IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981

PHYSICS AND MEDICINE: THE BEVATRON/BEVALAC EXPERIENCE, 1979-1980

F. Lothrop, J. Alonso, R. Force, H. Grunder, S. Lewis, R. Miller, M. Tekawa*
Lawrence Berkeley Laboratory, University of California
Berkeley, CA 94720

Summary

Heavy ion radiobiology has been integrated successfully into the research program at the Bevatron/Bevalac for the past several years. During the 1979-1980 year radiotherapy trials have been conducted side-by-side with the demanding program of heavy ion nuclear science research at this national facility. Careful attention is given to the scheduling of research on the SuperHILAC and Bevatron/Bevalac so that the nuclear science and biomedical programs at the Bevatron/Bevalac and the program at the SuperHILAC are served to maximum effect. Efforts to maximize the researchers' time have resulted in hardware, software, and operating improvements that offer a total machine availability of about 90% and a user availability of about 80%. Fast beam switching and beam sharing permit virtually simultaneous use of the Bevatron/Bevalac by two or more users. Current beam delivery systems will be augmented in FY81 to provide two ion energies per Bevatron/Bevalac pulse.

Introduction

Heavy ions have been accelerated at LBL's Bevatron since August of 1971 for research in both the nuclear science and biomedical disciplines. In August of 1974 the Bevalac came into being as the fusion of the SuperHILAC and the Bevatron into a single facility capable of delivering a variety of ions at energies from 50 MeV/nucleon to 2.1 GeV/nucleon. At the same time, by virtue of an elegant time-sharing technique, the SuperHILAC maintained its identity as an independent national research facility delivering ions at energies between 1.2 and 8.5 MeV/nucleon to the low-energy physics research program.

Encouraging results from studies in the biomedical field led to the installation of a treatment facility providing carbon, neon and argon ions for trial treatment of some forms of human cancer[1,2]. By the end of 1978 the Bevatron began regular patient therapy. Prior to patient trials the mix of nuclear science and biology was relatively easy to accommodate; the biology program used periodic blocks of time spaced far enough apart to maintain the efficiency of use of the accelerator for nuclear science experiments. Biology represented essentially just another experiment from the accelerator's point of view.

Scheduling

Achievement of a workable schedule of accelerator operation to include radiotherapy involved compromises by all participants; the SuperHILAC and Bevatron/Bevalac operating staffs, the nuclear scientists, the biologists, and the radiotherapists. An accelerator operated only for nuclear science would have large blocks of time (1-2 weeks) solidly devoted to a particular experiment with maintenance and studies between experimental runs. An accelerator operated only for radiotherapy and biology would be devoted to patient treatment during the day Monday through Friday, biology overnight, and maintenance and studies on the weekend. By November of 1978 a composite schedule had been instituted. An example, which is a small part of the master schedule for the SuperHILAC and Bevatron/Bevalac, is shown in Figure 1. The major attributes are: 1) radiotherapy (and some biology) Tuesday through Friday during the day, 2) nuclear science for short runs overnight during the week, except when a biomedical run is scheduled, 3) nuclear science on weekends, and 4) machine time for both the SuperHILAC and Bevatron/Bevalac on Monday. (Machine time includes maintenance and studies, plus some tuneup.) The success of the Bevatron/Bevalac is highly dependent on the SuperHILAC as an injector of heavy ions, and, therefore, the effect on the SuperHILAC research program of Bevatron/Bevalac requests for ions must be evaluated very carefully. A staff scheduling committee meets each week to resolve conflicts, disasters and potential disasters, and to detail the research program for the ensuing two to three months. The committee members include operations and development personnel from each machine and scientific liaison for each of the three research programs.

Multi-discipline Preparation

By the end of 1978 the Bevatron/Bevalac was technically ready to provide one of several projectiles at the energies and intensities desired for nuclear science and then, within minutes, provide a different particle at an energy and intensity suitable for therapy and/or biology. Computers by ModComp, supported by a large disc memory, assumed the tedium of monitoring, recording, maintaining, and recalling accelerator parameters previously set by operators for a particular mode of operation. In our synchrotron cycle the variety of parameters is large and includes information used every 200 microseconds for changing the frequency of the accelerating voltage, parameters used every 500 milliseconds for tuning the two injection lines, parameters used each 1-6 seconds for control of the magnetic guide field, and dc parameters for devices not needing to be pulsed in synchrony with the accelerator. Four ModComp II computers have been assigned to real-time control of machine functions, one in each of the time regimes. A ModComp IV-35 is the central processor in2a "star" configuration and handles all communications among operators, discs, tapes, and real-time processors.

The complete computer control system was applied to the Bevatron/Bevalac for the first time in the Fall of 1978 and was found to be praiseworthy for its universality and dispraiseworthy for the learning process imposed on the operations staff. In spite of the educational imposition, tuneup of the accelerator from one mode to another was expedited. By the spring of 1979 changes to the research program could be accomplished in as little as 15 minutes. Enhancement of these quick changes stemmed from the reproducibility of tunes: quick retrieval from the computer data base of the hundreds of parameters that needed to be reset, and the improved monitoring and

*This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division of the U.S. Department of Energy under Contract No. W-7405-ENG-48.

0018-9499/81/0600-2823$00.75©1981 IEEE

control hardware installed to achieve the potential offered by the ModComp system. Such brevity of change was absolutely essential to successful operation of the Bevatron/Bevalac as a combined nuclear science and therapy facility.

The Bevatron's local injector, designed to provide 20 MeV protons, was also capable of providing 5 MeV/nucleon deuterons, alphas, and carbon ions at diminishing intensities with heavier ions. An upgrade program was started which will enable it to deliver oxygen and neon ions, as well as the lighter ones, in quantities comparable to what is available from the SuperHILAC. Carbon intensities have already reached levels adequate for therapy. Ultimately, a change of tune from one program to another will routinely include a change of ion in addition to beam line, energy, and intensity, all in the space of a few minutes.

Beam lines served by the accelerator are shown in Figure 2. Of the eight beam lines set up in the experimental area, two are dedicated to biology and medicine, and are spurs from Channel II. Four of the nuclear science lines radiate from Channel I, and any one of them, in principle, can accept beam during biomed program operation. A septum magnet near the exit port of the machine provides the necessary splitting action. Beam may also be time-shared, but not to great benefit for the secondary experimenter.

Operating Experience

The overall statistics for FY79, shown in Table 1, are exemplary. Time spent in tuneup of the accelerator and beam lines at the start of the year was above 30%, decreasing as the operating year progressed and asymptotically approached 14% of the total operating time, a practical number for this accelerator. In the early portion of that operating period at least two phenomena contributed to the high tuneup time. The first was a recapture of skills by the operating crew, lost to some extent during the two-plus months of budgetary shutdown. The second was their acquisition of new skills required for mastery of the ModComp control system operation and quick changes of accelerator parameters twice a day. Nevertheless, mastery came and changes between nuclear science experiments and biomed/therapy work were reduced to reasonable times.

TABLE 1
Bevatron/Bevalac Operation Record
FY 79-80

	FY79	FY80
Nuclear Science	1856 hours	1927 hours
Biology & Medicine	1046	1518
Total operation for experiments	2902	3445
Machine development	299	420
Total research	3201	3865
Tuning	919	972
	4120	4837
Unscheduled maintenance	788	682
Total scheduled operation	4908	5519

The remaining loss to useful research time, failures of equipment, at 16% for 1979 and 12% for 1980, is as low as one should ever expect from a research machine and represents a concerted effort by the operations group to operate equipment conservatively and repair failures expeditiously. The advent of patient therapy had a substantial influence on the Bevatron/Bevalac availability in this respect. The staff was imbued with an espirit de corps and enthusiasm for a successful radiotherapy program that elevated the availability of the machine to the 85-90% figure rather than the 75-80% which is typical for straight nuclear science operation. Nuclear science deserves and gets the full attention of the staff, but the nature of that research is to exercise the limits of operation. Thus the percentage of its scheduled time actually available to nuclear science is less than that for biology and medicine, but is still very high, considering the complexity of the accelerator and its operation.

Ions Delivered

During the course of 1980 the Bevatron/Bevalac delivered eleven different ion species to its experimenters. Table 2 details the intensities and percentage of operating time for each ion.

Carbon, neon, and argon are the most popular ions. High intensity argon beams are most desired but because of conflicts with the SuperHILAC research program they are not often available. Argon operation in 1979 included a substantial amount of low intensity ($\geq 5\times10^7$/ pulse) operation whereas argon experiments in 1980 were designed for high intensity; they either accepted high intensity neon, or were one of the very few argon experiments run in 1980, or agreed to postpone the high intensity argon until a later time.

The zenith of versatility at the Bevatron/Bevalac was approached in July of 1980 when five different ion species were delivered in succession in a period of 24 hours. In a nuclear science experiment, emulsions were sequentially exposed to various incident particles. Adroit switching among injectors allowed time for readying a new ion beam for tuneup during the emulsion exposures. Initial alphas gave way to lithium, carbon, neon, and, finally, argon was run.

TABLE 2
Bevatron/Bevalac Ions Delivered

	FY79		FY80	
Ion	Intensity	Percent of Total	Intensity	Percent of Total
protons	1.5×10^{11}	5.7	1.5×10^{10}	7.1
deuterons	---		1.0×10^{7}	0.8
helium	1.3×10^{10}	3.1	1.5×10^{10}	7.5
carbon	2.2×10^{10}	45.4	1.2×10^{10}	29.6
nitrogen	1.0×10^{4}	.01	1.0×10^{6}	0.2
oxygen	5.0×10^{8}	2.1	3.5×10^{8}	1.8
neon	6.0×10^{9}	22.5	4.5×10^{9}	41.4
silicon	---		2.5×10^{8}	0.6
calcium	4.0×10^{7}	3.0	1.0×10^{7}	0.3
argon	6.0×10^{8}	16.2	2.6×10^{8}	8.9
iron	1.4×10^{6}	2.0	$1\ \times10^{3}$	1.8

Conclusion

Nuclear science and biomedical use of the Bevatron/Bevalac are fundamentally incompatible and really efficient operation of either program will occur at this accelerator only in the absence of the other. However, by observing some boundary conditions for each discipline, important programs of research can be and have been carried out effectively[3].

Therapy progress is substantial. Approximately 50 patients have been treated with heavy ions, many of them to far better effect than other modalities have accomplished. The program will continue through the operational portion of FY81 and is expected to resume in 1982, after the Bevatron remodeling for uranium capability is complete.

Nuclear science research is continuing at a substantial rate, limited for the most part by severe funding restrictions common to all DOE national laboratories, exacerbated in our case by the versatility inherent in this one accelerator in terms of ion type, energy and intensity. Experiments are designed to capitalize on this versatility, thus limiting severely the possibilities of beam-sharing so easily accomplished at single-ion and/or single-energy facilities.

Experimental multiplicity, the number of research hours per operating hour, is low now but is expected to increase substantially when "mezzanine" operation begins in 1981. Two-energy operation on a single Bevatron/Bevalac pulse will be available, as will a "transparent" therapy mode. In that mode all of the beam is delivered to a nuclear science experiment at its optimum energy except for about two minutes of every half hour, when the beam is delivered at the other energy level to the therapy area.

Rapidly gained expertise in multi-programmed, multi-tasked computer control systems and in their application to the Bevatron/Bevalac, extensive use of septum split of accelerated beam, and imminent use of the mezzanine mode make this complex outstanding for heavy ion research in nuclear science, radiotherapy, and radiobiology. Experience gained now by the operations staff will be directly and immediately applicable to the design and operation of the next generation of relativistic heavy ion accelerators.

Despite the complexities of scheduling for both disciplines, the Bevatron/Bevalac has operated extremely well in its new role of purveyor of particles to therapy, biomed and nuclear science, with an overall availability of 85-90% and with actual operation for nuclear science at 75-80% of scheduled, and for biomed and therapy some 80-85% of scheduled.

References

1. J. Castro et al, "Heavy Ion Therapy", Biological and Medical Research with Accelerated Heavy Ions at the Bevalac 1974-1977 (1977), Lawrence Berkeley Laboratory report LBL 5610.

2. J. Castro et al, "Clinical Results in Heavy Particle Radio Therapy", Biological and Medical Research with Accelerated Heavy Ions at the Bevalac 1977-1980 (1980). Lawrence Berkeley Laboratory Report LBL 11220.

3. J. Alonso, T. Criswell, J. Howard, R. Singh, D. Geller "Operations Experience at the Bevalac Radiotherapy Facility", (1981), LBL 11725, these proceedings.

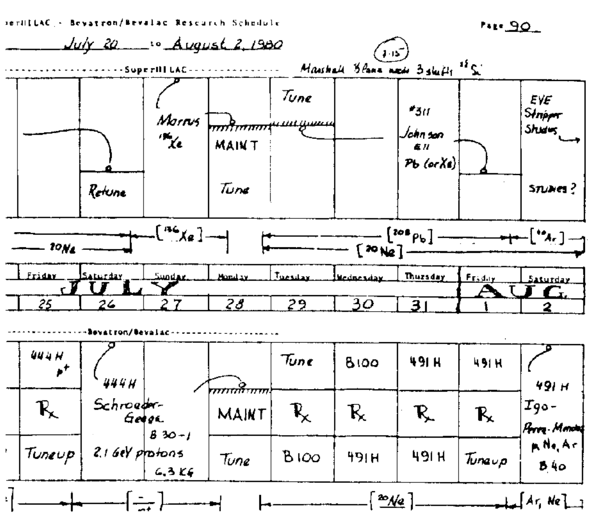

Figure 1 - A portion of the SuperHILAC - Bevatron/Bevalac master schedule. While the SuperHILAC program is operating with heavy ions (xenon and lead) the Bevatron/Bevalac program is operating with protons from the local injector, and neon and argon from the SuperHILAC.

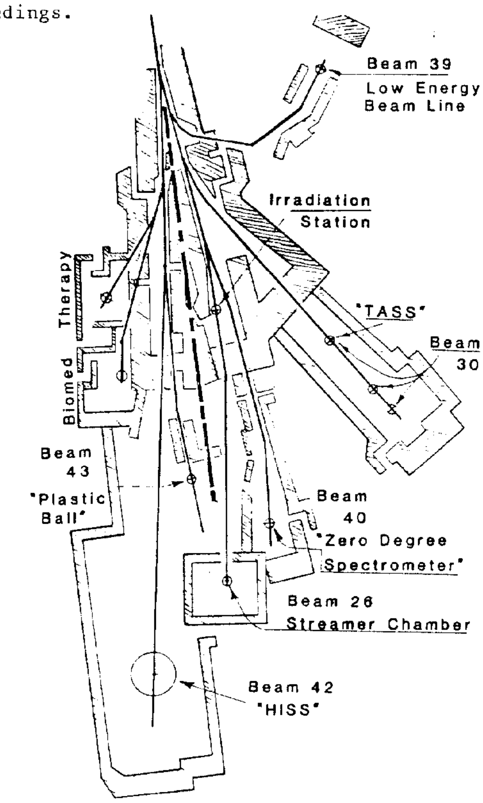

Figure 2 - Bevatron/Bevalac Experimental Area. Same - pulse beam sharing is possible between one beam line to the left of, and one to the right of the (imaginary) sharing axis.