Title
MIXING AND MATCHING BEVALAC PROGRAMS: A PROGRESS REPORT ON RAPID-SEITCHING OF IONS AND OTHER OPERATIONS HIGHLIGHTS

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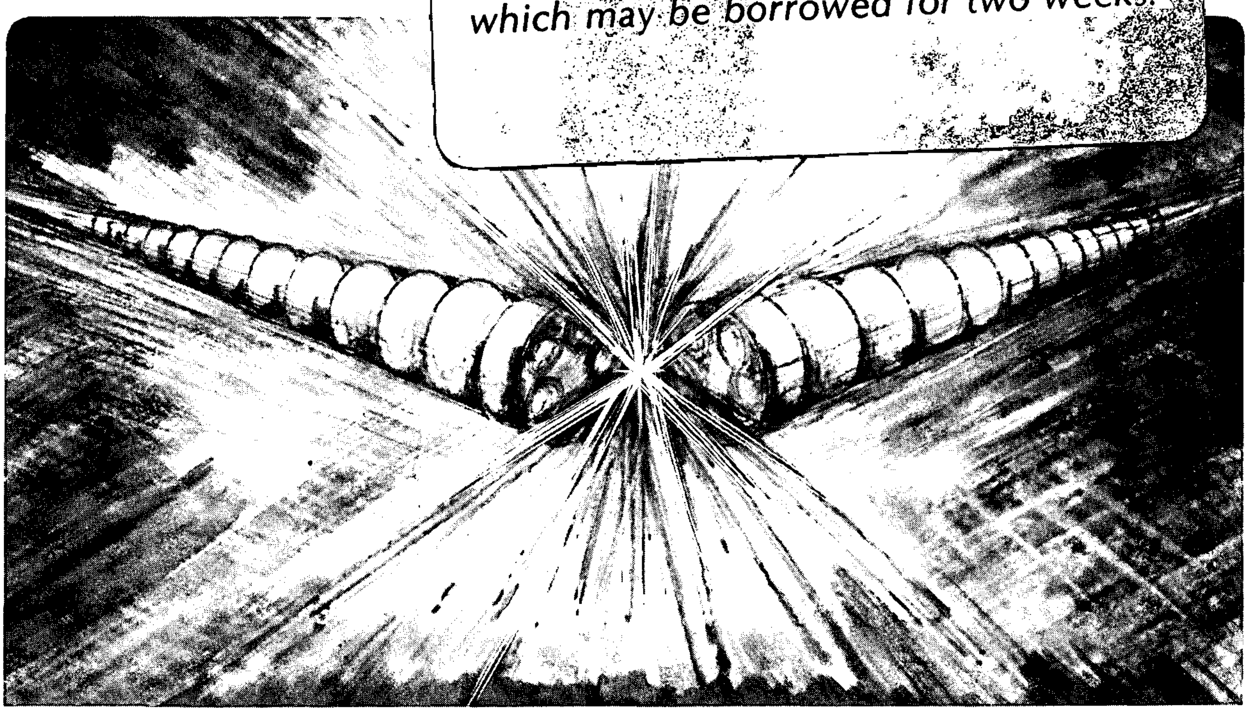

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MIXING AND MATCHING BEVALAC PROGRAMS: A PROGRESS REPORT ON RAPID-SWITCHING OF IONS AND OTHER OPERATIONS HIGHLIGHTS*

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Abstract

Rapid switching of ion, energy, and beam line has been accomplished on a routine basis; typical transfer time is 1-2 minutes in worst case situations. Operational efficiency has been improved by substantial reduction of inter-experiment tune time and improved optics in the external beam area installed in 1985. A comparison of current research efficiency and previous year efficiency is given. It is shown that compatibility and productivity for two simultaneous, independent research programs are not mutually exclusive.

Introduction

For the most recent 17 of its 35 years of existence the Bevalac has provided unique beams of heavy ions to several research disciplines; nuclear science, atomic physics, astrophysics, biology, and medicine. Each has its own requirements on the accelerator for time, ion, energy, and intensity. Each has also made facilities demands on the accelerator that have led to major advances in accelerator technology and beam delivery. Expanding heavy ion beam needs have led to a number of projects, the most spectacular of which was the improvement in 1980-1982 of the Bevatron vacuum by 4 orders of magnitude(1), giving the Bevalac the capability of accelerating all masses of ions. Continuing efforts have led to major improvements in the SuperHILAC beam intensity performance as an injector for the Bevalac.(2)

Transmission in the external beam transport system has been dictated by optical solutions derived many years ago for proton operation with septum splits at the first focus and the second focus of channel 1. Septum splitting of heavy ions has not been satisfactory for us because of fragmentation and associated contamination of the downstream beam. Modifications to the external beam transport system to adapt to requirements for heavy beams have been undertaken. In addition, each beam line has been outfitted with its own diagnostics packages to aid rapid-switch beam delivery.

Recently, a newly developed capability, the production and delivery of radioactive beams (4) has been exploited by nuclear science experimental groups. At the same time the medical community has been addressing the question of using positron emitters as diagnostic particles; for them we have delivered radioactive neon-19 beams.

Nuclear Science programs generally require substantial blocks of time (50-200 hours per run) of ions ranging from mass 40 to mass 238, at energies of 25-2100 MeV/nucleon, depending on the ion mass and experiment requirements, at intensities ranging from a few particles per second to 10^9 per second. Tuneup and setup time for each experiment is substantial, occupying 8 to 24 hours of accelerator time. Once a tuneup is effected, its parameters can be stored in the Bevalac control computer data-base for recall later, and a subsequent speedy tuneup for the same experiment. Atomic physics and astrophysics experiments have requirements similar to nuclear science experiments.

Biology experiments require beam energies sufficient to penetrate tissue to a depth of up to 25 centimeters of water (generally in the 100-800 Mev/nucleon region, depending on the ion species), intensities that for the most part are high, and ions that range in mass from 1 to 40, although some heavier ion experiments are being undertaken.

By breaking the Bevalac operating time into blocks, each program, except radiotherapy, can be accommodated at times during the year appropriate to the individual programs. Radiotherapy at the Bevalac consists of irradiation of deep-seated tumors not reachable by any other means with neon, occasionally carbon, silicon, or argon, beams. These treatments are given to a patient over the time span of several weeks, one treatment per day for four days per week. Each irradiation requires only a few minutes of Bevalac time following 20 to 30 minutes of making the patient ready for treatment. Ion beams between patient treatments are useless to the therapy program, and have been used rather inefficiently in the past. It became clear early on that the radiotherapy program must be incorporated into the rest of the programs as transparently as possible.

At the 1985 Particle Accelerator Conference our progress on developing a fast-switching technique for implementation of just such transparency was reported.(3) That technique, which involves a change in one minute or less of ion species, final energy, intensity, and beam line, is now in regular use. Fundamental to the success of rapid switching was the completion of our local injector upgrade project so that we could change ions easily right at the entrance of the Bevatron, and would not be required to reconfigure the SuperHILAC every few minutes. The "local" now is used primarily for therapy neon; other light ions from deuterons through silicon are also available from this source.

Specific Achievements

Beam Species and Intensities

Ions new to the Bevalac since 1984 include fluorine, magnesium, sulfur, nickel, and xenon-129. For the most part, the ions requested are standard to our inventory and fit new experimental work well to previous work. Radioactive beams have been produced from neon (neon -18 and -19), fluorine (fluorine -20 and -21), and calcium (calcium -39). Production of these beams is by means of a beryllium production target located at F1, the first focus at the exit of the Bevalac. Intensities of the secondary beams are on the order of 10^{-3} of the primary beam, so intensities on the order of 10^6 neon -19 ions per second have been achieved(4).

External Beam Lines

Particular improvements to the external beam area include replacement of two septum magnets with full-aperture dipoles; installation in the vacuum box

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at F1 of an expanded variety of remotely operated targets and stripping foils of varying thicknesses, adjustable collimators, intensity and position sensitive devices; and provision for continuous vacuum from the Bevatron to the target area.

Prior to the septum magnet replacement beam halo was generated in the F1 area by scraping of the primary beam against aperture limitations, giving rise to multi-energy, multi-charge state (in some cases) beams at the target. Beam halo has been greatly reduced by installation of the larger aperture magnets.

A variety of targets and stripper foils in the vacuum at F1 now provide the operator with the means for easy generation of radioactive beams when needed, or electron stripping from heavy beams after acceleration. Heavy ions injected at a relatively low charge state appropriate to the injected energy, final energy (and magnetic guide field values), and intensity may be transmitted beyond F1 at the low charge state of acceleration or stripped to a higher charge state, as appropriate to the experimenter's needs. Indeed, at maximum energy, one may have fully stripped ions as heavy as uranium at excellent stripping efficiencies.(5)

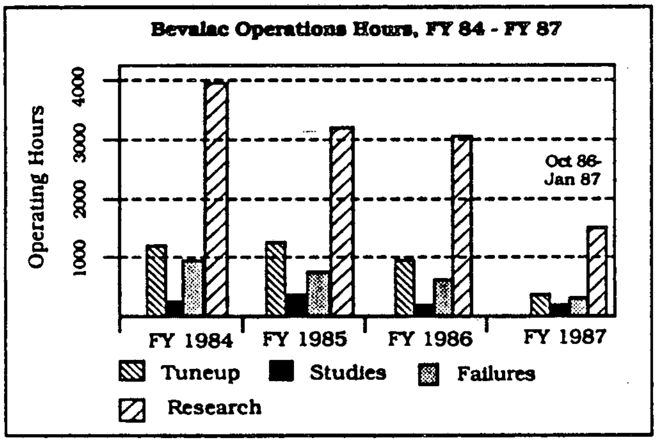

Figure 1. Bevalac operating hours for the years 1984-1987. Total hours have tracked the budget, with FY 1987 expected to produce about 3100 research hours.

Rapid Switching of Beams

As reported above, rapid changes of mode of operation now are routine and are beginning to lead to substantially improved operating statistics. Operating hours for the years FY1984 to FY1987 are shown in Figure 1. The normalized fractions of time for research, accelerator studies, tuneup, and failures are shown in Figure 2. Our goal has been to maximize research hours while keeping the ratio of nuclear science to biomed time at 2:1, minimize tuneup time, and keep failure time around 15% of the total. Very significant among the information in Figure 1 is that the total hours of operation have decreased as operating budgets have shrunk. Research in FY 1984-1986 stayed just above 60% of the total. For the first half of the FY 1987 operating year, however, research is inching up toward 70% of the total, and the fraction of time devoted to tuneup has dropped significantly. Our failure rate remains relatively constant at about 16%, a number with which we are comfortable.

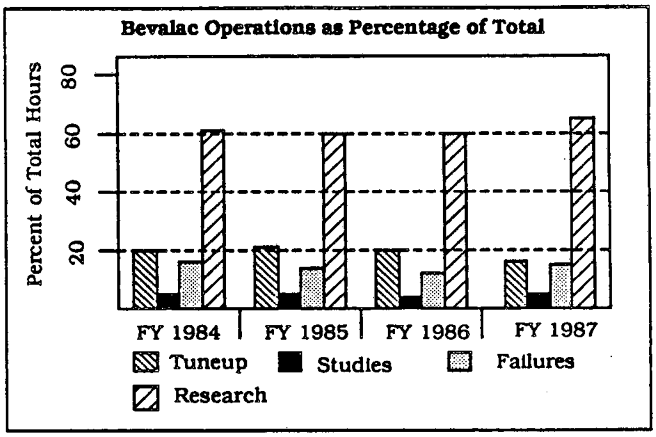

Figure 2. Percentage of total operation hours taken by the various modes. Note that for the first part of FY 1987 the research percentage is higher and the tuneup percentage is significantly lower.

Through fiscal 1986 we were still commissioning many aspects of the rapid switching program and were working with a general scheduling plan shown in Figure 3. That plan had a repeat pattern of one week, during which the radiotherapy took most of the day shifts Tuesday through Friday, biology took what it could of the radiotherapy neon, and nuclear science got the weekends and some time during weeknights. Biology programs also used some weekends from time to time for non-neon investigations.

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Owl	NS	NS	TUNE	NS	STUDIES	NS	NS
Day	NS	MAINT	RADIOTHERAPY AND BIOLOGY				NS
Swing	NS	TUNE	NS	STUDIES	NS	TUNE	NS

NS = Nuclear Science
MAINT = maintenance

Figure 3. Standard operating week before fast switch operation at the Bevalac

This year (FY 1987) we have developed a scheduling plan based on the reliability of the local injector for radiotherapy ion delivery and the success of the rapid switch that is shown in Figure 4. The repeat period is now two weeks. A tune with a SuperHILAC ion is established along with a tune for the local injector ion on Monday night. The tune will be saved and recalled many times during the week as the accelerator mode is shifted between radiotherapy and another program. Particularly significant is the pattern of weekday, daytime operation. A typical program is shown in Figure 5. While the divisions of time in this particular figure are arbitrary, they do conform to the detailed scheduling model now in effect. Accelerator-related time (time devoted to special tuneups, studies, or failures during the course of a shift) is not scheduled but does occur as the result of failures or curiosities that arise during the course of a day. It is expected that during an 8 hour day shift two hours will be devoted to therapy, four hours will be for nuclear science, and the rest will be devoted to tuneups and other accelerator related time. This program is in sharp contrast to the previous program in which the radiotherapy/biology disciplines occupied about 6 hours of the day shift, and tuning and accelerator related time accounted for the other two.

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Owl	NS	NS	TUNE	NS	NS	NS	NS
Day	NS	MAINT	RADIOTHERAPY & NUC SCI				NS
Swing	NS	TUNE & STUDIES	NS	NS	NS	NS	NS

First week of two-week fast switch cycle

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Owl	NS	NS	BIO	BIO	BIO	TUNE	NS
Day	NS	MAINT	RADIOTHERAPY & BIOLOGY			RT & TUNE	NS
Swing	NS	TUNE	BIO	BIO	BIO	TUNE	NS

Second week of two-week fast switch cycle

NS = Nuclear Science
BIO = Biology/Medicine
MAINT = Accelerator Maintenance
RT = Radiotherapy

Figure 4. Current scheduling model that takes advantage of fast switching modes at the Bevalac.

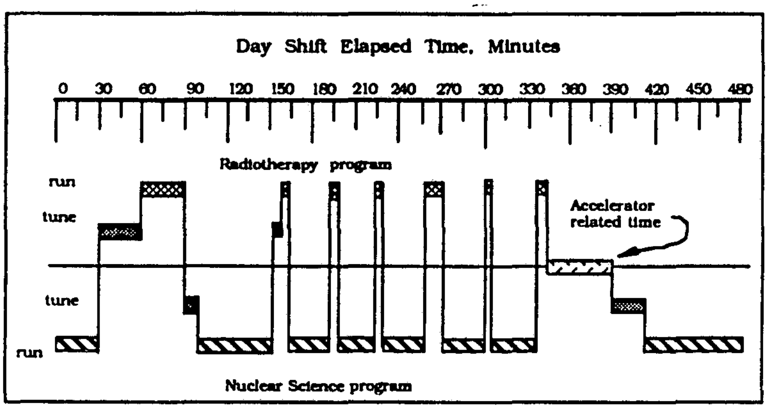

Figure 5. Typical beam sharing during weekday operation of the Bevalac. In this case, radiotherapy dosimetry and 6 treatments are shown interspersed with nuclear science operation.

Conclusions

Flexibility, versatility, and efficiency of beam delivery to various experimental programs are the watchwords and guidelines under which we are operating the Bevalac. We have provided an accelerator complex that supplies virtually any ion in the periodic chart (and some that are not) at energies from 20 MeV/n to 2100 MeV/n. We are able to change ion, energy, and beam line accelerator parameters completely within the time span of about one minute, and can provide very high quality, reproducible beams to any target area. We have been and are demonstrating the advantages that accrue to both the biomedical community and the nuclear science community with the Bevalac configured for rapid switching. We are also demonstrating the versatility to be expected from the next generation of relativistic heavy ion accelerators.

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