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January through March 1964

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Contents

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ABSTRACT

The Bevatron provided beam for physics research 85% of the scheduled operating time. On March 15 the Bevatron started seven-day-a-week operation. The study of high-intensity beam loss continued, with no conclusions made as to the cause. Changes in pole-face-winding currents increased the maximum accelerated beam to 5×10^{12} protons per pulse. Double pulsing of the rapid beam ejector was tried in preparation for simultaneous operation for two bubble-chamber experiments. One primary experiment finished and three new primary experiments were set up and started operation. Low rate of rise of magnetic field at low fields was tried, and the beam was successfully steered through this "mezzanine" region. Radiation background and activation studies continued at the Bevatron.

I. OPERATION

The Bevatron operation record is shown in Fig. 1. Beam was on for 85% of the scheduled operating time. The beam was off 7% of the time because of equipment failure and 8% of the time for experimental setup, tuning, and routine checks.

Since March 15, 1963 the Bevatron has been operating from 4 p. m. Monday through 4 p. m. Saturday. Maintenance has been done on Mondays from 8 a. m. until 4 p. m. On March 15, 1964 the Bevatron started operating on a seven-day-a-week schedule 24 hours per day. Monday from 8 a. m. to 4 p. m. is a maintenance period. The time from 4 p. m. until midnight on Monday is usually a Bevatron development and study period. The remainder of the week is devoted to operating the Bevatron for basic physics research. An additional period of from 4 to 8 hours, for Bevatron development, is frequently taken on Thursdays.

II. SHUTDOWN

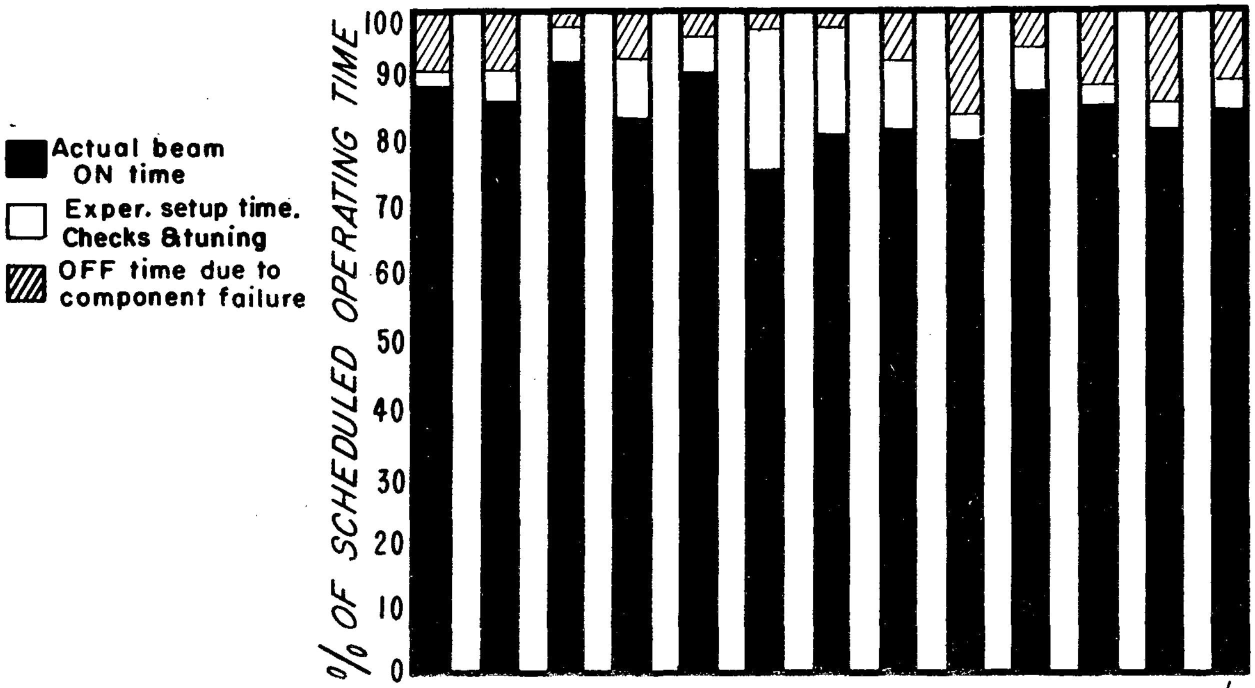
There were two short vacuum shutdowns of about one hour each on Saturday, January 11 and January 18. The first shutdown was to clear a short on the newly installed (December 1963) vertical beam induction electrodes. The second shutdown was to install some terminating resistors at the electrodes. There was a shutdown from 8 a. m. February 2 to 4 p. m. February 8, to remove the Lofgren experiment in the EPB channel and to set up the beam channel for the 25-inch bubble chamber. This beam channel is used by both the Trilling-Goldhaber and Powell-Birge experiments. Installation of the University of Washington experiment started in the north tangent tank area during this time. Their magnets and beam pipe were installed in the main shielding wall.

There was a vacuum shutdown during this week to hone the guide rails and reset the guide rollers on the east plunging magnet for the EPB. A new set of vertical beam induction electrodes was installed in the east tangent tank at the exit of quadrant IV. This system is covered in more detail in the following section of this report. General maintenance was done on the Bevatron and associated equipment during this period.

III. BEVATRON DEVELOPMENT

A. High-Intensity Beam Loss

The loss of beam at high intensity has been previously reported.[1, 2] The search for the cause of the loss continues. One phase of this search was the study of vertical betatron oscillations. The vertical induction electrode system installed last December was used in this study. Vertical oscillations were observed. During the February shutdown a dual system of induction electrodes was installed. This system provided a set of plates for monitoring and a set of plates for driving the vertical betatron



Week of	12/29	1/5	1/12	1/19	1/26	2/2	2/9	2/16	2/23	3/1	3/8	3/15	3/22
Crew hours	88	152	128	128	128	128	128	128	128	128	128	160	144
Turnon & maintenance time (h)	8	10	10	10	10	4	10	10	10	10	10	10	10
Scheduled operating time (h)	52	118	96	104	70	24	108	110	109	109	102	133	128
Scheduled Bevatron test time (h)	12	24	22	14	48	0	10	8	9	9	16	17	6
Scheduled shutdown time (h)	16	0	0	0	0	100	0	0	0	0	0	0	0
Holiday (h)	56	0	0	0	0	0	0	0	0	0	0	0	24

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Fig. 1. Bevatron operating schedule, January through March 1964.

oscillation. Attempts were made to both increase and decrease the amplitude of the oscillation by driving the plates with the proper phase and frequency of rf. No effect on the beam was observed. We were unable to correlate the beam loss with the vertical oscillations.

B. Pole-Face-Winding Changes

The currents in the pole-face windings provide adjustment of the magnetic field shape in the radial direction of the Bevatron. These changes are represented by changes in the "n" value of the magnetic field, where n is given by $n = -RdB/BdR$. In the past the currents in the pole-face windings have been adjusted to give the maximum captured beam. More accelerated beam was obtained after making some adjustments on the pole-face-winding currents. This effect prompted a more extensive study of the pole-face-winding currents. The currents were readjusted for maximum accelerated beam rather than maximum captured beam. During the course of these current adjustments, the inflector's radial position was also varied. The accelerated-beam intensity was maximum with the inflector radius at 619.5 in. instead of 621 in., where it had previously operated. The old and new n values are shown in Fig. 2. These values are measured with a field probe at one sector in the magnet, and are not necessarily the average values around the Bevatron. These changes raised the maximum accelerated beam to 5×10^{12} protons per pulse (ppp) from 2.5×10^{12} ppp. The previously observed maximum had been 3×10^{12} ppp.

C. Bevatron Settlement

The vertical position of the EPB appeared to change during the period of the Lofgren experiment. A detailed examination showed that the beam entering the quadrupoles Q3A and Q3B was off axis by 1/4 inch. These quadrupoles are located in the EPB beam line a few feet after the beam leaves the main Bevatron vacuum system. The off-axis beam in the quadrupole caused a further vertical displacement and beam distortion farther down the beam line. This was corrected for by shifting the vertical position of Q3A and Q3B to the new EPB axis.

This shift in the vertical position of the EPB is undoubtedly due to the slow settlement and shifting of the magnet sectors of the Bevatron.[1,3] So far this is the only observed effect on the beam that is caused by Bevatron settlement.

D. Double Pulse of Rapid Beam Ejector[4]

Requests for beam time for future experiments indicated that double pulsing of the rapid beam ejector (RBE) would be necessary if we were to have simultaneous operation of the experiments. The RBE provides short beam pulses (300 μsec) for bubble-chamber operation. This is done by discharging a capacitor bank through a coil mounted in the east straight section. There are two capacitor banks and control circuits but only one high-voltage power supply. The coil has a limited power dissipation, and because of this limitation we could not use two full

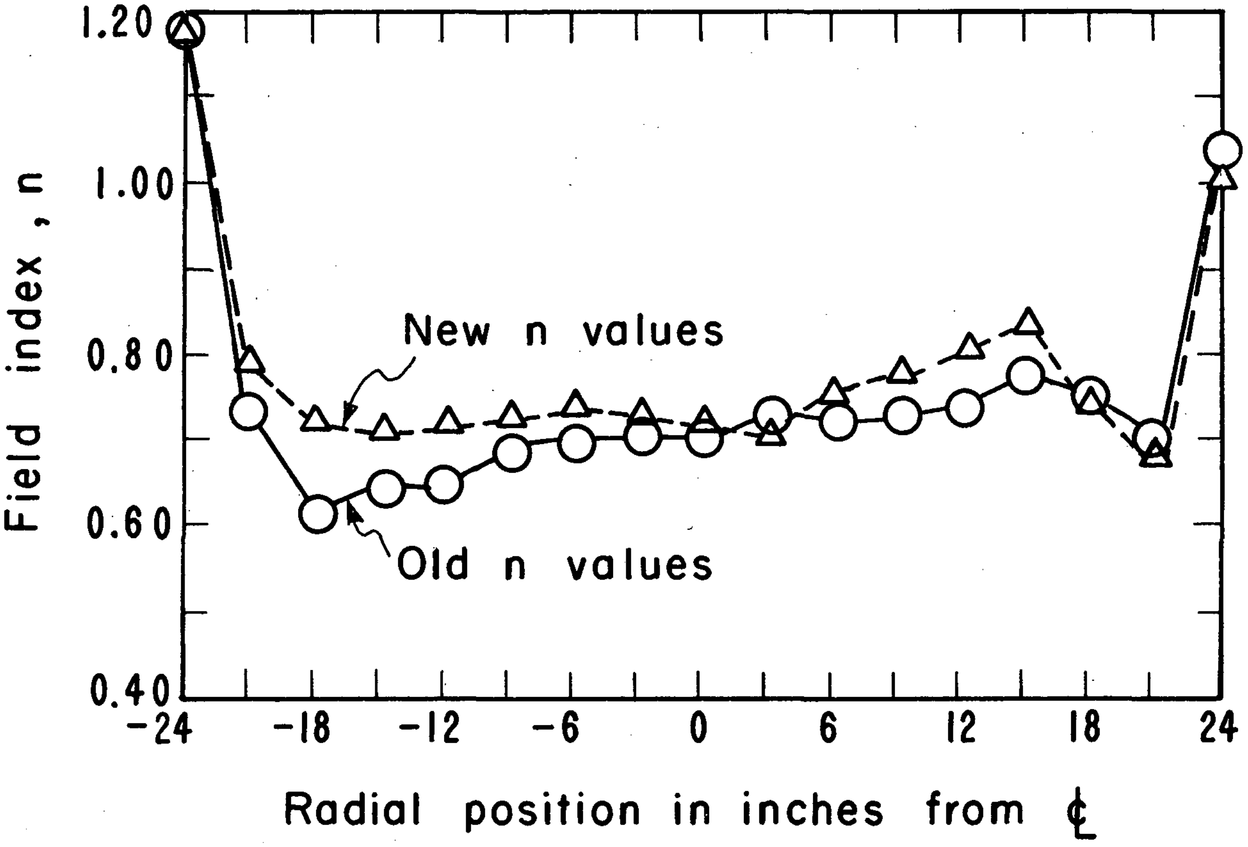

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Fig. 2. Old and new n values of the magnetic field.

capacitor banks. Various combinations were tried. If the large bank was used first, it was not possible to save some of the beam and spill it later in the Bevatron cycle. The final mode of operation was with a quarter bank discharged on the first pulse and a full bank on the second pulse. This gave satisfactory operation. Future plans call for a separate high-voltage supply for each capacitor bank and completely separate controls. This will remove some of the critical adjustments as to high voltage, capacity of each bank, and the rf compensation. The rf compensation is necessary to retain phase control of the beam during and after the RBE. Without the compensation all of the beam would be lost after the RBE pulse owing to loss of phase stability.

IV. EXPERIMENTAL PROGRAM

The two experiments at the 72-inch hydrogen bubble chamber continued through this quarter. These are the Alvarez Group's (K^-, p) and (π^-, p) reactions. The Lofgren Group studying elastic and inelastic p-p scattering finished this quarter. This experiment was done in the EPB channel. A new beam channel was set up in the EPB for two experiments involving the 25-inch hydrogen bubble chamber: the Trilling-Goldhaber and the Powell-Birge experiments. A new secondary beam channel was set up with a target in the north straight section. This was for the University of Washington Group.

A summary of all the experiments is shown in Table I. The three new primary experiments are discussed below.

The University of Washington experiment is designed to measure the Σ^+ magnetic moment. Polarized Σ^+ hyperons will be produced from the reaction $\pi^+ + p \rightarrow K^+ + \Sigma^+$ by allowing separated π^+'s of 1.05 BeV to strike a CH_2 target. These Σ^+'s will then pass through a magnetic field, which will cause the magnetic moment to precess. The amount of precession will depend upon the value of the magnetic moment and the proper component of $\int Hdl$ along the Σ^+ path up to the point of decay. From a knowledge of the path and the magnetic field, $\int Hdl$ can be evaluated, and hence a determination of the magnetic moment can be made.

The general problem of measuring the magnetic moment of the Σ^+ is made difficult by its short life and small production cross section. In this experiment the Σ^+ mean decay length is 1.5 cm. This lifetime is so short that even with very high fields ($\approx$200 kG), the precession in one mean decay length is expected to be small. For this reason it is extremely important to employ the highest fields possible. This experiment uses a 200-kG pulsed (0.1-sec) magnetic field which will give a precession of 16 deg per nuclear magneton for particles traveling two mean lives. To overcome the difficulty of the short mean decay length there is a small spark chamber which can operate within the magnetic field volume, and permits visual detection of the Σ^+ within one to two mean lifetimes of the point of production.

The second new major experiment started this quarter is the Trilling-Goldhaber experiment. This group is studying the interactions of

Table I. Summary of Bevatron experimental research program, January through March 1964.

				Beam time					
				This quarter		Start of run through March 1964			
Group	Start of experiment	End of experiment	Experiment	12-hour periods	Hours	12-hour periods	Hours	Pulse schedule	Primary or Secondary Experiment
Internal groups									
Alvarez Powell-Birge	3-23-63	In progress	Study of π^- interactions in the 72-inch hydrogen bubble chamber.	20	214	145	1509	1:1	P
Trilling-Goldhaber				0	0	3	41	1:1	S
Alvarez	4-26-63	In progress	Study of K^--p interactions in the 72-inch hydrogen bubble chamber.	33	340	135	1425	1:1	P
Lofgren	10-2-63	2-1-64	Study of elastic and inelastic p-p scattering at large and small angles.	0	0	14	159	1:1	S
	11-12-63	2-1-64		33	392	66	768	1:1	P
Segrè-Chamberlain	2-7-64	In progress	Test of K^+ particle detector in preparation for a future experiment to study K-Σ relative parity.	32	367	32	367	1:1	S
Trilling-Goldhaber	2-18-64	In progress	Study of K^+-nucleon interactions, using the 25-inch hydrogen bubble chamber.	39	400	39	400	1:1	P
Powell-Birge	3-24-64	In progress	Investigation of Y_1^* interactions in K^--nucleon reactions, using the 25-inch bubble chamber.	11	109	11	109	1:1	P
External groups									
Institution and experimenter									
Univ. Washington Masek	4-10-63	Continuing (see below)	Spark-chamber and counter tests.	--	--	10	106	1:1	S
Univ. Washington Masek	2-8-64	In progress	Setup and preparation for an experiment to investigate the magnetic moment of the Σ^+ hyperon, using a spark chamber in a 200-kG pulsed magnetic field.	32	365	32	365	1:1	S

K^+ with protons and neutrons in the momentum region of 850 to 1600 MeV/c. They are specifically investigating the interaction leading to inelastic pion production as a function of the momentum of the incident K^+ meson. An earlier study[5,6] showed that the cross section for the K^+ interactions in hydrogen leading to inelastic processes increases by a factor of almost eight when the K^+ momentum is raised from 800 MeV/c to 1200 MeV/c.

Additional goals of this experiment are to investigate the observed enhancement in the K^0-π^+ effective mass at 720 MeV and in the K^0-p effective mass at 1480 MeV. Also a study will be made of the angular distribution of effective masses as one passes through the threshold of formation of definite states, specifically the K^0-π^+, K^* (885) and p-π^+, N^*_{33}(1238) states. This experiment is being done in the 25-inch hydrogen bubble chamber. The beam is a separated K^+ beam produced from a target in the EPB.

The third new major experiment this quarter is that of the Powell-Birge group, using the same beam channel and 25-inch bubble chamber as the Trilling-Goldhaber experiment. The beam in this experiment is a separated K^- beam instead of the K^+ beam. The two groups alternate in using the beam channel and 25-inch bubble chamber.

This experiment is studying Y_1^* resonances from reactions of K^- on protons and neutrons at K^- energies in the region of the Kerth resonance. This group will also measure the cross sections for Y_1^* production on the neutron in deuterium and measure the decay asymmetries and anisotropies of the Y_1^* produced both in hydrogen and deuterium. The 1765 Y_1^* resonance will also be studied in its various decay channels from both the $I_Z = 0$ and $I_Z = -1$ states.

V. MAGNET POWER SUPPLY

The Magnet pulsing record is shown in Table II.

A. Mezzanine Operation

R. Frias

1. History

In early 1962 a method was developed of obtaining a relatively constant current at maximum magnet field, in the Bevatron power supply. This operational mode has become known as "flat top."[7] On January 6, 1964, tests were performed at low current (0-2000 A) to determine if it was possible to provide a second constant-current period prior to maximum magnet field. This early constant-current period has been called the "mezzanine."

2. Electrical Characteristics

The Bevatron power supplies and magnet are electrically connected as shown in Fig. 3. To provide a constant-current period, supply "A" is

Table II. Bevatron motor-generator set monthly fault report.

Month (1964)	4 to 6 pulses per minute						7 to 9 pulses per minute						10 to 17 pulses per minute						Totals					Comments
	1500 to 6900 A			7000 to 9000 A			1500 to 6900 A			7000 to 9000 A			1500 to 6900 A			7000 to 9000 A				Faults				
	Pulses	Faults[a] 14	26	Pulses	Faults[a] 14	26	Pulses	Faults[a] 14	26	Pulses	Faults[a] 14	26	Pulses	Faults[a] 14	26	Pulses	Faults[a] 14	26	Pulses (P)	Arc-backs	Arc-throughs	Total (F)	P/F	
Jan.										192221	18	27	125392		4	10612	2		328225	20	31	51	6435	
Feb.										179440	24	11	31879		6	133180	10	17	344499	34	34	68	5066	
March	186									352			4961			336999	19	37	342498	19	37	56	6116	

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[a] 14 indicates an arc-back, 26 indicates an arc-through.

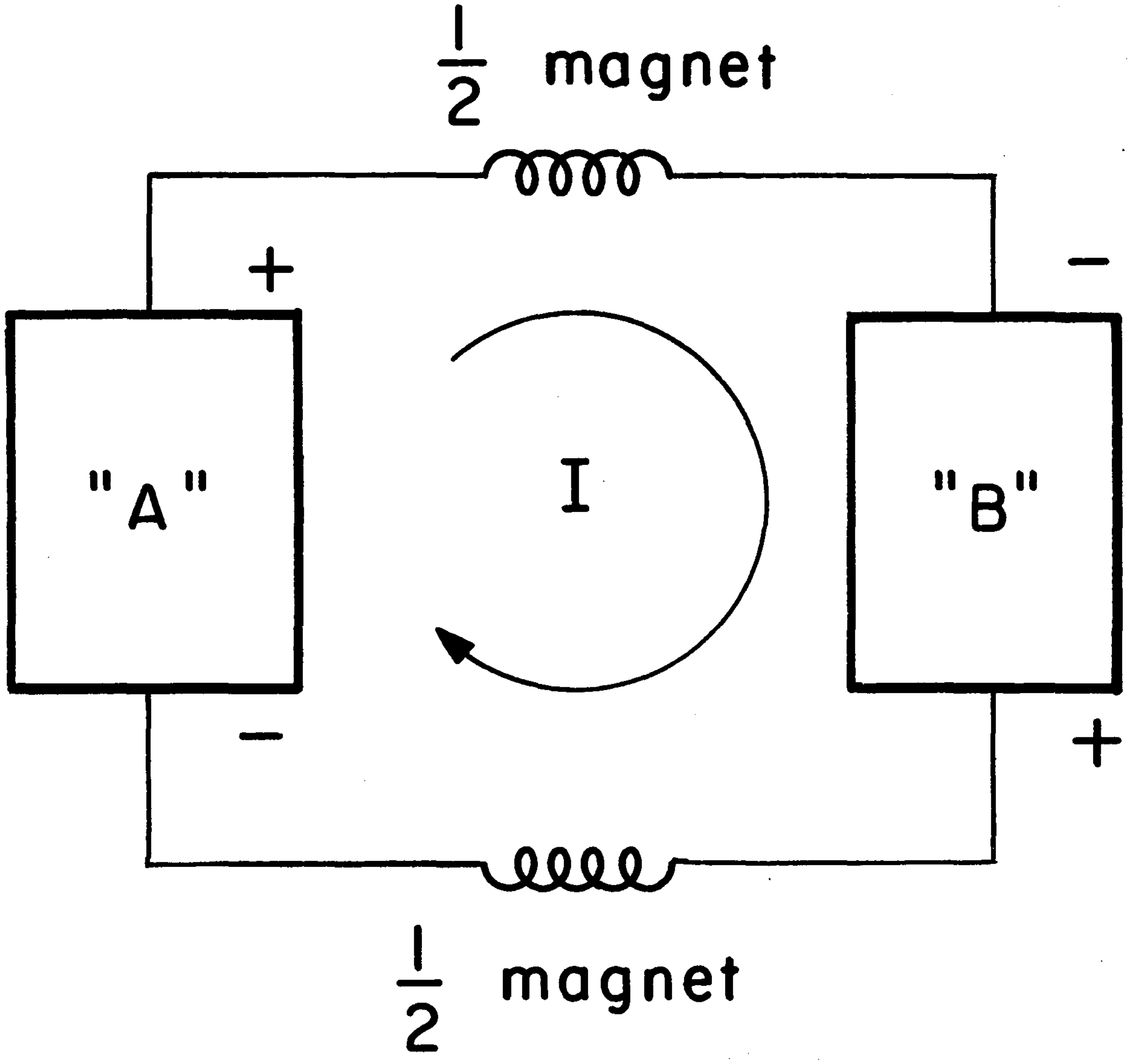

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Fig. 3. Simplified diagram of Bevatron magnet and power supplies.

inverted, which results in a reduced magnet voltage of only the IE drop and inductance voltage. As long as this condition is maintained the rate of change of current is determined by this voltage and the unbalance of the two supplies. The maximum length of a mezzanine period is determined by the power limitations of the Bevatron motors. Unlike flat-top, where the "B" supply is inverted at the end of flat top, thereby forcing the magnet current back to zero, the mezzanine mode allows the "A" supply to again rectify, forcing magnet current to a higher value. Figure 4 shows a photograph of the Bevatron magnet voltage and current wave shapes during a mezzanine pulse.

3. Test Results

In general the results of the test were satisfactory and have prompted further development towards an operational mezzanine at higher current levels. The tests were limited to 2000 A because of excessive torsional and electrical transients during the change from rectification to inversion. Critical timing circuitry has to be provided in the magnet-pulsing control chassis in order to reduce these transients. Acceptance of the results was based on the fact that the Bevatron's accelerated beam could be tracked through the mezzanine and again accelerated at the end of this period.

4. Present Status

Development of improved control circuitry is underway and mostly complete, and fabrication and installation is in progress. The ultimate aim is to have both the mezzanine and flat-top modes available during a single pulse, thereby increasing the flexibility of the Bevatron.

VI. RADIATION DETECTION AND CONTROL STUDIES

W. L. Everette

A. Stray Radiation During Beam Accelerations

1. Modes of Operation

Reflecting, momentarily, on Bevatron scheduling for this period we see that the time was used in 5:8 proportion by two pairs of primary-beam control groups. The Wenzel Group continued p-p scattering work through the end of January. The K-63 experimenters (Murray et al.) worked compatibly with the Wenzel Group by alternating scheduling K^--p and π^--p experimentation. Thus, method of targeting, shielding arrangements, and environs radiation were as described in the fourth quarterly report for 1963.[3]

During the shutdown period February 3 through 8, a change was made in experimental arrangements. The p-p scatter targets and beam-defining magnets were replaced by similar equipment for the Trilling-Goldhaber group ($K^{\pm}$-p, using the 25-inch bubble chamber). Target locations were not changed appreciably (see Fig. 5), but an improved beam-stop

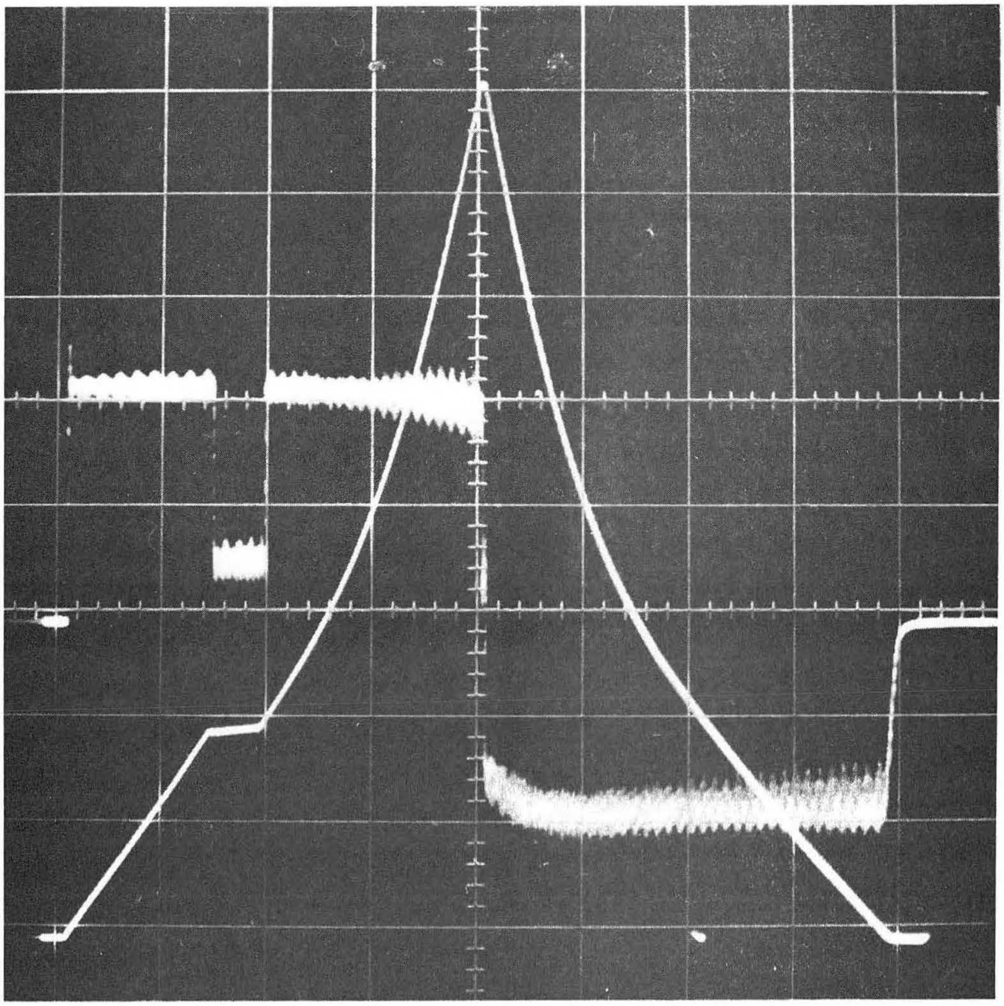

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Fig. 4. Bevatron magnet voltage and current during a mezzanine pulse.

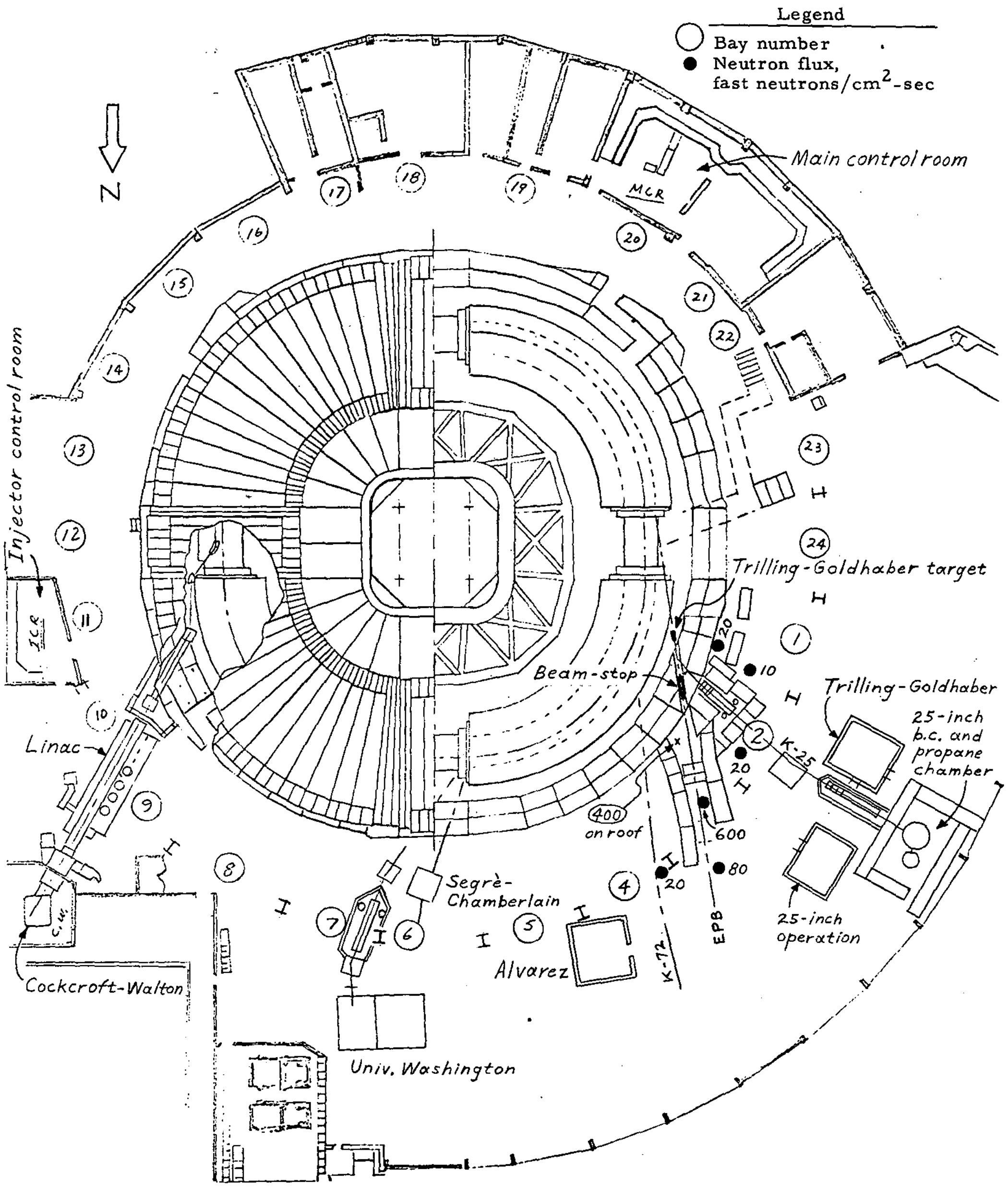

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Fig. 5. Shielding arrangement for 25-inch-bubble-chamber operations.

was installed at the center of the Bevatron shield wall which decreased stray radiation in the vicinity of the beam channel. Compatible beam sharing was established for K-63 and the 25-inch bubble-chamber work, and these groups are scheduled to be the beam-controlling groups for several months. The University of Washington (Masek) and the Segrè-Chamberlain Group used targets at N. O. W. and in travel-target section "H" (Quad III) in a parasitic mode of beam interception.

2. Building Survey

Radiation surveys for this period are listed in Table III. One study was made in January to determine neutron flux in the utilities tunnel under the external-beam channel. Results of the measurements (given in Fig. 6) provided a basis for deciding to move barriers from the entrances, around in the tunnel, to building bays 1 and 4, respectively. In future arrangements concrete blocks and magnet iron will cover the floor over the tunnel and will provide neutron attenuation by a factor of approximately 10^3.

A future external-beam transport system passes through the building annex to a beam-stop at the "B" door. The front section of the shield enclosure was assembled during the February shutdown. With blocks placed across and inside the channel, work will proceed on the downstream section while the external beam is used for the 25-inch-bubble-chamber experiment. Neutron intensities around this structure are shown in Fig. 5.

As the circulating-beam intensity increases, the neutron flux at the straight-section roof becomes more prominent. A problem already exists at the south and east tangent tanks. Three studies were made in March (see Figs. 7, 8, and 9) and show beyond doubt that the plunging magnets are the source of these high fluxes. Just how many neutrons on the floor come from the roof was not determined.

B. Special Studies

To determine the effect of primary radiation on biological targets, a Masonite phantom was placed directly in the external beam and exposed to approximately 6×10^7 protons. The dose at different depths in the phantom was measured in gamma- and neutron-sensitive film. A faint spot about 1/2 in. in diameter appeared on the gamma film. The dose, as read from this spot, was 2 mrem at the front surface of the phantom and was between 2.2 and 1.7 mrem over the entire 10-in. section. The dose as indicated by the neutron film was 1.3 rem at the front surface and increased to 7 rem at a depth of 2 inches.

A study was made to determine whether or not a hazard exists from radiation activation of air in the vicinity of the machine. The answer was negative. In the preliminary estimates radionuclide yields from only eight—the most abundant—air isotopes were considered. These were:

Table III. Summary of neutron-survey data for January through March 1964.

Date of survey	Survey		Beam intensity (ppp)		Targets				Data reference
							Spill		
	Area	Detector	Internal	External	Designation	Location	(%)	(BeV)	
1-10	Utilities tunnel	Ag(n, γ)-fast neutrons	--	6×10^{10}	1. Alvarez	29°, QIII	--	6	Fig. 6
					2. Wenzel	EPB channel	--	6	
					3. Beam-stop	Annex floor	--	6	
1-13 (3 weeks)	Utilities tunnel	Location film, beta and gamma	--	$\approx 10^{11}$	1. Alvarez	29°, QIII	--	6	Fig. 6
					2. Wenzel	EPB channel	--	6	
					3. Beam-stop	Annex floor	--	6	
2-18	Building floor, bays 2-4	Ag(n, γ)-fast neutrons	--	5×10^{10}	1. Alvarez	29°, QIII	--	6	Fig. 5
					2. Trilling-G.	EPB channel	--	6	
					3. Beam-stop	Bev. shield wall	--	6	
3-20	Bevatron shield roof	Ag(n, γ)-fast neutrons	2×10^{12}	$(0.5-3) \times 10^{10}$	1. Alvarez	29°, QIII	90% of int. beam	6	Fig. 7, curve 1
					2. Segrè-Chamberlain	Section H	6% of int. beam	6	
					3. Masek	N. O. W.	3% of int. beam	6	
					4. Trilling-G.	S. I. W. EPB channel	1% of int. beam	6	
					5. Beam-stop	Bev. shield wall	100% of ext. beam	6	
3-24	Bevatron shield roof	Ag(n, γ)-fast neutrons	2×10^{12}	10^{11}	1. Masek	N. O. W.	80% of int. beam	6	Fig. 7, curves 2, 3, 4
					2. Trilling-G.	S. I. W. EPB channel	20% of int. beam	6	
					3. Beam-stop	Bev. shield wall	100% of ext. beam	6	
3-26	Bev. shield roof over east straight section	Ag(n, γ)-fast neutrons	2×10^{12}	10^{11}	1. Alvarez 2. Masek	29°, QIII N. O. W.	≈80% of int. beam	6	Fig. 8
					3. Trilling-G.	S. I. W. EPB channel	≈20% of int. beam	6	
					4. Beam-stop	Bev. shield wall	100% of ext. beam	6	
3-31	Top of east straight section	$Al^{27}(n, p)$ fast neutrons $E_n \geq 6$ MeV	--	10^{11}	--	--	--	6	Fig. 9

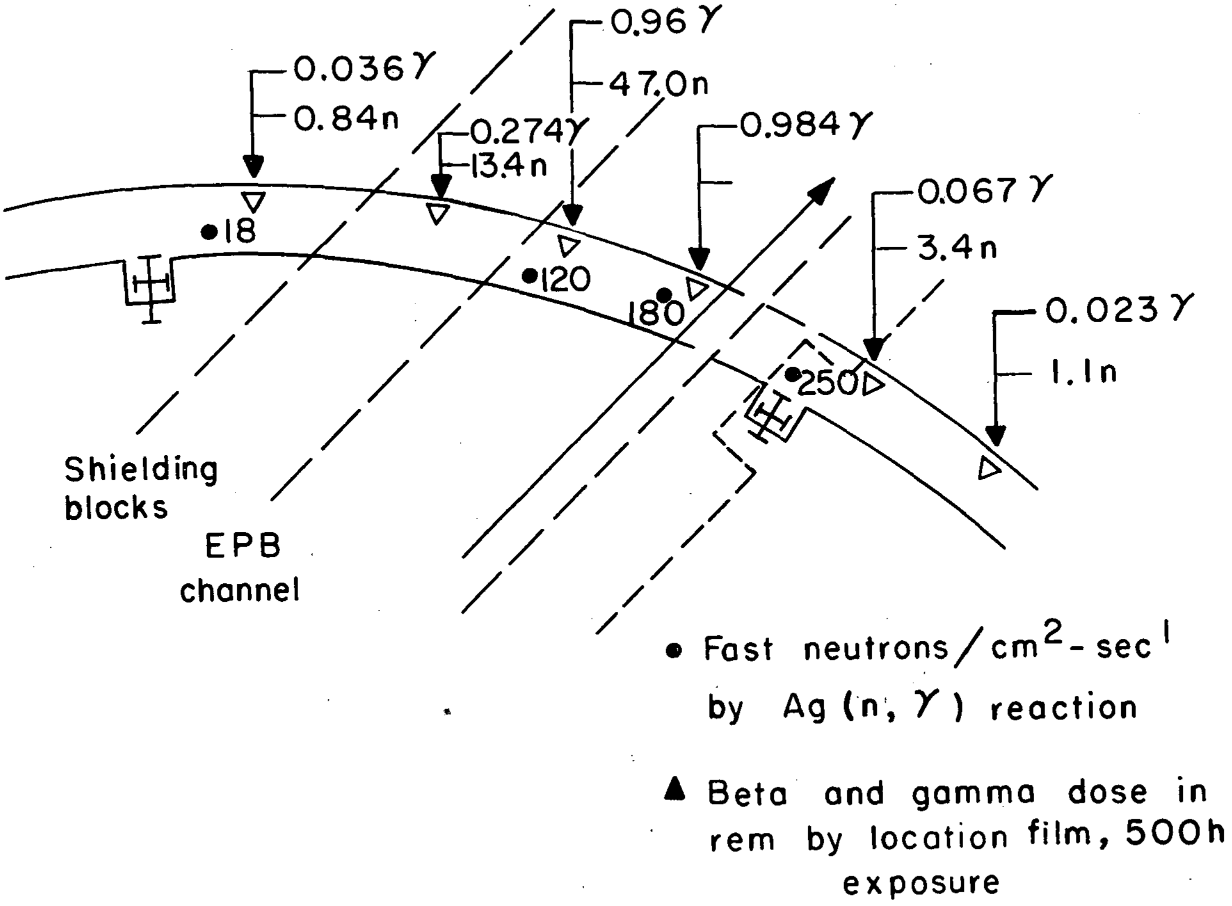

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Fig. 6. Neutron and gamma photon study in the west utilities tunnel.

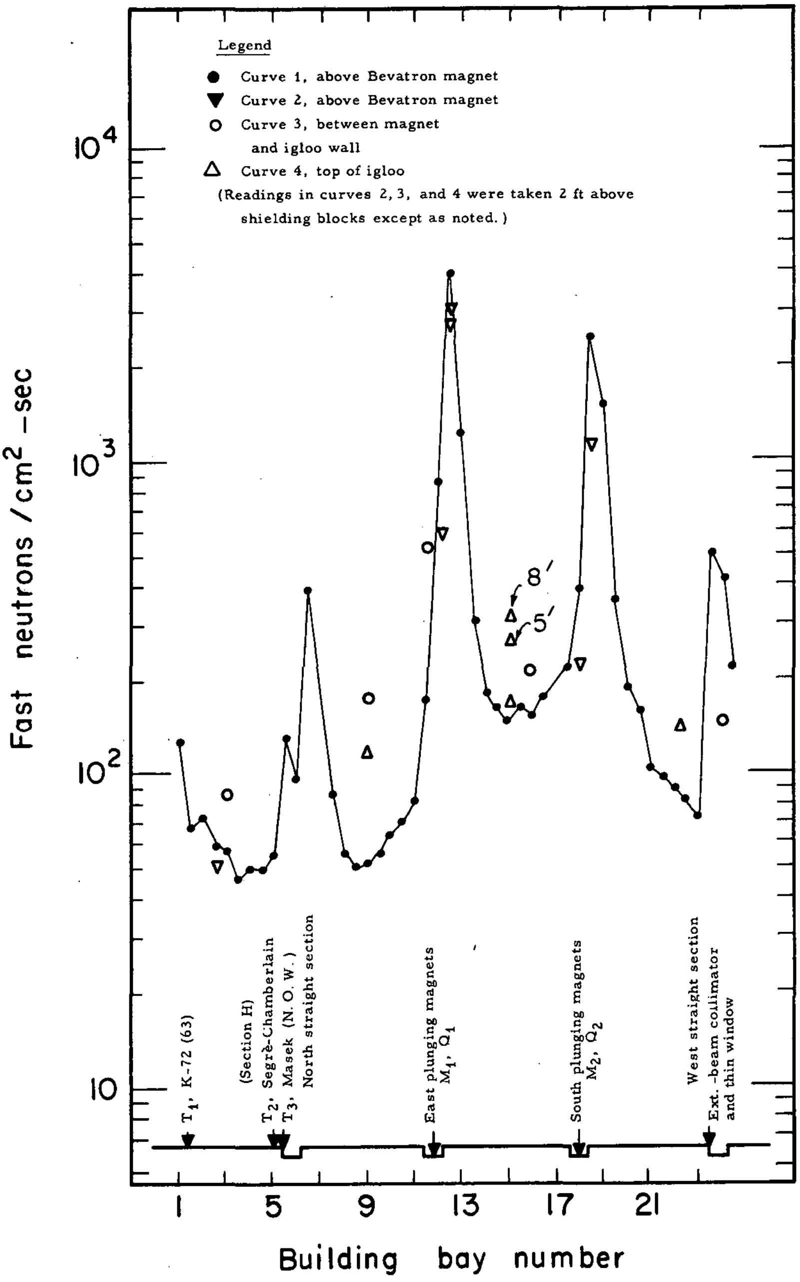

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Fig. 7. Fast-neutron flux on the Bevatron shield roof.

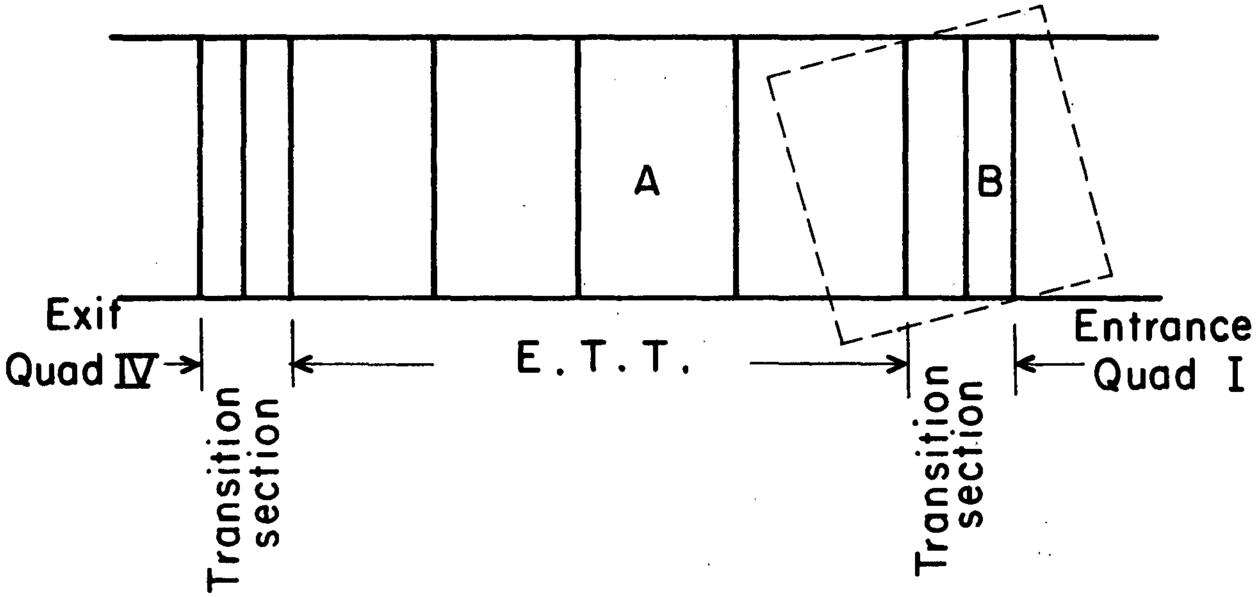

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Fig. 8. Study of neutron flux on top of east tangent tank roof.

Four measurements were made:

1. The counter was placed on the shield roof over the middle and downstream end of the E. T. T.
   Point A over shield roof = 1150 fast neutrons/cm^2-sec
   Point B over shield roof = 4400 fast neutrons/cm^2-sec
2. The counter was placed on the shield roof over the middle and downstream end of the E. T. T. where the counter was surrounded with 20 to 30 in. of paraffin on all sides except the side against the floor.
   Point A over shield roof + CH_2 = 1050 fast neutrons/cm^2-sec
   Point B over shield roof + CH_2 = 4400 fast neutrons/cm^2-sec
3. Step 1 was repeated with 2 ft of heavy concrete placed over the E. T. T. (see dashed rectangle in sketch).
   Point B over shield roof + concrete = 825 fast neutrons/cm^2-sec
4. Step 2 was repeated with 2 ft of heavy concrete placed over the E. T. T. (The block was not large enough to measure point A in this way.)
   Point B over shield roof + concrete + CH_2 = 604 fast neutrons/cm^2-sec

The two feet of concrete lowered the flux by at least a factor of 5 to 7. It appears then that a half-value layer for these conditions would be 74 g/cm^2. This is equivalent to 8.5 in. of concrete or 4 in. of iron.

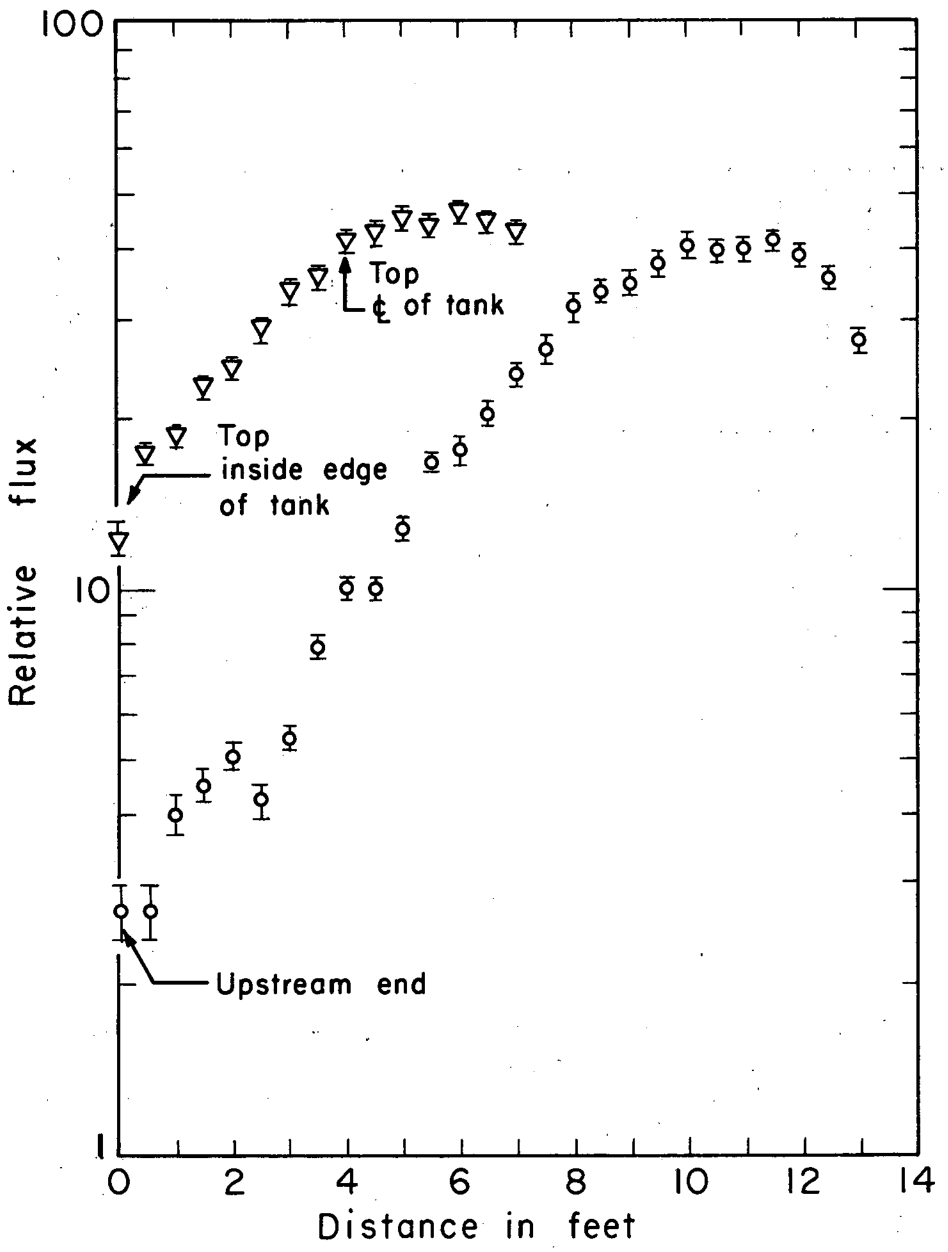

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Fig. 9. Profile of neutron flux, $E_n > 6$ MeV, at top of E. T. T.; source, M_1Q_1.

	Isotope	Half-life	Radiation	M.P.C.[*]
Thermal reaction	A^{41}	1.83 h	β^+, γ	2×10^{-6} μCi/cm^3
High-energy reaction	C^{11}	20.4 min	β^+	For mixed gases
	N^{13}	10.1 min	β^+	not containing
	O^{15}	2.05 min	β^+	Sr^{90}, I^{129},
	C^{40}	1.4 min	β^-, γ	Pb^{210}, etc.
	S^{37}	5.04 min	β^-, γ	M. P. C. =
	F^{18}	1.87 h	β^+	3×10^{-8} μCi/cm^3

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[*] Maximum permissible concentration.

Air activity was detected by a NaI crystal, and two methods of sampling were used. One measurement was made by capturing the air before irradiation. Only C^{11} (12.6×10^{-6} μCi/cc) and A^{41} (1.9×10^{-6} μCi/cc) were seen after a 4-h irradiation at 10^6 fast neutrons/cm^2-sec. These isotopes were negligible in samples of moving air. Since all regions in the unshielded area are well ventilated we conclude that there is no immediate hazard from gaseous radionuclides. Presently a study of radionuclides from dust is under way.

Fast-neutron flux was measured in the pit regions by using gold activation foils. The average circulating beam was about 8×10^{10} ppp. Targets were used at E. I. M. (string spill at I-26), S. I. M. (external-beam spill at I-27 to inversion), Section H, and in the external-beam target for 6-BeV protons. The plunging magnets at the east and south tanks were in use.

Location	Flux (fast neutrons/cm^2-sec)
East Straight Section,	
downstream end of pit	61,000
inside platform, upstream (at magnet)	35,000
inside platform, center (igloo wall)	13,000
West Straight Section,	
downstream end of pit	10,000
under inside platform	7,000
Center of Igloo Region	450

C. Radioactivity Buildup

A history of radioactivity buildup is presented in Fig. 10. Conditions for all measurements were roughly similar; all on-site readings were taken within 2 h following shutdown, using a portable ionization chamber (Juno) with the low-energy, beta filter closed. Inside the vacuum tank the plunging magnets represent a formidable source of radioactivity since they intercept scattered particles from all targets and also collimate the extracted beam. The intensity of radioactivity reported for sector 81 represents the highest value found in a target region. The area of interest is only a few square feet. Some degree of saturation is perhaps evident but it is too early yet to make an accurate prediction of the final value.

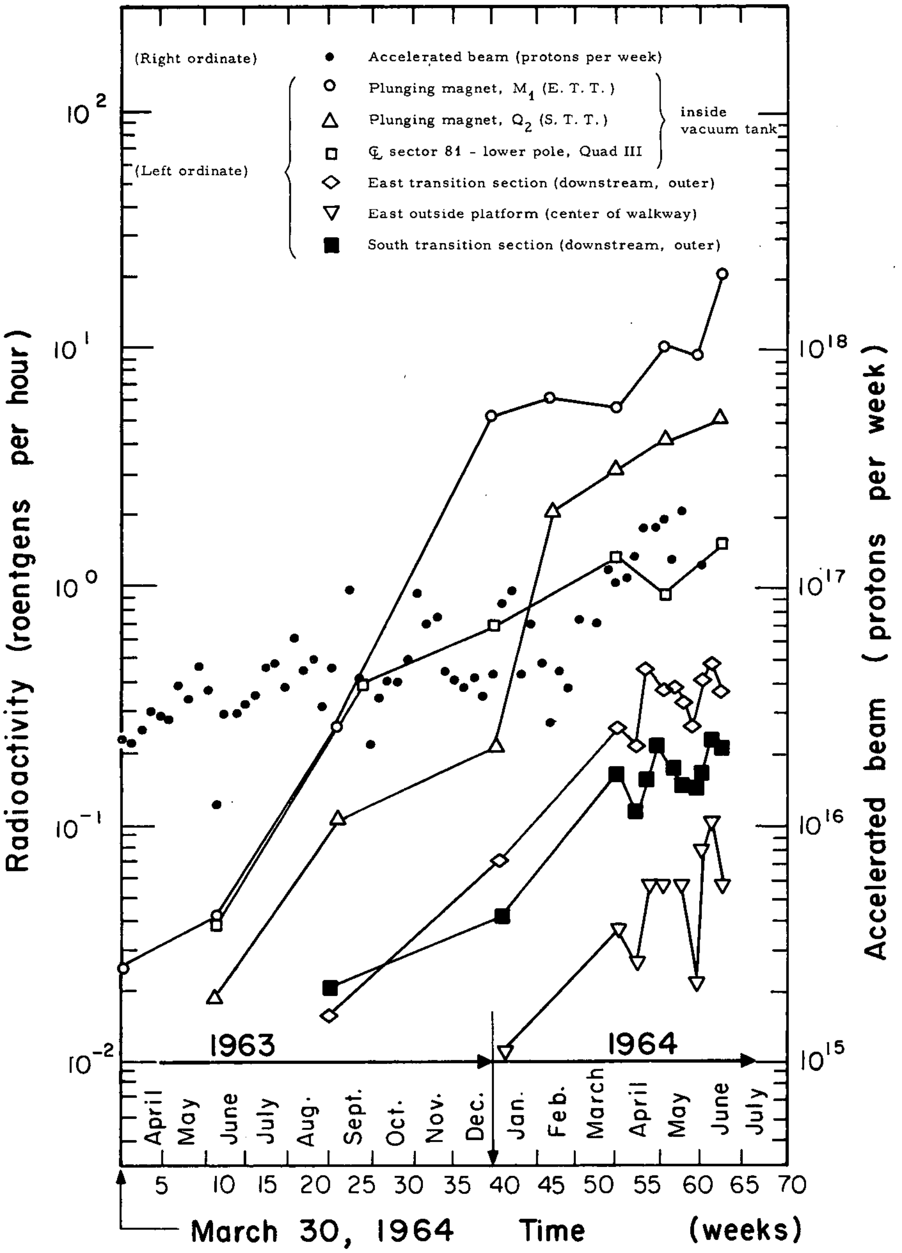

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Fig. 10. Radioactivity buildup and accelerated proton beam at the Bevatron.

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