
1.8.3.2	Network Server/Bridge	1	ea	6500			6.50								
1.8.3.3	Network Interface	1	ea	1100			1.10								
1.8.3.4	Network Assembly	1	lot				0.00								
1.8.3.5	Network Engineering	1	lot				0.00								
1.8.4	SOFTWARE DEVELOPMENT	1	lot	17000		0.00	17.00	1	MONTH	18.00	18.00	5000	0.00	90.00	107.00
1.8.4.1	Development Computers	2	ea	5000			10.00								
1.8.4.2	Peripherals	2	ea	2000			4.00								
1.8.4.3	Purchased Programs	2	ea	1500			3.00								
1.8.4.4	Software Engineering	1	lot				0.00								
1.8.5	TVDG PROCESS CONTROLS	1	lot	26500		0.00	26.50	1	MONTH	17.00	17.00	5735	0.00	97.50	124.00
1.8.5.1	P.S. Controller	1	ea	10000			10.00								
1.8.5.2	Vacuum Controller	1	ea	4000			4.00								
1.8.5.3	Instrumentation Controller	1	ea	9000			9.00								
1.8.5.4	Safety Interface	1	ea	3500			3.50								
1.8.5.5	TVDG Controls Assembly	1	lot				0.00								
1.8.5.6	TVDG Controls Engineering	1	lot				0.00								
1.8.6	BOOSTER EXTRACTION CONTROLS	1	lot	24200		0.00	24.20	1	MONTH	14.00	14.00	6000	0.00	84.00	108.20
1.8.6.1	Septum/Bump/Foil Controls	1	ea	16700			16.70								
1.8.6.2	Drive Sextupole Controls	1	ea	3500			3.50								
1.8.6.3	Vacuum Controls	1	ea	4000			4.00								
1.8.6.4	Extraction Controls Assembly	1	lot				0.00								
1.8.6.5	Extraction Cont. Engineering	1	lot				0.00								
1.8.7	BEAM PROCESS CONTROLS	1	lot	50100		0.00	50.10	1	MONTH	24.00	24.00	4850	0.00	116.40	166.50
1.8.7.1	P.S. & Collimator Controls	1	lot	31100			31.10								
1.8.7.2	Vacuum Controls	1	lot	4000			4.00								
1.8.7.3	Instrumentation Controls	1	lot	15000			15.00								
1.8.7.4	Beam Controls Assembly	1	lot				0.00								
1.8.7.5	Beam Controls Engineering	1	lot				0.00								
1.8.8	INTERLOCK SYSTEM	1	lot	120000		0.00	120.00	1	MONTH	6.00	6.00	5000	0.00	30.00	150.00

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UBS #	DESCRIPTION	MATERIALS			PROJECT		BNL LABOR SUMMARY					PROJECT					
		Qt'y	unit	unit cost \$	cost basis	cost inventory	M&S K\$	Quant	Time	Unit of Time	Man Months	Net Project Months	Code	Rate \$/month	AVAILABLE LABOR K\$	PROJECT LABOR K\$	PROJECT TOTAL K\$
1.8.9	CONTROL SYSTEM INTEGRATION	1	lot	36000		0.00	36.00	1		MONTH	14.00	14.00		5857	0.00	82.00	118.00
1.8.9.1	Cables & Connectors	1	lot	10000			10.00										
1.8.9.2	Racks & Hardware	1	lot	15000			15.00										
1.8.9.3	Miscellaneous Parts	1	lot	5000			5.00										
1.8.9.4	Assembly Materials	1	lot	3000			3.00										
1.8.9.5	EDIA Materials	1	lot	3000			3.00										
1.8.9.6	Systems Assembly	1	lot				0.00	1	8	MONTH	8.00	8.00	15	5000		40.00	
1.8.9.7	Systems Engineering	1	lot				0.00	1	6	MONTH	6.00	6.00	3	7000		42.00	

WBS #	DESCRIPTION	MATERIALS			PROJECT		BNL LABOR SUMMARY						PROJECT			
		Qty	unit	cost \$	cost basis	M&S K\$	INVENTORY M&S K\$	Quant	Time	Unit	Man of Months	Net Project Months	Code \$/month	Rate AVAILABLE LABOR K\$	LABOR K\$	PROJECT TOTAL K\$
1.9	BEAM INSTRUMENTATION	1	LOT	374000		0.00	0.00	1	MONTH	33.50	33.50	33.50	5448	0.00	182.50	556.50
1.9.1	BEAM PROFILE MONITOR	8	ea	33000		0.00	374.00	8	MONTH	14.00	14.00	14.00	5857	0.00	82.00	346.00
1.9.1.1	Harps	8	ea	20000			160.00									
1.9.1.2	Readout Electronics	8	ea	32000			96.00									
1.9.1.3	Local Monitor Cabling	8	ea	1000			8.00									
1.9.1.4	Profile Monitor Assembly	8	ea				0.00									
1.9.1.5	Profile Monitor Engineering	1	lot				0.00									
1.9.2	SECONDARY EMISSION CHAMBERS	4	ea	1500		0.00	6.00	4	0.5 MONTH	2.00	2.00	2.00	5000		10.00	16.00
1.9.3	FLAG SYSTEM	5	ea	10800		0.00	54.00	5	MONTH	8.50	8.50	8.50	5353	0.00	45.50	99.50
1.9.3.1	Flag Frame	5	ea	500			2.50									
1.9.3.2	Flag Box	5	ea	3000			15.00									
1.9.3.3	Flag Drive	5	ea	4300			21.50									
1.9.3.4	Flag Control Power	5	ea	1000			5.00									
1.9.3.5	Video System	5	ea	2000			10.00									
1.9.3.6	Flag System Assembly	5	ea				0.00									
1.9.3.7	Flag System Engineering	1	lot				0.00									
1.9.4	DATA ACQUISITION & DISPLAY	1	lot	50000		0.00	50.00	1	9 MONTH	9.00	9.00	9.00	5000		45.00	95.00

WBS #	DESCRIPTION	MATERIALS			PROJECT		BIL LABOR SUMMARY					PROJECT			
		Qt'y	unit	unit cost \$	cost basis \$	INVENTORY M&S K\$	M&S K\$	Quant	Time	Unit of Time	Man Months	Code \$/month	AVAILABLE LABOR K\$	LABOR K\$	TOTAL K\$
1.10	EXPERIMENTAL AREA OUTFITTING	1	LOT	1094800		50.00	944.80	1		MONTH	50.66	4338	0.00	219.77	1164.57
1.10.1	TARGET AREA B (CELL CULTURE)														
1.10.1.1	Clean Room Facility	1	lot	281000		50.00	231.00	1		MONTH	10.00	4025	0.00	40.25	271.25
1.10.1.2	Target Holder	50	ea	100000			100.00								
1.10.1.3	Target Positioner (x,y)	1	ea	7000			7.00	1	1 MONTH	1.00	1.00	16	3500	3.50	
1.10.1.4	Laser Alignment System	1	ea	2000			2.00	1	1 MONTH	1.00	1.00	16	3500	3.50	
1.10.1.5	Extractor Tube	1	ea	30000			30.00								
1.10.1.6	Gas Manifold	1	ea	2000			2.00								
1.10.1.7	Target Bench	1	ea	5000			5.00								
1.10.1.8	Optical Bench	1	ea	50000		50.00	0.00	2	2 MONTH	4.00	4.00	16	3500	14.00	
1.10.1.9	Ion Chamber	2	ea	25000			10.00								
1.10.1.10	Shielded Reference Area	1	ea	10000			20.00	1	1 MONTH	1.00	1.00	16	3500	3.50	
1.10.1.11	Video System	1	ea	20000			0.00	0.125	12 MONTH	1.50	1.50	15	5000	7.50	
1.10.1.12	General Outfitting Labor	1	lot				0.00	0.125	12 MONTH	1.50	1.50	4	5500	8.25	
1.10.1.13	Target Room A Engineering	1	lot												
1.10.2	TARGET AREA A (LARGE BEAM)														
1.10.2.1	Animal Positioning Chairs	1	lot	194000		50.00	144.00	1		MONTH	9.50	4053	0.00	38.50	182.50
1.10.2.2	Target Holder	50	ea	10000			30.00	3	0.5 MONTH	1.50	1.50	16	3500	5.25	
1.10.2.3	Target Positioner (x,y)	1	ea	100			5.00								
1.10.2.4	Laser Alignment System	1	ea	20000			20.00	1	1 MONTH	1.00	1.00	16	3500	3.50	
1.10.2.5	Gas Manifold	1	ea	2000			2.00	1	1 MONTH	1.00	1.00	16	3500	3.50	
1.10.2.6	Target Bench	1	ea	5000			5.00								
1.10.2.7	Optical Bench	1	ea	50000		50.00	0.00								
1.10.2.8	Ion Chamber (large)	1	ea	50000			50.00	1	2 MONTH	2.00	2.00	16	3500	7.00	
1.10.2.9	Shielded Reference Area	1	ea	10000			10.00								
1.10.2.10	Video System	1	lot	20000			20.00	1	1 MONTH	1.00	1.00	16	3500	3.50	
1.10.2.11	General Outfitting Labor	1	lot				0.00	0.125	12 MONTH	1.50	1.50	15	5000	7.50	
1.10.2.12	Target Room A Engineering	1	lot				0.00	0.125	12 MONTH	1.50	1.50	4	5500	8.25	
1.10.3	TARGET AREA C														
1.10.3.1	Miscellaneous	1	lot	138000		50.00	88.00	1		MONTH	8.00	4156	0.00	33.25	121.25
1.10.3.2	Small Animal Holder	3	ea	5000			5.00								
1.10.3.3	Target Positioner (x,y)	1	ea	20000			20.00	1	1 MONTH	1.00	1.00	16	3500	3.50	
1.10.3.4	Laser Alignment System	1	ea	2000			2.00	1	1 MONTH	1.00	1.00	16	3500	3.50	
1.10.3.5	Gas Manifold	1	ea	2000			2.00								
1.10.3.6	Target Bench	1	ea	5000			5.00								
1.10.3.7	Optical Bench	1	ea	50000		50.00	0.00								
1.10.3.8	Ion Chamber	1	ea	25000			25.00	1	2 MONTH	2.00	2.00	16	3500	7.00	
1.10.3.9	Shielded Reference Area	1	ea	10000			10.00								
1.10.3.10	Video System	1	lot	10000			10.00	1	1 MONTH	1.00	1.00	16	3500	3.50	
1.10.3.11	General Outfitting Labor	1	lot				0.00	0.125	12 MONTH	1.50	1.50	15	5000	7.50	
1.10.3.12	Target Room A Engineering	1	lot				0.00	0.125	12 MONTH	1.50	1.50	4	5500	8.25	
1.10.4	READY ROOM B														
1.10.4.1	Work Bench	1	lot	43200		0.00	43.20	1		MONTH	5.16	4606	0.00	23.77	66.97
1.10.4.2	Laminar Flow Hood	2	ea	2000			4.00								
1.10.4.3	Sink/Counter	1	ea	9000			9.00								
1.10.4.4	Refrigerator	1	ea	1000			1.00								
1.10.4.5	Dual Incubator	1	ea	1500			1.50								
		1	ea	7200			7.20								
								1	24 hr	0.16	0.16	27	6353	1.02	

H. Foelsche

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LBS #	DESCRIPTION	QTY	MATERIALS			PROJECT M&S K\$	BHL LABOR SUMMARY					PROJECT		
			unit	cost \$	cost basis		Quant	Time	Unit of Time	Man Months	Code	Rate \$/month	AVAILABLE LABOR K\$	LABOR K\$
1.10.7.9	Locking Cabinet	4	ea	500		2.00								
1.10.7.10	ph Meter	1	ea	3000		3.00								
1.10.7.11	Homogenizer	1	ea	3000		3.00								
1.10.7.12	Portable Hood	1	ea	1000		1.00								
1.10.7.13	Spiral Plater	1	ea	2000		2.00								
1.10.7.14	Spectrophotometer	1	ea	8000		8.00								
1.10.7.15	Power Supply	3	ea	2000		6.00								
1.10.7.16	Radioactive Waste Storage	1	lot	30000		30.00								
1.10.7.17	Radiation Monitors	10	ea	4000		40.00								
1.10.7.18	Cage Cleaning Area	1	lot	1000		1.00								
1.10.7.19	Animal Equipment	1	lot	97200	0.00	97.20								
1.10.7.19.1	Mouse Cages	200	ea	40		8.00								
1.10.7.19.2	Rat Cages	200	ea	40		8.00								
1.10.7.19.3	Primate Cages	3	ea	8000		24.00								
1.10.7.19.4	Cat Cages	3	ea	6500		19.50								
1.10.7.19.5	Dog Cages	4	ea	7300		29.20								
1.10.7.19.6	Cage Racks	4	ea	500		2.00								
1.10.7.19.7	Transport Cages	3	ea	1500		4.50								
1.10.7.19.8	Miscellaneous	1	tot	2000		2.00								
1.10.7.20	Desk	2	ea	1000		2.00								
1.10.7.21	General Outfitting Labor	1	tot			0.00	0.25	12 MONTH	3.00	15	5000		15.00	
1.10.7.22	Support Lab Engineering	1	tot			0.00	0.25	12 MONTH	3.00	4	5500		16.50	

LBS #	DESCRIPTION	MATERIALS				PROJECT		ENR LABOR SUMMARY				PROJECT		PROJECT			
		Qty	unit	unit cost \$	cost basis M&S K\$	INVENTORY M&S K\$	M&S K\$	Quant	Time	Unit of Time	Man Months	Net Project Months	Code	Rate \$/month	AVAILABLE LABOR K\$	LABOR K\$	TOTAL K\$
1.11	UTILITIES & SERVICES	1	LOT	430000		0.00	430.00			MONTH	11.00	11.00	6529	0.00	0.00	71.82	501.82
1.11.1	ELECTRICAL POWER DISTRIBUTION	1	LOT	130000		0.00	130.00			MONTH	3.00	3.00	6569	0.00	0.00	19.71	149.71
1.11.1.1	Experimental areas	1	lot	65000			65.00			MONTH	1	1.00	27	6353		6.35	
1.11.1.2	Power Supply House	1	lot	65000			65.00			MONTH	1	1.00	27	6353		6.35	
1.11.1.3	Power Engineering						0.00			MONTH	1	1.00	3	7000		7.00	
1.11.2	COOLING WATER SYSTEM	1	LOT	300000		0.00	300.00			MONTH	8.00	8.00	6515	0.00	0.00	52.12	352.12
1.11.2.1	Cooling System	1	lot	300000			300.00			MONTH	6	6.00	27	6353		38.12	
1.11.2.2	Cooling System Engineering						0.00			MONTH	2	2.00	5	7000		14.00	

WBS #	DESCRIPTION	MATERIALS				PROJECT		BML LABOR SUMMARY					PROJECT			
		QTY	UNIT	UNIT COST \$	COST BASIS	INVENTORY M&S K\$	M&S K\$	QUANT	TIME	UNIT OF TIME	MAN MONTHS	NET PROJECT MONTHS	CODE \$/MONTH	AVAILABLE LABOR K\$	LABOR K\$	TOTAL K\$
1.12	TANDEM & BEAM MODIFICATIONS	1	LOT	4181252		50.00	4131.25			MONTH	154.35	154.35	5334	0.00	823.29	4954.54
1.12.1	MP6 TANDEM UPGRADE	1	LOT	2220002		0.00	2220.00			MONTH	45.00	45.00	5533	0.00	249.00	2469.00
1.12.1.1	Acceleration Tubes, etc	1	lot	1200000			1200.00									
1.12.1.2	Dead Section Pumps, etc	1	lot	200000			200.00									
1.12.1.3	Voltage Dividers	1	lot	260000			260.00									
1.12.1.4	Connection Improvements	1	lot	20000			20.00									
1.12.1.5	Equipotential Ring Mounts	1	lot	20000			20.00									
1.12.1.6	Additional SF6	1	lot	200000			200.00									
1.12.1.7	Charging System, etc	1	lot	200000			200.00									
1.12.1.8	Ion Source Equipment	1	lot	30000			30.00									
1.12.1.9	Beam Chopper, etc	1	lot	30000			30.00									
1.12.1.10	Corona Actuator	1	ea	30000			30.00									
1.12.1.11	Generating Voltmeter	1	ea	10000			10.00									
1.12.1.12	Chart Recorder	1	ea	10000			10.00									
1.12.1.13	Terminal Foil Changer	1	ea	10000			10.00									
1.12.1.14	MP6 Assembly Labor	1	lot				0.00				33.00	33.00	15	5000	165.00	
1.12.1.15	MP6 Engineering	1	lot				0.00				12.00	12.00	3	7000	84.00	
1.12.1.16	Miscellaneous	0%	of	2220000			0.00				0.00	0.00			0.00	0.00
1.12.2	BEAM BYPASS	1	LOT	1961250		50.00	1911.25			MONTH	109.35	109.35	5252	0.00	574.29	2485.54
1.12.2.1	Magnet System	1	LOT	853000		50.00	803.00									803.00
1.12.2.1.1	90 Degree Dipole	2	ea	150000			300.00									
1.12.2.1.2	Power Supply (90 Degree)	2	ea	45000			90.00									
1.12.2.1.3	24 Degree Dipole	2	ea	40000			80.00									
1.12.2.1.4	Power Supply (24 Degree)	2	ea	25000		50.00	0.00									
1.12.2.1.5	Quadrupole Doubler	4	ea	22000			88.00									
1.12.2.1.6	Quad Power Supply	1	lot	70000			70.00									
1.12.2.1.7	Trim Magnet Pair	3	ea	6000			18.00									
1.12.2.1.8	Trim Power Supply	6	ea	5000			30.00									
1.12.2.1.9	Switching Magnet & P.S.	1	ea	75000			75.00									
1.12.2.1.10	NMR Gaussmeter	1	ea	40000			40.00									
1.12.2.1.11	Remove SREL Magnet	1	ea	12000			12.00									
1.12.2.2	Instrumentation System	1	LOT	223000		0.00	223.00									223.00
1.12.2.2.1	Profile Monitors	4	ea	30000			120.00									
1.12.2.2.2	Monitor Electronics	4	ea	12000			48.00									
1.12.2.2.3	Beam Stops	2	ea	20000			40.00									
1.12.2.2.4	Analog Multiplexer	1	ea	15000			15.00									
1.12.2.3	Vacuum System	1	LOT	161000		0.00	161.00									161.00
1.12.2.3.1	Pipe & Hardware	1	lot	40000			40.00									
1.12.2.3.2	Ion Pumps & P.S.	1	lot	35000			35.00									
1.12.2.3.3	Cryopumps & Controllers	1	lot	36000			36.00									
1.12.2.3.4	Ion Gauges, Controllers	1	lot	30000			30.00									
1.12.2.3.5	Valves	1	lot	20000			20.00									
1.12.2.4	Beam Line Control System	1	LOT	45000		0.00	45.00			MONTH	3.00	3.00	5000	0.00	15.00	60.00
1.12.2.4.1	Translator, etc	1	lot	15000			15.00									
1.12.2.4.2	Instrument Controllers	1	lot	20000			20.00									
1.12.2.4.3	Relay Extension	1	lot	10000			10.00									
1.12.2.4.4	Software Development	1	lot				0.00								15.00	
1.12.2.5	Other Items	1	LOT	57000		0.00	57.00			MONTH	6.00	6.00	6400	0.00	38.40	95.40
1.12.2.5.1	Misc Mechanical Hardware	1	lot	15000			15.00									

WBS #	DESCRIPTION	MATERIALS			PROJECT		BNL LABOR SUMMARY					PROJECT			
		qt'y	unit	unit cost \$	cost basis M\$	M\$	Quant	Time	Unit of Time	Man Months	Net Project Months	Code	Rate \$/month	AVAILABLE LABOR K\$	LABOR K\$
1.12.2.5.2	Installation	1	lot	12000		12.00	1	6 MONTH	6.00	6.00	30	6400		38.40	300.00
1.12.2.5.3	Communications, Security	1	lot	30000		30.00									240.00
1.12.2.6	Conventional Construction	1	lot	300000		300.00									132.00
1.12.2.7	General Support Labor	1	lot			0.00	1	48 MONTH	48.00	48.00	15	5000		240.00	471.14
1.12.2.8	Beam Line Engineering	1	lot			0.00	1	24 MONTH	24.00	24.00	4	5500		132.00	
1.12.2.9	Miscellaneous	25%	of	1289000		322.25	35%	81.0 MONTH	28.35	28.35				148.89	

WBS #	DESCRIPTION	MATERIALS			PROJECT		BNL LABOR SUMMARY					PROJECT			
		QTY	unit	unit cost \$	cost basis	M&S K\$	Quant	Time Unit	Man Months	Net Project Months	Code	Rate \$/month	AVAILABLE LABOR K\$	LABOR K\$	PROJECT TOTAL K\$
1.13	INSTALLATION	1	LOT	1232434		20.00	1	130.4 MONTH	130.47	129.80		4680	4.87	605.75	1818.18
1.13.1	CABLE	1	lot	794910		0.00	1	29.87 MONTH	29.87	29.87		5505	0.00	164.43	959.34
1.13.1.1	Extraction System Cable	1	lot	58690		0.00	1	3.44 MONTH	3.44	3.44		5634	0.00	19.38	
1.13.1.1.1	Septum&Bump Cable 500 MCH	8000	ft	7.00		56.00									
1.13.1.1.2	E/S Septum 100KV Coax	200	ft	5.00		1.00									
1.13.1.1.3	Purchase Connectors	1	lot	1690		0.00									
1.13.1.1.4	Installation	1	lot	0.00		0.00									
	Rigging	3	lot	0.00		0.00									
	Cut to Length	60	length	0.00		0.00									
	Add Connectors	120	conn	0.00		0.00									
	Test	60	length	0.00		0.00									
	Pull In Place	60	length	0.00		0.00									
1.13.1.2	Transfer Magnet Cable	1	lot	463320		0.00	1	18.08 MONTH	18.08	18.08		5615	0.00	101.51	
1.13.1.2.1	Purchase Cable 500 MCH	64800	ft	7.00		453.60									
1.13.1.2.2	Purchase Connectors	648	conn	15.00		9.72									
1.13.1.2.3	Installation	1	lot	0.00		0.00									
	Rigging	10	lot	0.00		0.00									
	Cut to Length	324	length	0.00		0.00									
	Add Connectors	648	conn	0.00		0.00									
	Test	324	length	0.00		0.00									
	Pull In Place	324	length	0.00		0.00									
1.13.1.3	Collimator Control Cable	1	lot	12600		0.00	1	0.313 MONTH	0.31	0.31		5038	0.00	1.58	
1.13.1.2.1	Purchase Cable	2500	ft	5.00		12.50									
1.13.1.2.2	Purchase Connectors	20	conn	5.00		0.10									
1.13.1.2.3	Installation	1	lot	0.00		0.00									
	Rigging	1	ea	0.00		0.00									
	Cut to Length	10	length	0.00		0.00									
	Add Connectors	20	conn	0.00		0.00									
	Test	10	length	0.00		0.00									
	Pull In Place	10	length	0.00		0.00									
1.13.1.4	Vacuum System Cable	1	lot	116120		0.00	1	1.373 MONTH	1.37	1.37		4793	0.00	6.58	
1.13.1.4.1	Purchase Cable	3000	ft	35000		0.00									
	Power Cable	4000	ft	5.00		20.00									
	Vacuum I&C Cable	104	ea	780.00		81.12									
1.13.1.4.2	Purchase Connectors	1	lot	0.00		0.00									
1.13.1.4.3	Installation	2	lot	0.00		0.00									
	Rigging	52	length	0.00		0.00									
	Cut to Length	104	conn	0.00		0.00									
	Add Connectors	52	length	0.00		0.00									
	Test	52	length	0.00		0.00									
	Pull In Place	52	length	0.00		0.00									
1.13.1.5	Instrumentation Cable	1	lot	49530		0.00	1	0.99 MONTH	0.99	0.99		4730	0.00	4.68	
	Purchase Cable	9750	ft	5.00		48.75									
	Purchase Connectors	78	conn	10.00		0.78									
	Installation	1	lot	0.00		0.00									
	Rigging	1	lot	0.00		0.00									

WBS #	DESCRIPTION	MATERIALS			PROJECT M&S		BNL LABOR SUMMARY							PROJECT		
		Qt'y	unit	unit cost \$	cost basis \$	M&S \$	Quant	Time	Unit of Man	Net Project Months	Code	Rate \$/month	AVAILABLE LABOR \$	LABOR \$	TOTAL \$	
1.13.1.6	Cut to Length	39	length	0.00	0.00	0.00	39	0.5 hr	0.13	0.13	27	6353		0.83		
	Add Connectors	78	conn	0.00	0.00	0.00	78	0.5 hr	0.26	0.26	22	2000		0.52		
	Test	39	length	0.00	0.00	0.00	39	0.5 hr	0.13	0.13	21	2700		0.35		
	Pull in Place	39	length	0.00	0.00	0.00	39	1.5 hr	0.39	0.39	27	6353		2.48		
	Controls Cable	1	lot	63500	0.00	63.50	1	2.746 MONTH	2.75	2.75		5603	0.00	15.39		
	Purchase Cable	12500	ft	5.00	10.00	62.50										
	Purchase Connectors	100	conn	1.00		1.00										
	Installation	1	lot	0.00	0.00	0.00	1	2.746 MONTH	2.75	2.75		5603	0.00	15.39		
	Rigging	1	lot	0.00	0.00	0.00	1	12 hr	0.08	0.08	27	6353		0.51		
	Cut to Length	50	length	0.00	0.00	0.00	50	0.5 hr	0.17	0.17	27	6353		1.06		
1.13.1.7	Add Connectors	100	conn	0.00	0.00	0.00	100	0.5 hr	0.33	0.33	22	2000		0.67		
	Test	50	length	0.00	0.00	0.00	50	0.5 hr	0.17	0.17	21	2700		0.45		
	Pull in Place	50	length	0.00	0.00	0.00	50	6 hr	2.00	2.00	27	6353		12.71		
	Utilities/Services Cable	1	lot	21900	0.00	21.90	1	1.68 MONTH	1.68	1.68		5617	0.00	9.44		
	Purchase Cable 500 MCM	1500	ft	14.00		21.00										
	Purchase Connectors	60	conn	15.00		0.90										
	Installation	1	lot	0.00	0.00	0.00	1	1.68 MONTH	1.68	1.68		5617	0.00	9.44		
	Rigging	1	lot	0.00	0.00	0.00	1	12 hr	0.08	0.08	27	6353		0.51		
	Cut to Length	30	length	0.00	0.00	0.00	30	0.5 hr	0.10	0.10	27	6353		0.64		
	Add Connectors	60	conn	0.00	0.00	0.00	60	0.5 hr	0.20	0.20	22	2000		0.40		
1.13.1.8	Test	30	length	0.00	0.00	0.00	30	0.5 hr	0.10	0.10	21	2700		0.27		
	Pull in Place	30	length	0.00	0.00	0.00	30	6 hr	1.20	1.20	27	6353		7.62		
	Interlock Cable	1	lot	9250	0.00	9.25	1	1.246 MONTH	1.25	1.25		4701	0.00	5.86		
	Purchase Cable	2500	ft	3.50	8.75	8.75										
	Purchase Connectors	100	conn	5.00	0.00	0.50	1	1.246 MONTH	1.25	1.25		4701	0.00	5.86		
	Installation	1	lot	0.00	0.00	0.00	1	12 hr	0.08	0.08	27	6353		0.51		
	Rigging	1	lot	0.00	0.00	0.00	50	0.5 hr	0.17	0.17	27	6353		1.06		
	Cut to Length	50	length	0.00	0.00	0.00	100	0.5 hr	0.33	0.33	22	2000		0.67		
	Add Connectors	100	conn	0.00	0.00	0.00	50	0.5 hr	0.17	0.17	21	2700		0.45		
	Test	50	length	0.00	0.00	0.00	50	0.5 hr	0.17	0.17	21	2700		3.18		
1.13.1.9	Pull in Place	50	length	0.00	0.00	0.00	50	1.5 hr	0.50	0.50	27	6353				
	Interconnecting Busbar	1	lot	0	0.00	0.00	1	0.00 MONTH	0.00	0.00		5576	0.00	0.00		
	Purchase Materials	0.0000	lb	2.85	0.00	0.00										
	Fabricate Busbar	0.0000	lot	10.00	0.00	0.00	0.000	0.10 MONTH	0.00	0.00		5576	0.00	0.00		
	Rigging	0.0000	lot	0.00	0.00	0.00	0.000	12 hr	0.00	0.00	27	6353	0.00	0.00		
	Cut, Bend	0.0000	ea	10	0.00	0.00	0.000	1 hr	0.00	0.00	22	2000	0.00	0.00		
	Insulate	0.0000	ea	0	0.00	0.00	0.000	1 hr	0.00	0.00	21	2700	0.00	0.00		
	Installation Busbar	0.0000	ea	0	0.00	0.00	0.000	1 hr	0.00	0.00	21	2700	0.00	0.00		
	TRAY	4000	ft	15.00		60.00	INCLUDES MANPOWER								60.00	
	1.13.2	COOLING WATER HOSE	1	lot	11024	0.00	11.02	1	5.733 MONTH	5.73	5.73		5591	0.00	32.06	
Purchase Hose		1060	ft	6.00		6.36										
Purchase Connectors		212	conn	22.00		4.66										
Installation		1	lot	0.00	0.00	0.00	1	5.733 MONTH	5.73	5.73		5591	0.00	32.06		
Rigging		1	lot	0.00	0.00	0.00	1	12 hr	0.08	0.08	27	6353		0.51		
Cut to Length		106	length	0.00	0.00	0.00	106	0.5 hr	0.35	0.35	27	6353		2.24		
1.13.3																

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WBS #	DESCRIPTION	MATERIALS				PROJECT		BNL LABOR SUMMARY					PROJECT			
		Qt'y	unit	unit cost \$	cost basis \$	INVENTORY M\$	M\$	Quant	Time	Unit of Time	Man Months	Net Project Months	Code \$/month	AVAILABLE LABOR K\$	LABOR K\$	TOTAL K\$
	Add Connectors	212	conn	0.00	0.00	0.00	0.00	212	0.5 hr	1 MONTH	0.71	0.71	22	2000	1.41	
	Test	106	length	0.00	0.00	0.00	0.00	106	0.5 hr	1 MONTH	0.35	0.35	21	2700	0.95	
	Pull in Place	106	length	0.00	0.00	0.00	0.00	106	6 hr	1 MONTH	4.24	4.24	27	6353	26.94	
1.13.4	MISCELLANEOUS PARTS	1	lot	5000	0.00	5.00	5.00	1	1	1 MONTH	1.00	1.00	27	6353	6.35	11.35
1.13.5	STAGING	1	lot	500	0.00	0.50	0.50	1	1	1 MONTH	1.00	1.00	27	6353	6.35	6.85
1.13.6	RIGGING	1	lot	0	0.00	0.00	0.00	1	11.6	1 MONTH	11.60	11.60	27	6353	73.69	73.69
1.13.6.1	Miscellaneous Equipment	10	lot	0	0.00	0.00	0.00	10	12 hr	1 MONTH	0.80	0.80	27	6353	5.08	
1.13.6.2	Extraction Magnets	2	ea	0	0.00	0.00	0.00	2	12 hr	1 MONTH	0.16	0.16	27	6353	1.02	
1.13.6.3	Transfer Magnets	51	ea	0	0.00	0.00	0.00	51	12 hr	1 MONTH	4.08	4.08	27	6353	25.92	
1.13.6.4	Extraction Power Supplies	12	ea	0	0.00	0.00	0.00	12	12 hr	1 MONTH	0.96	0.96	27	6353	6.10	
1.13.6.5	Transfer Power Supplies	51	ea	0	0.00	0.00	0.00	51	12 hr	1 MONTH	4.08	4.08	27	6353	25.92	
1.13.6.6	Collimators, Strippers	13	ea	0	0.00	0.00	0.00	13	12 hr	1 MONTH	1.04	1.04	27	6353	6.61	
1.13.6.7	Vacuum System	2	lot	0	0.00	0.00	0.00	2	12 hr	1 MONTH	0.16	0.16	27	6353	1.02	
1.13.6.8	Instrumentation	3	lot	0	0.00	0.00	0.00	3	12 hr	1 MONTH	0.24	0.24	27	6353	1.52	
1.13.6.9	Utilities & Services	1	lot	0	0.00	0.00	0.00	1	12 hr	1 MONTH	0.08	0.08	27	6353	0.51	
1.13.7	SURVEY	1	lot	0	0.00	0.00	0.00	1	3.32	1 MONTH	3.32	3.32	27	6353	21.09	21.09
	Extraction Magnets	2	ea	0	0.00	0.00	0.00	2	6 hr	1 MONTH	0.08	0.08	27	6353	0.51	
	Transfer Magnets	51	ea	0	0.00	0.00	0.00	51	6 hr	1 MONTH	2.04	2.04	27	6353	12.96	
	Collimators, Strippers	13	ea	0	0.00	0.00	0.00	13	6 hr	1 MONTH	0.52	0.52	27	6353	3.30	
	Instrumentation	17	ea	0	0.00	0.00	0.00	17	6 hr	1 MONTH	0.68	0.68	27	6353	4.32	
1.13.8	HOOKUP	1	lot	0	0.00	0.00	0.00	1	28.93	1 MONTH	28.93	28.93	27	3526	102.03	102.03
	Miscellaneous Equipment	10	lot	0	0.00	0.00	0.00	10	48 hr	1 MONTH	3.20	3.20	20	3500	11.20	
	Extraction Magnets	2	ea	0	0.00	0.00	0.00	2	16 hr	1 MONTH	0.21	0.21	20	3500	0.75	
	Transfer Magnets	51	ea	0	0.00	0.00	0.00	51	16 hr	1 MONTH	5.44	5.44	20	3500	19.04	
	Extraction Power Supplies	12	ea	0	0.00	0.00	0.00	12	32 hr	1 MONTH	2.56	2.56	16	3500	8.96	
	Transfer Power Supplies	51	ea	0	0.00	0.00	0.00	51	16 hr	1 MONTH	5.44	5.44	16	3500	19.04	
	Collimators, Strippers	13	ea	0	0.00	0.00	0.00	13	16 hr	1 MONTH	1.39	1.39	18	3500	4.85	
	Vacuum System	56	unit	0	0.00	0.00	0.00	56	4 hr	1 MONTH	1.49	1.49	20	3500	5.23	
	Instrumentation	17	unit	0	0.00	0.00	0.00	17	20 hr	1 MONTH	2.27	2.27	16	3500	7.93	
	Interlocks	50	unit	0	0.00	0.00	0.00	50	20 hr	1 MONTH	6.67	6.67	16	3500	23.33	
	Utilities & Services	1	lot	0	0.00	0.00	0.00	1	40 hr	1 MONTH	0.27	0.27	27	6353	1.69	
1.13.9	RUN & TEST	1	lot	0	0.00	325.00	325.00	1	33.01	1 MONTH	33.01	33.01	27	3523	116.31	441.31
	Miscellaneous Equipment	10	lot	0	0.00	0.00	0.00	10	60 hr	1 MONTH	4.00	4.00	20	3500	14.00	
	Extraction Magnets	2	ea	0	0.00	0.00	0.00	2	20 hr	1 MONTH	0.27	0.27	20	3500	0.93	
	Transfer Magnets	51	ea	0	0.00	0.00	0.00	51	20 hr	1 MONTH	6.80	6.80	20	3500	23.80	
	Extraction Power Supplies	12	ea	0	0.00	0.00	0.00	12	40 hr	1 MONTH	3.20	3.20	16	3500	11.20	
	Transfer Power Supplies	51	ea	0	0.00	0.00	0.00	51	20 hr	1 MONTH	6.80	6.80	16	3500	23.80	
	Collimators, Strippers	13	ea	0	0.00	0.00	0.00	13	20 hr	1 MONTH	1.73	1.73	18	3500	6.07	
	Vacuum System	56	unit	0	0.00	0.00	0.00	56	8 hr	1 MONTH	2.99	2.99	20	3500	10.45	
	Instrumentation	17	unit	0	0.00	0.00	0.00	17	32 hr	1 MONTH	3.63	3.63	16	3500	12.69	
	Interlocks	50	unit	0	0.00	0.00	0.00	50	10 hr	1 MONTH	3.33	3.33	16	3500	11.67	
	Utilities & Services	1	lot	0	0.00	0.00	0.00	1	40 hr	1 MONTH	0.27	0.27	27	6353	1.69	
	Commissioning	250	hrs	1300	0.00	325.00	325.00	1	1	1 MONTH	0.27	0.27	27	6353	1.69	
1.13.10	INSTALLATION SUPPORT	1	LOT	36000	20.00	20.00	16.00	1	MONTH	1 MONTH	16.00	15.33	28	5519	83.43	99.43
1.13.10.1	Magnet Transporter	1	unit	20000	20.00	20.00	0.00	1	0.666	MONTH	0.67	-0.00	28	7303	-0.00	-0.00
1.13.10.1.1	Transporter Parts	1	Lot	15000	15.00	15.00	0.00	1	100 hr	1 MONTH	0.67	-0.00	28	7303	-0.00	-0.00
1.13.10.1.2	Transporter Assembly	1	Lot	5000	5.00	5.00	0.00	1	100 hr	1 MONTH	0.67	-0.00	28	7303	-0.00	-0.00

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WBS #	DESCRIPTION	MATERIALS			PROJECT		BML LABOR SUMMARY					PROJECT		PROJECT TOTAL K\$	
		qty	unit	unit cost \$	cost basis \$	INVENTORY M&S K\$	M&S K\$	Quant	Time Unit	Man Months	Net Project Months	Code \$/month	AVAILABLE LABOR K\$		LABOR K\$
1.13.10.2	Tooling	1	unit	6000		0.00	6.00	1	0.333 MONTH	0.33	0.33	7303	0.00	2.43	8.43
	Purchase Materials		1 Lot	5000		5.00									
	Fabricate Tooling	1	Lot	1000		1.00	10.00	1	50 hr	0.33	0.33	7303		2.43	10.00
1.13.10.3	Miscellaneous Stores	1	Lot	10000											
1.13.10.4	Installation Engineering	1	lot			0.00	0.00	1	15.00 MONTH	15.00	15.00	5400	0.00	81.00	81.00
1.13.10.4.1	Cable Engineering	1	lot	0		0.00	0.00	1	1.500 MONTH	1.50	1.50	5500	0.00	8.25	8.25
	Cable Layout	1	lot	0		0.00	0.00	1	1 MONTH	1.00	1.00	5500		5.50	5.50
	Specify Cables	1	lot	0		0.00	0.00	1	0.5 MONTH	0.50	0.50	4	5500	2.75	2.75
	Bid & Award Cables	1	lot	0		0.00	0.00	1	0.00 MONTH	0.00	0.00	4	5500	0.00	0.00
1.13.10.4.2	Busbar Engineering	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	4500	0.00	0.00	0.00
	Detailed Design Busbar	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	12	4500	0.00	0.00
	Specify Material	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	12	4500	0.00	0.00
	Bid & Award Material	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	12	4500	0.00	0.00
1.13.10.4.3	Cable Tray Engineering	1	lot	0		0.00	0.00	1	0.500 MONTH	0.50	0.50	4500	0.00	2.25	2.25
	Tray Layout	1	lot	0		0.00	0.00	1	0.5 MONTH	0.50	0.50	4500		2.25	2.25
	Specify Material	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	12	4500	0.00	0.00
	Bid & Award Material	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	12	4500	0.00	0.00
1.13.10.4.4	Cooling Water Hose	1	lot	0		0.00	0.00	1	0.500 MONTH	0.50	0.50	4500	0.00	2.25	2.25
	Water Distribution Plans	1	lot	0		0.00	0.00	1	0.5 MONTH	0.50	0.50	12	4500	2.25	2.25
	Specify Material	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	12	4500	0.00	0.00
	Bid & Award Material	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	12	4500	0.00	0.00
1.13.10.4.5	Magnet Transporter	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	5166	0.00	0.00	0.00
	Conceptual Design	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	6	5500	0.00	0.00
	Detailed Engineering	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	6	5500	0.00	0.00
	Detailed Design	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	12	4500	0.00	0.00
	Specify Parts	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	12	4500	0.00	0.00
	Bid & Award Parts	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	12	4500	0.00	0.00
1.13.10.4.6	Tooling	1	lot	0		0.00	0.00	1	0.500 MONTH	0.50	0.50	4500	0.00	2.25	2.25
	Specify Tools	1	lot	0		0.00	0.00	1	0.5 MONTH	0.50	0.50	12	4500	2.25	2.25
	Bid & Award Tools	1	lot	0		0.00	0.00	1	0.000 MONTH	0.00	0.00	12	4500	0.00	0.00
1.13.10.4.7	General Supervision	1	lot	0		0.00	0.00	1	12 MONTH	12.00	12.00	6	5500	66.00	66.00

WBS #	DESCRIPTION	MATERIALS			PROJECT		BNL LABOR SUMMARY					PROJECT					
		qt'y	unit	unit cost \$	cost basis	INVENTORY M&S K\$	PROJECT M&S K\$	Quant	Time	Unit of Time	Man Months	Net Project Months	Code	Rate \$/month	AVAILABLE LABOR K\$	LABOR K\$	PROJECT TOTAL K\$
1.14	GENERAL SYSTEM SUPPORT	1	LOT	250000		85.00	165.00			MONTH	73.00	73.00		5606	0.00	409.25	574.25
1.14.1	MANUFACTURING SUPPORT	1	LOT	210000		85.00	125.00			MONTH	31.00	31.00		5145	0.00	159.50	284.50
1.14.1.1	Tooling & Instruments	1	LOT	85000		85.00	0.00			MONTH	10.00	10.00		5000	0.00	50.00	
	Magnet Assembly Tooling	1	lot	25000		25.00	0.00			MONTH	2	2.00	17	5000		10.00	
	Power Supply Support	1	lot	25000		25.00	0.00			MONTH	2	2.00	17	5000		10.00	
	Collimator Assembly Tooling	1	lot	5000		5.00	0.00			MONTH	2	2.00	17	5000		10.00	
	Vacuum Assembly Support	1	lot	5000		5.00	0.00			MONTH	2	2.00	17	5000		10.00	
	Controls Assembly Support	1	lot	25000		25.00	0.00			MONTH	2	2.00	17	5000		0.00	
1.14.1.2	General Expenses	1	lot	100000			100.00	0.125	24	MONTH	3	3.00	4	5500		16.50	
1.14.1.3	Manufacturing QA	1	lot	25000			25.00			MONTH	12	12.00	19	5000		60.00	
1.14.1.4	Manufacturing Supervision	1	lot							MONTH	6	6.00	6	5500		33.00	
1.14.1.5	Manufacturing Engineering	1	LOT	15000		0.00	15.00			MONTH	12.00	12.00		5500	0.00	66.00	81.00
1.14.2	DESIGN SUPPORT	1	lot	10000			10.00	0.25	12	MONTH	3	3.00	1	7500		22.50	
1.14.2.1	Beam Design	1	lot	5000			5.00			MONTH	3	3.00	11	5500		16.50	
1.14.2.2	Design Room Supervision	1	lot							MONTH	6	6.00	12	4500		27.00	
1.14.2.3	General Design Expenses	1	LOT	25000		0.00	25.00			MONTH	30.00	30.00		6125	0.00	183.75	208.75
1.14.3	ADMINISTRATION & MANAGEMENT	1	lot	5000			5.00	0.5	30	MONTH	15	15.00	3	7000		105.00	
1.14.3.1	Engineering Supervision	1	lot	5000			5.00	0.25	30	MONTH	7.5	7.50	1	7500		56.25	
1.14.3.2	Project Supervision	1	lot	15000			15.00	0.25	30	MONTH	7.5	7.50	25	3000		22.50	
1.14.3.3	Administrative Expenses	1	lot														

[illegible]

Installation Labor Table				CLASSIFICATION	CODE	MONTHLY SALARY
CUT	Cable Cut	1 length	0.5 hrs	Senior Scientist	1	7500
PULL	Cable Pull	1 length	6 hrs	Junior Scientist	2	5000
CONN	Connector Attachment	1 ea	0.5 hrs	Senior Engineer, Electrical	3	7000
TEST	Test Cable	1 length	0.5 hrs	Junior Engineer, Electrical	4	5500
RIGG	Rigging	1 unit	12 hrs	Senior Engineer, Mechanical	5	7000
HUBH	Hookup Beam Component	1 unit	16 hrs	Junior Engineer, Contract	6	5500
HUPS	Hookup Power Supply	1 unit	16 hrs	Senior Engineer, Contract	7	4500
HUCI	Hookup Contr. & Instr	1 unit	20 hrs	Junior Computer Analyst	8	3500
HUUT	Hookup Utility	1 lot	40 hrs	Senior Computer Analyst	9	6000
HUVA	Hookup Vacuum	1 unit	4 hrs	Junior Computer Analyst	10	5000
SURV	Survey Beam Component	1 unit	6 hrs	Senior Designer	11	5500
RTRH	Run & Test Beam Component	1 unit	20 hrs	Junior Designer, Contract	12	4500
RIPS	Run & Test Power Supply	1 unit	20 hrs	Senior Designer, Contract	13	4200
RTCI	Run & Test Contr. & Instr	1 unit	32 hrs	Junior Technician, Electrical	14	3300
RTVA	Run & Test Vacuum System	1 unit	8 hrs	Senior Technician, Electrical	15	5000
BCUT	Cut & Bend Busbar	1 unit	1 hrs	Junior Technician, Mechanical	16	3500
81MSUL	Insulate Busbar	1 unit	1 hrs	Senior Technician, Mechanical	17	5000
81NST	Install Busbar	1 unit	1 hrs	Junior Technician, Mechanical	18	3500
				Senior Technician, Electro-mechanical	19	5000
				Junior Technician, Electromechanical	20	3500
				Senior Technician, Contract Labor	21	2700
				Junior Technician, Contract Labor	22	2000
				Senior Administrative	23	6250
				Junior Administrative	24	4200
				Senior Clerical/Support	25	3000
				Junior Clerical/Support	26	2500
				Building Trades	27	6353
				Central Shops	28	7303
				Staff Shop	29	5126
				Davis Bacon Labor	30	6400

END

**DATE
FILMED**

6 / 29 / 92