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ACHIEVEMENT OF BEVALAC RAPID MODE SWITCHING

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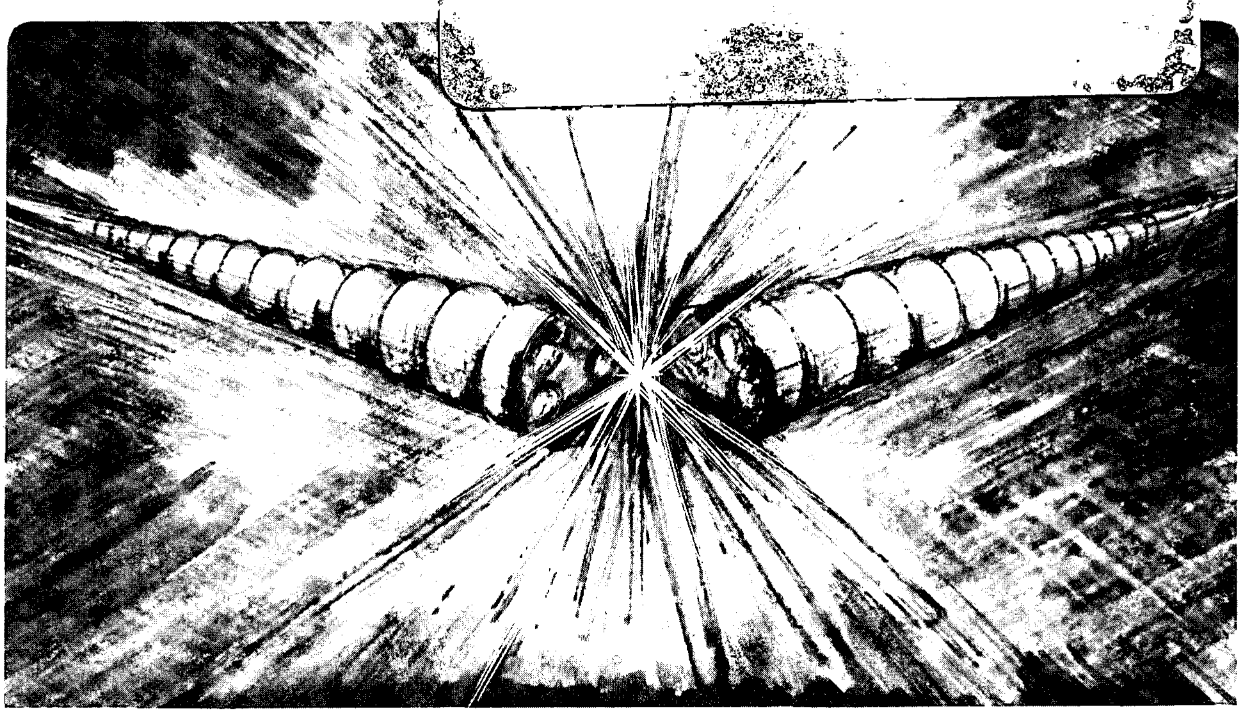

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ACHIEVEMENT OF BEVALAC RAPID MODE SWITCHING** LBL-18939

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Abstract

Rapid changes of ion, intensity, beam line, and output energy between two modes have been achieved. The techniques for switching among the Bevalac's several injectors are described. Energy level limits at the output (for q/A=1/2) are 470-2100 MeV/n (high power) or 50-1050 MeV/n (low power). Depending on specific field value differences, the total time required for a mode change is less than one minute. This mode of operation greatly improves program efficiency in interleaving medical and nuclear science programs at the Bevalac.

Introduction

The Bevalac complex is comprised of the Bevatron and its experimental area, the SuperHILAC and its experimental area, and the tandem combination of the two accelerators (the Bevalac). The SuperHILAC is a linear accelerator with output energies from 1.2 to 8.5 MeV/n, at a pulse rate of 36 per second. For most applications, 34 of the 36 pulses are used by SuperHILAC experimenters, and two pulses per second are used for injection into the Bevatron. Source switching is done at the 36/second rate, so that users have independent choice of ions. In one example, the Bevatron will use neon at 8.5 MeV/n and the SuperHILAC will use xenon at 5 MeV/n compatibly.

The Bevatron is a weak-focusing positive-ion synchrotron with output energies from 20 MeV/n to 2000 MeV/n, (protons from .35 to 4.9 GeV) depending on the ion species and research requirements. Its pulse rate is 10 to 15 per minute, depending on the maximum energy being delivered. Table 1 lists the ion inventory in October, 1984.

Heavy ions to be accelerated to relativistic energies in the Bevalac come from one of four sources, three at the SuperHILAC and one at the Bevatron; the SuperHILAC sources are called Eve, Adam, and Abel, and the Bevatron source is called the "local". The choice of source is determined by the desired ion and the program. Eve supplies ions of gases, and will provide hydrogen, helium, carbon, nitrogen, oxygen, and neon to experiments, either at the SuperHILAC, or, more likely, at the Bevatron. Adam supplies ions of gases and solids over most of the periodic chart, stopping at about the mass of lanthanum. Abel is particularly useful for the heaviest of elements and is used for the tantalum, gold, uranium range. In addition, it can supply substantial quantities of the lighter ions, overlapping strongly with the capabilities of Adam. The local injector supplies low-mass gases and solids up to about mass 28, and has been established primarily for the Bevalac radiotherapy program.

Bevalac Particle Inventory
October, 1984

Ion	Atomic Weight A	Atomic Number Z	Accel. Charge	Max. Energy MeV/amu	Intensity, particles/pulse @ F1
Hydrogen	1	1	1	4900	2×10^9
(molecular)	2	1	1	2100	1×10^9
Helium	4	2	2	2100	3×10^9
Boron	11	5	5	1840	1×10^9
Carbon	12	6	6	2100	5×10^9
Oxygen	16	8	8	2100	6×10^9
Neon	20	10	10	2100	1×10^{10}
Aluminum	27	13	13	2000	5×10^8
Silicon	28	14	14	2100	8×10^8
Argon	40	18	18	1815	1×10^9
Calcium	40	20	20	2100	4×10^7
	48	20	20	1640	1×10^7
Manganese	55	25	25	1840	1×10^6*
Iron	56	26	24	1700	2×10^8
			16	1050	5×10^7*
Krypton	84	36	33	1510	1×10^7*
Niobium	93	41	35	1420	2×10^6
			23	770	8×10^7
Xenon	132	54	45	1240	1×10^5
	136		45	1180	3×10^6
Lanthanum	139	57	48	1260	4×10^7
			32	690	8×10^7
Holmium	165	67	54	1170	2×10^5
Gold	197	79	61	1080	1×10^5
			37	490	1×10^7
			11	50	1×10^5
Uranium	238	92	68	960	1×10^6
			40	410	1×10^7

* Low intensities are at experimenters' requests; no maximization has been done.

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Bevalac research programs are divided into two major categories, nuclear science and biology & medicine. Our nuclear science program encompasses ions spanning the periodic chart at particle energiesfrom low to relativistic. Biomedical studies include heavy-ion radiotherapy four days per week and biology in support of the therapy as well as independent radiobiological studies. These independent studies are generally treated the same as the nuclear science programs; blocks of time are reserved for the individual experiments at the ion and energy of choice. Radiotherapy, however, involves daily treatment of about 10 patients per day for four days per week with neon ions at an energy of 670 MeV/n. Each patient requires about 25 minutes of setup time per day at the end of a beam line, and about 5 minutes of actual beam time, so the total time per patient is about 30 minutes, of which 25 do not require beam.

Heavy ion radiotherapy is unique to the Bevalac and is an extremely valuable project that receives high priority. We have found, however, that the nuclear science program has been at a disadvantage because of the rigid clinical requirements imposed on the Bevalac, to wit, treatments every week of operation, four days per week, with neon at 670 MeV/n. These treatments extend for about 8 hours per day. The other 16 hours per day, and the weekends, are generally devoted to the nuclear science program. Major interruptions occur to the physics program because it must start and stop every treatment day. Not only must it start and stop, the transients of accelerator tuneups reduce the 16 hours to an effective 8-10 hours of target time. Such a set of programs requires rapid changes of ion, energy, and beam line to maintain efficiency of operation for all users.

The Challenge

Ideally, the heavy-ion radiotherapy program should be transparent to the nuclear science program; most of our operating time should be spent in the non-therapy mode, transferring to the therapy mode only when the beam is actually needed for treatment. In order to establish this rapid switch, a way had to be found to reduce the transient effects of program changes. The specific goals to be met include fast, reproducible changes of

1) target area/beam line,
2) energy, and
3) ion.

Effecting these changes in one minute or less constitutes realization of the goal. Beam-line switching with no change of ion or energy was developed first and has been in regular use for several years. However, the demand for 670 MeV/n neon is not large and delivery of it to another beam line is often not useful to the physicist for more than initial tuneup and equipment checks. A different energy, or a different ion, or both, is necessary, if the interpatient time is to be used effectively.

Rapid Switching

Rapid changes under computer control from one beam line to another were accomplished soon after the radiotherapy program started at the Bevalac. The choices available are shown in the Figure, which is a representation of the Bevalac complex and the delivery options available, as seen from the switchyard point of view. Each of the switch points is real and represents a choice to be made in the establishment of an operating condition. Synchronous switching

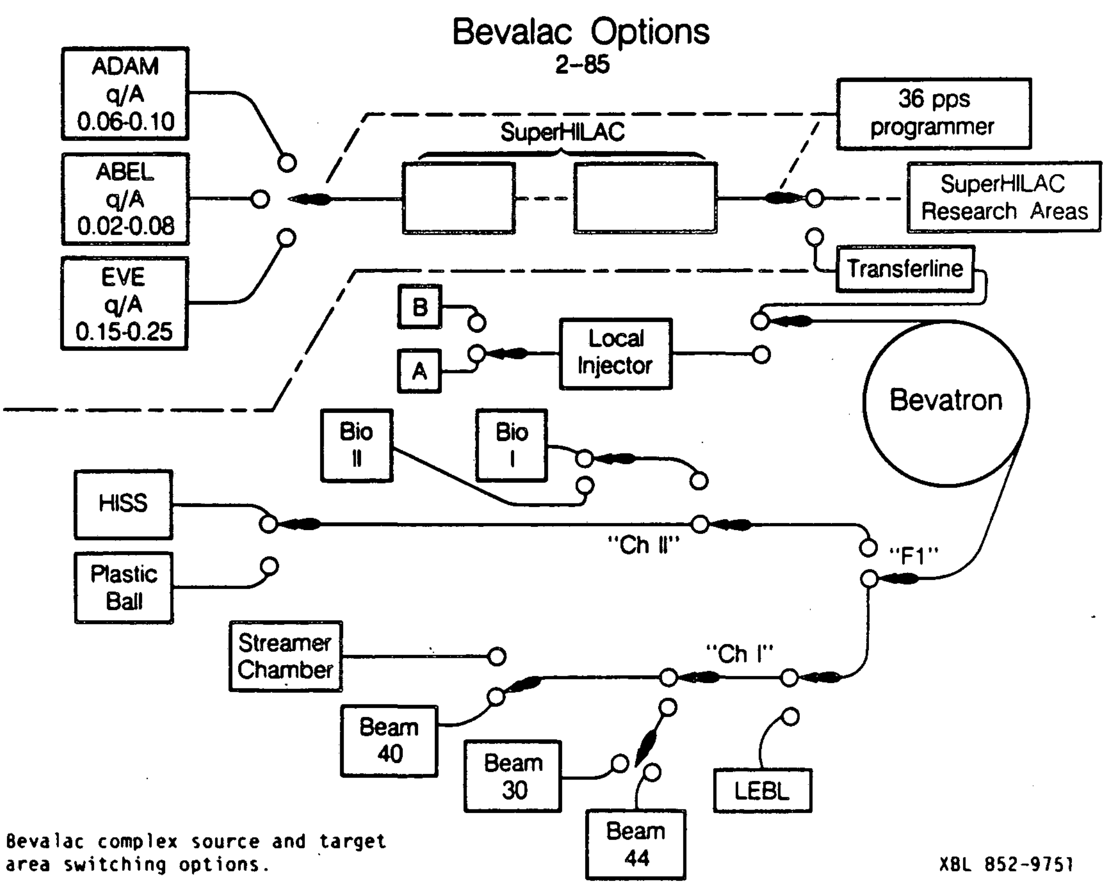

Figure. Bevalac complex source and target area switching options.

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means are in place at the SuperHILAC to connect the desired source to the desired beamline/target area at the 36 per second rate. As an example, the ABEL injector will deliver a heavy ion to the SuperHILAC experimental area at 32-34 pulses per second; Adam or Eve will deliver a lighter ion to the transferline at 2-4 pulses per second. At the output end of that line, a choice is made between the SuperHILAC injection system and the "local" injector. (It is local to the Bevatron) Bevatron acceleration and energy parameters are selected on the basis of the injector choice and the delivery area. Once particles have been accelerated, they are taken through the experimental area switchyard in which several more choices are made. By virtue of necessary economies in the target and beamline areas, not all target stations are available at all times with the push of a button. Rapid switching is available at "Fl", between "BioI" and "ChII", and between "BioI" and "BioII". Radiotherapy is done in "BioI", and all other target areas can be made available by rapid switching from that area. Certain other combinations of target areas may be made accessible to rapid switching. Most of the switch points shown are available to the control computers, and thus can be included in programmed changes.

Variables not included in the switch point diagram are the beam intensity and energy. At the present time these are subject to manual intervention, but could be put into the switching algorithms. Beamline switching at constant energy requires less than one minute for selection of (dipole magnet) switch points and settling of new current values in each magnet. If a change of energy is required, the Bevatron power supply must be reset to supply a different magnet current to the Bevatron.

The supply is comprised of a pair of 3MVA motors driving a pair of 7 kV, 7000 ampere generators and two mercury-vapor rectifier banks. Either one or two generators are used to power the synchrotron magnet, depending on the ion energies required. Field changes with both units operating are permissible from approximately half-field to full field. With one motor-generator combination, field values from low to about half-maximum are available. The therapy energy, 670 MeV/n neon, is attainable in either configuration. Therefore, the radiotherapy program can be made independent of the other activities at the Bevalac with regard to energy. Tests were conducted on the Bevatron power supply with the result that large changes of field, including settling and stabilization, may be made in a minute or less. Inertia in the power supply is a major constraint on any generalized change algorithm, and therefore the one minute figure achieved became the goal for an entire change of Bevalac parameters.

A change of ion presents the most difficult technical problems. By virtue of the computer control systems in place at the Bevalac complex, it is possible to save all the parameters required for transport and acceleration of any particular ion in magnetic disc memory, then load those parameters into active memory at the appropriate time. Parameters of interest include electric current values for transport magnets, set point values for other control devices, the Bevatron magnetic field value for the energy desired, and a 32 kilobyte lookup table containing acceleration r.f. frequency values corresponding main magnet guide field values and different for each charge/mass ratio, used for control of the digital master oscillator. All these parameters are retrieved from disc and loaded into the appropriate computer memories in less than one minute.

Each species of ion will have its own charge/mass ratio, determined in part by the desired or necessary rigidity to accomplish a goal. If both ions originate in the SuperHILAC, then that accelerator must switch ions into the transferline, the transferline must be changed, and the Bevatron injection parameters, frequency-field program, and extraction parameters must be changed. We have demonstrated that such changes can be accomplished. In June, 1984, the radiotherapy program operated with 670 MeV/n neon ($q/A=0.5$, $B=5667$ gauss) for a two week period during which rapid switches were made twenty times each day, four days each week to gold ions at 1.2 GeV/n ($q/A=.31$, $B=12,575$ gauss). Switch times were less than one minute. Because the SuperHILAC must be operated in a mode dedicated to the Bevalac for the fast switch to be really effective, at the cost of sacrificing the SuperHILAC nuclear physics research program, regular use of the fast switch has not been made until the Bevatron local injector is brought back on line. That unit has been modified from a proton-carbon injector of modest intensity capability to a sophisticated device able to supply the substantial currents of neon and silicon required for heavy ion radiotherapy.[1] With it in operation we expect to switch routinely between it and the SuperHILAC in a rapid-switch mode, giving the radiotherapy program its intense beams of ions briefly each half hour, and delivering a stable beam of heavy ions to either the biomedical program or the nuclear science program during the time that therapy is not active.

A major feature contained in the local/SuperHILAC injector alternation is that both accelerators are required only to deliver a single ion species under static conditions and each may be optimized and stabilized for that ion. Selection is then done at the input to the Bevatron, a demonstrably stable machine.

Conclusion

The challenge we have met is changing all of the Bevalac complex operating parameters, including ion species, delivery point (or target area), energy, and intensity between two arbitrarily chosen sets that correspond to the needs of two separate experiments in the period of less than one minute. In programmatic terms we have achieved what we call "transparency" of the radiotherapy program. It now becomes a series of minor interruptions to our nuclear science program, mostly invisible and certainly not burdensome. As an added benefit of achieving transparency, we now have the capability and the opportunity to fast-switch between selected nuclear science beam lines, allowing preliminary tuneup of one experiment from time to time at minimum disruption to the operating experiment. Major contributors to this record are the capabilities for storage of complete parameter tables in the control computer, the availability of multiple ion sources operating virtually simultaneously, favorable disposition of the various power supply components to quick changes, and the ingenuity of the scientists, engineers, operators, and technicians who developed the concepts, the hardware, and the software necessary to this project.

Reference

[1] J. Staples, et al, "Heavy Ion Upgrade of the Bevatron Local Injector", Proceedings of the 1984 Linear Accelerator Conference, Seeheim, Germany, (May 7-11, 1984).

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