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July through September 1964

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BEVATRON OPERATION AND DEVELOPMENT. 43

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ABSTRACT

The Bevatron beam was on for 87.1% of the scheduled operating time. A loss in efficiency of injected-beam pickup was caused by a shorted turn in one of the inflector magnets. This caused some jitter in normal beam operation for a period of about ten weeks until the magnet was replaced during a scheduled shutdown in September. Two primary experiments ended this quarter and installation was started on three new primary experiments. Injector studies showed a misalignment of the injector beam-transport system. The injector was realigned during the shutdown. The external proton beam channel was extended to the third focus.

I. OPERATION

The Bevatron operation record is shown in Fig. 1. The beam was on for 87.1% of the scheduled operating time. The beam was off for 7.2% of the time because of equipment failure and 5.7% of the time for experimental setup, tuning, and routine checks.

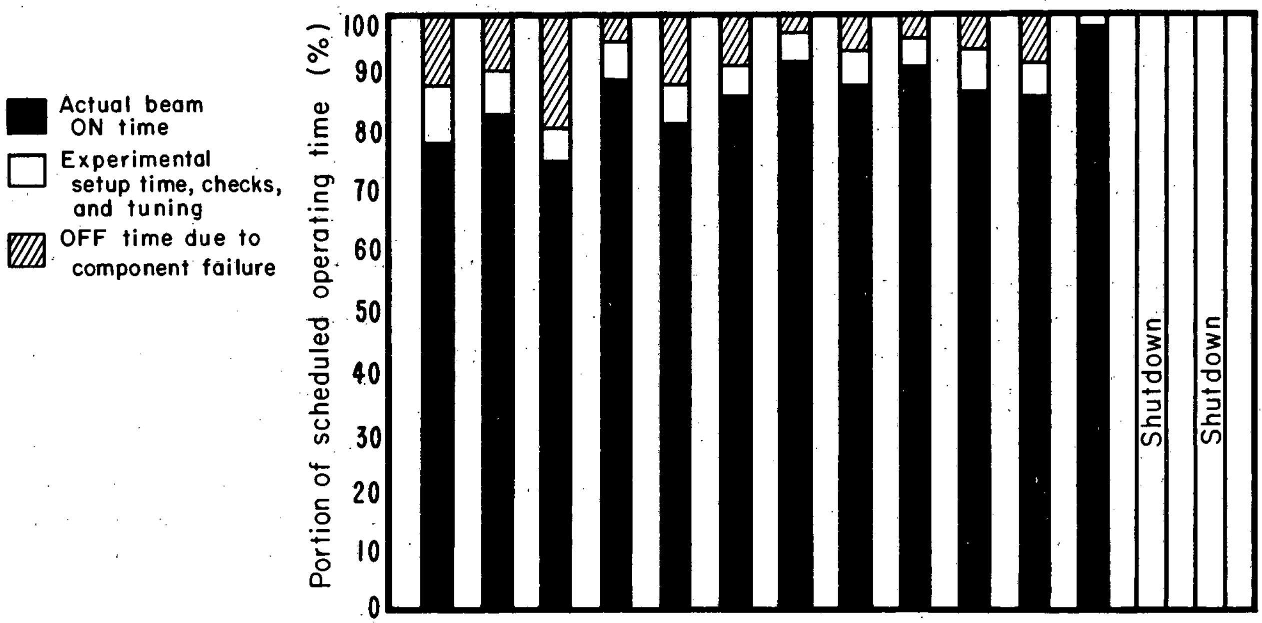
Early in July operation of the injected beam became erratic. The beam signal would suddenly disappear from the east Faraday cup monitor and then slowly return to normal, more or less independently of tuning by the Bevatron crew. An electrical alignment of the inflector system required a higher current than normal in the final magnetic stage of the inflector system IM3 to steer the beam through the system. IM3 is located in the east tangent tank just ahead of the final electrostatic inflector. Changes in the resistance of the magnet winding, and the increased current, indicated a possible shorted turn in IM3. The magnet power supply was changed from current regulation to voltage regulation. This produced less jitter in the injected beam, and we were able to operate in a reasonable manner this way. Beam capture was less efficient in the Bevatron than previously, and we had to inject 8 to 10 mA of beam instead of 4 to 6 mA to accelerate our normal-intensity beam of 2.5×10^{12} protons per pulse.

A spare IM3 magnet was already in production and this job was speeded up in case a catastrophic failure in IM3 occurred. We decided to operate IM3 in the above condition rather than try to repair it at that time. If IM3 were to fail before the replacement was ready, we would shut down and try to repair it. Otherwise, we would continue operation until the spare was ready, and then pick a convenient time for the shutdown. We could then either repair or replace IM3 depending on what was found on examining the magnet coils. We continued operating in this manner until September 14, when we shut down the Bevatron for 3 weeks.

II. SHUTDOWN

The Bevatron was turned off on 14 September for a 3-week shutdown. The primary job was to fix the IM3 inflector magnet. Because of the high level of residual radiation in the east tangent tank (see Sec. VI. C), the work time allowed per person in the area was rather short. A brief examination of IM3 showed an apparently burned section in one coil. We decided to replace the magnet. References for the position of the magnet were made. The magnet was removed and the new one installed. The "burned" section observed turned out to be deposited organics rather than damage to the epoxy coil covering. The actual short (found later from electrical measurements) appeared to be in the end region where the conductors cross over from one coil layer to the next. It is believed to be a failure brought about by a fabrication fault rather than by radiation damage. The epoxy in the general area showed no particular damage from radiation.

The start of the shutdown was actually determined by completion of the University of Washington (Masek) experiment and of the Powell-Birge



Week of	6/28	7/4	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30	9/6	9/13	9/20	9/27
Crew hours	168	168	168	168	168	168	168	168	168	168	144	168	168	168
Turnon & maintenance time (h)	10	10	10	10	10	10	10	10	10	10	10	4	0	0
Scheduled operating time (h)	146	150	148	157	154	146	150	152	150	145	106	24	0	0
Scheduled Bevatron test time (h)	12	8	10	1	4	12	8	6	8	13	28	0	0	0
Scheduled shutdown time (h)	0	0	0	0	0	0	0	0	0	0	0	140	168	168
Holiday (h)	0	0	0	0	0	0	0	0	0	0	24	0	0	0

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Fig. 1. Operations record.

Group 25-inch hydrogen and 30-inch Freon bubble chamber runs. These experimental setups were removed and the following setups installed. In the external proton beam (EPB) the Michigan-Stanford experiment was set up at the new third focus, F_3. The first part of the Crowe Group experiment was installed in the main shielding of the Bevatron at the first focus of the external proton beam. The Segrè-Chamberlain experiment was set up at the north area of the main Bevatron shielding. This experiment will use the internal proton beam on a target in the north (north outside west, N. O. W.) straight section.

An inside-radius Faraday cup was installed in the south straight section. It is to be used for beam studies and as a diagnostic tool for beam monitoring at injection.

Routine maintenance was also carried out during this shutdown.

III. BEVATRON DEVELOPMENT AND STUDIES

A. Study Periods

Most of the Bevatron study periods were devoted to extending the EPB beam channel and to investigating the injector transport system. The EPB channel is discussed in more detail in Section VI of this report.

B. Injector Studies

Robert W. Allison, Jr., and Emery Zajec

Observations of the total injected beam were made after 1/4 turn in the machine, with a quartz scintillator in the south tangent tank. The size of this quarter-turn beam is, as expected, approximately 13 in. radially by 2 in. vertically. However, large deflections vertically were observed when the inflection-system components were tuned. This indicated that all the bending magnets and quadrupoles except IM3 were misaligned. In addition, varying the linac rf level or the strength of the linac quadrupoles caused a vertical position shift of about 3 in. at the south scintillator.

Because of these observed beam effects, an elevation survey was made of IM1 and IM2. IM1 was low by 0.195 in. and IM2 low by 0.214 in. from the initial elevations established in September 1962. A complete elevation alignment of the linac and beam transport system was done during the shutdown in September.

With reference to the linac entrance elevation (8615.436 in.), the linac and transport system had settled as follows: linac exit, 0.90 in.; IQ1, 0.163 in.; IQ3, 0.289 in.; debuncher entrance, 0.394 in.; debuncher exit, 0.294 in.

During the repositioning, the linac entrance was lowered 0.070 in. to 8615.366 in., and the rest of the system was leveled to this value. This lowering of the injection system was to compensate for the general settlement[1] of the Bevatron magnet. The elevations before and after the repositioning are shown in Fig. 2.

IV. EXPERIMENTAL PROGRAM

The Powell-Birge experiment investigating the Y_1^* interactions in the K^--nucleon reactions in the 25-inch hydrogen bubble chamber ended this quarter, along with the University of Washington (Masek) experiment investigating the magnetic moment of the Σ^+ hyperon in 200-kG pulsed magnetic fields. The Alvarez Group study of the K^--p interactions in the 72-inch hydrogen bubble chamber continued through this quarter.

Emulsion exposures were made in the 800-MeV/c K^- beam which was set up for the 25-inch hydrogen bubble chamber experiment. A summary of the experimental program is shown in Table I.

V. MAGNET POWER SUPPLY

The magnet pulsing record is shown in Table II.

VI. RADIATION DETECTION AND CONTROL STUDIES

William L. Everette

A. Arrangement of Experimental Facilities

No major changes were made in the experimenter schedule during the running time of the third quarter period. Therefore, the arrangements shown in Fig. 2 of the second quarterly report are valid for this period. There were two minor exceptions. The exploratory work conducted by the Segrè-Elioff Group (using target EPB-F_1) and by the Perl-Longo Group (n-p scattering at 0 deg, forward of the external beam stop) was concluded July 24. Following this date, work commenced on phase II of the external beam transport system, which is designed to transport the proton beam through the building annex to a beam stop in the adjacent parking lot. The final arrangement is shown in Fig. 3. The beam size measured at focuses F_1, F_2, and F_3 are as follows (the dimensions are for full width at half maximum):

	width (in.)	height (in.)
F_1	1/4	1/8
F_2	1/4	3/8
F_3	3/16	3/32

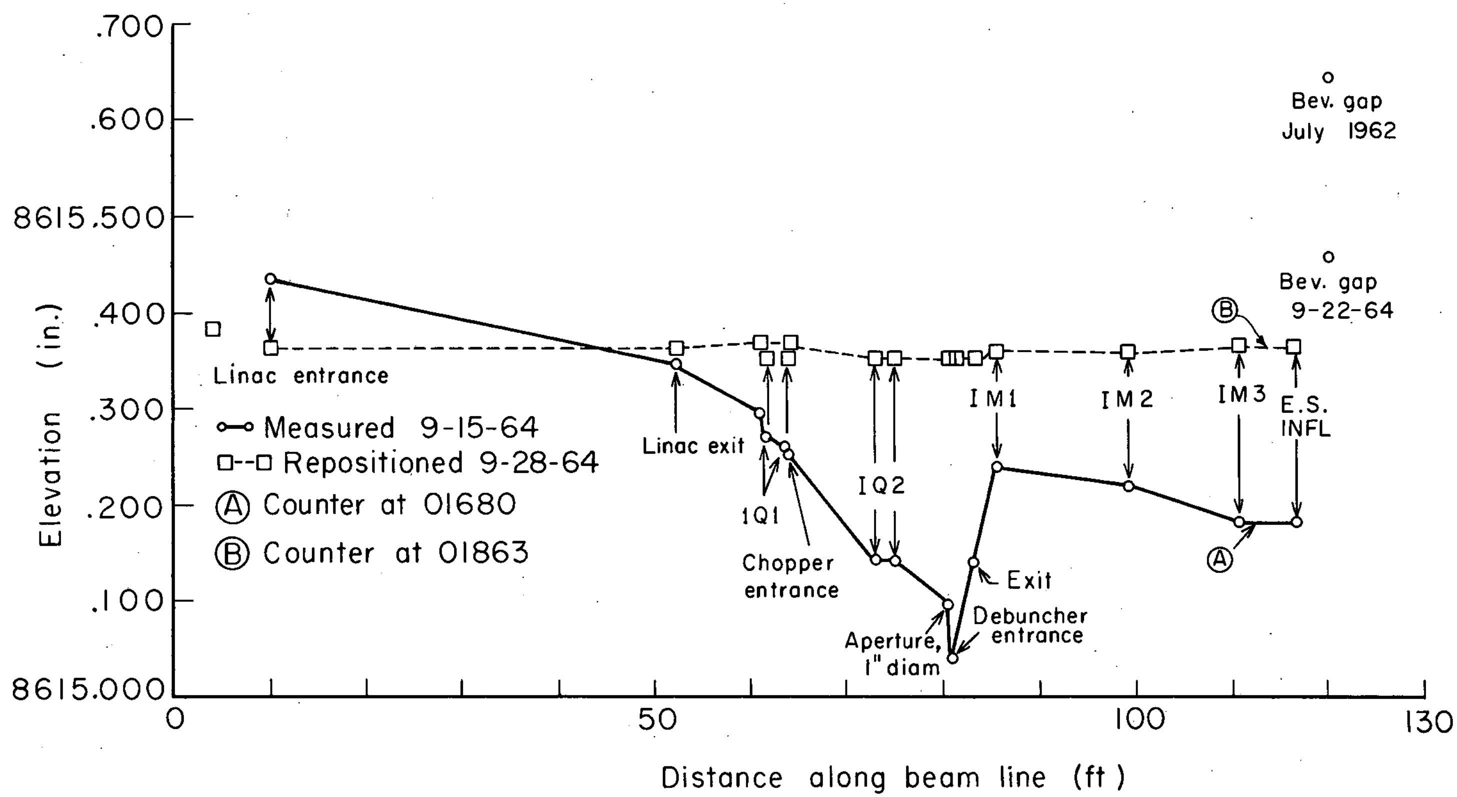

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Fig. 2. Elevation of linac-injector system.

Table I. Summary of Bevatron experimental research program, July through September, 1964.

Group	Start of experiment	End of experiment	Experiment	Beam time: This quarter (July-Sept.) 12-hour periods	Hours	Start of run through September 1964 12-hour periods	Hours	Pulse schedule	Primary or Secondary Experiment
Internal groups									
Alvarez (#16) Powell-Birge (#14)	3-23-63	In progress	Study of π^- interactions in the 72-inch bubble chamber using hydrogen, deuterium.	7	82	175	1845	1:1	P
Trilling-Goldhaber (#15)				0	0	3	41	1:1	S
Alvarez (#17)	4-26-63	In progress	Study of K^- interactions in the 72-inch bubble chamber using hydrogen, deuterium.	70	841	281	3045	1:1	P
Lofgren (#20)	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	Same as above	0	0	66	768	1:1	P
Segrè-Chamberlain	2-7-64	8-19-64	Test of K^+-particle detector in preparation for a future experiment to study K-Σ relative parity.	2	25	72	822	1:1	S
Trilling-Goldhaber (#29)	2-18-64	9-12-64	Study of K^+-nucleon interactions using the 25-inch hydrogen bubble chamber.	30	343	102	1142	1:1	P
Powell-Birge (#18)	3-24-64	9-13-64	Investigation of Y_1^* interactions in K^--nucleon reactions using the 25-inch bubble chamber.	35	395	114	1188	1:1	P
Powell-Birge-Frye	4-21-64	8-8-64	Study of hyperfragments produced by K^- mesons in the 30-inch Freon bubble chamber.	29	318	69	738	1:1	S
Lofgren-Segrè	5-14-64	7-24-64	Study $K^+ - \mu^+ \pi^0 + \nu$, measuring polarization as a function of energy.	0	0	4	44	1:1	S
	6-23-64	7-24-64	Same as above	11	114	12	125	1:1	P
Barkas	6-9-64	6-9-64	Emulsion exposure in an 800-MeV/c K^--meson beam in preparation for a future series of emulsion exposures.	0	0	1	10	1:1	P
Segrè-Chamberlain	6-9-64	6-9-64	Tuneup and test of the 25-inch bubble chamber beam transport system on antiprotons.	0	0	0	5	1:1	P
Barkas	7-1-64	7-12-64	Emulsion exposure in an 800-MeV/c K^- beam.	5	56	5	56	1:1	P
Mack-Jackson	7-14-64	7-21-64	Evaluation of counting equipment.	2	21	2	21	1:1	S
External groups									
Institution and experimenter									
Univ. Washington Masek	4-10-63	Continued below	Spark chamber and counter tests.	-	-	10	106	1:1	S
Univ. Washington Masek	2-8-64	9-4-64	Experiment to investigate the magnetic moment of the Σ^+ hyperon using a spark chamber in a 200-kG pulsed magnetic field.	36	416	110	1235	1:1	S
				0	6	28	288	1:1	P
	4-12-64	9-4-64	Same as above	3	25	3	25	1:2	P
				69	733	83	894	1:3	P
Tufts University Schnepps, Kang, Kwak	4-13-64	4-15-64	Emulsion exposure in a 1.1-BeV/c K^- beam	0	0	2	26	1:1	P
Delhi, India Bhowmik	4-15-64	4-18-64	Emulsion exposure to stopping K^- mesons	0	0	4	42	1:1	P
Univ. Washington Lord, Piserschio	4-18-64	4-20-64	Emulsion exposure to stopping K^- mesons	0	0	3	36	1:1	P
Stanford-Michigan Perl-Longo	5-6-64	In progress	Tests in preparation for a future n-p scattering experiment	2	12	4	39	1:1	S
Univ. Chicago (Enrico Fermi Inst.) M. Raymund	7-7-64	7-8-64	Emulsion exposure in an 800-MeV/c K^- beam	2	22	2	22	1:1	P
Univ. New York-Buffalo P. L. Jain	7-8-64	7-8-64	Emulsion exposure in an 800-MeV/c K^- beam	-	4	-	4	1:1	P
Univ. Warsaw, Poland M. Danysz	7-8-64	7-9-64	Emulsion exposure in an 800-MeV/c K^- beam	2	23	2	23	1:1	P
Univ. Calif., San Diego Piccioni	7-27-64	7-28-64	Tests in preparation for a future experiment	-	6	-	6	1:1	P
Columbia University Lee	8-20-64	9-2-64	$\bar{P}$-production cross section by protons for energies below threshold	2	21	2	21	1:1	P

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	
April	779						1210			3021			6776	2	2	396484	18	32	408270	18	34	52	7851	
May													7671			424194	12	8	431865	12	8	20	21593	
June				359			1327		1	35693	2	6	12340			317993	30	32	367712	32	39	71	5179	
July	3096	1	5	422			8481			1750			76289	2	5	310154	28	33	400192	31	43	74	5408	
Aug.	185			384			1076			267643	14	21	16238			98172	5	8	383698	19	29	48	7993	
Sept.							387			76478		5	59959			18552			155376		5	5	31075	

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

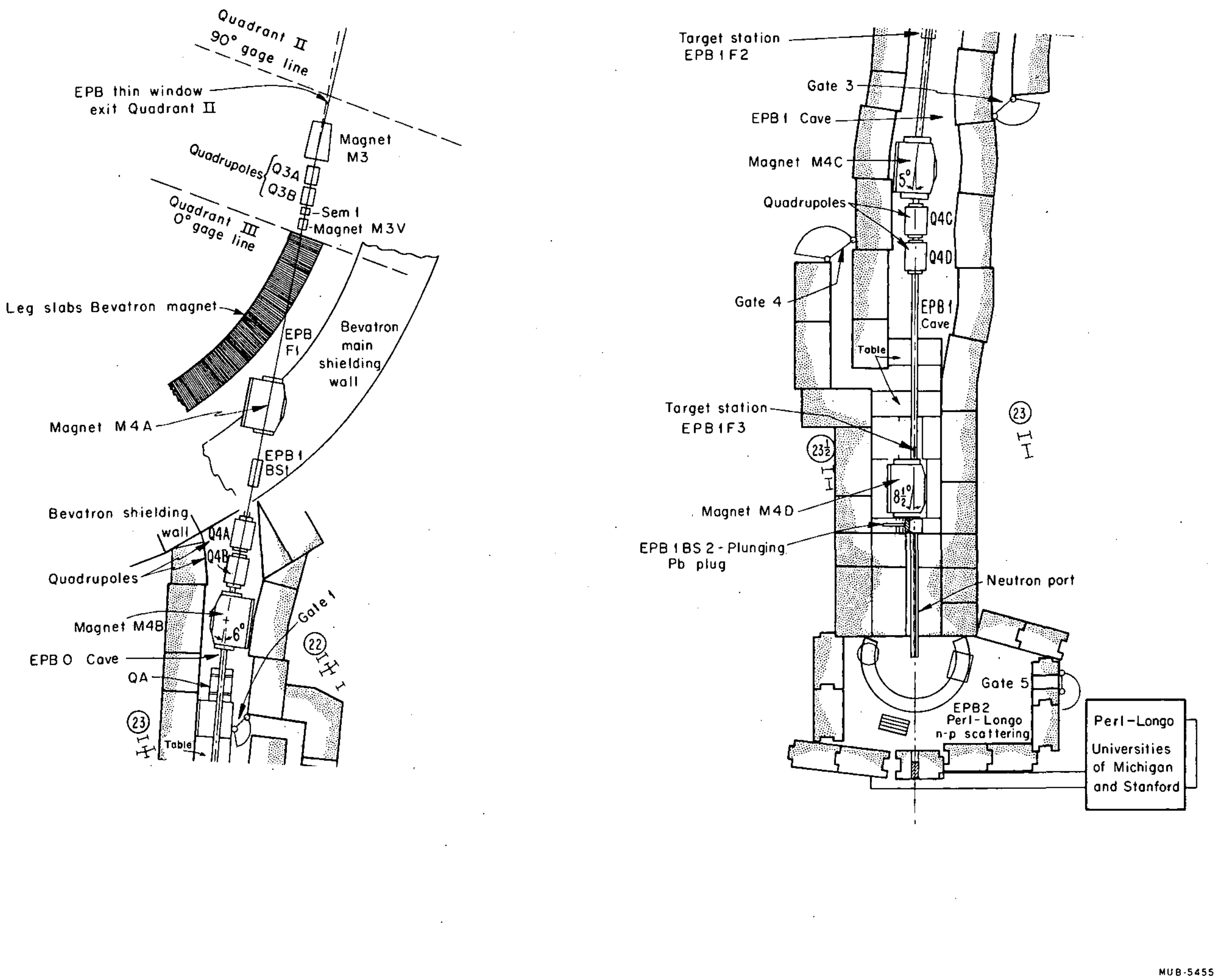

Fig. 3. Phase II EPB transport and shielding arrangement.

B. Detection and Control of Neutrons and the External Beam

Neutron intensities in working spaces about the building were reported previously and did not change significantly for this period.

During modifications in the external beam shielding, part of the shielding structure was disassembled and magnets M4B, Q4A, and Q4B were installed during machine maintenance periods. Since the machine was shut down, there were no problems of neutron exposure.

In the new arrangement, M4B is enclosed at its corners, top, and outboard side with pieces of iron and lead in such a way as to wall off the upstream portion of the shielding enclosure, leaving a 7-foot entrance hall. A 4-foot concrete-block wall partition, downstream from M4B, encloses a small quadrupole magnet and completes an entrance labyrinth to the upstream section. A 4-foot iron beam stop (EPB BS1), raised to intercept the proton beam, and the amount of shielding in the upstream section of the enclosure give adequate protection to workmen outside for beam intensities as high as 5×10^{11} ppp at 5 BeV. The distance from EPB BS1 to the small quadrupole is roughly 40 ft. The neutron intensity forward of the partition is about 80 n/cm^2-sec in line with the beam port, and less than 30 n/cm^2-sec at other points adjacent to the blocks. These values drop rapidly as one moves away from the partition, and are no cause for alarm.

A monitored entrance gate will be installed at this location and will be interlocked with one segment, EPB 0, of the external beam radiation safety chain. The EPB 0 segment includes all beam space up to EPB BS1. When the EPB shield enclosure and radiation safety chain are complete, modification and maintenance work may be safely conducted while an experimenter is using EPB 0 at target F_1. The outboard section of the EPB facility will be known as EPB 1, and will have a safety subchain that may be operated in series with the EPB 0 chain. A simple schematic diagram of the radiation safety chain is shown in Fig. 4.

The arrangement for the Perl-Longo run was designed for a neutron beam, but the port is so near the forward direction that some consideration for safe disposal of the proton beam was essential. The methods presently used exist in two arrangements. When the neutron beam is used, the proton beam is deflected 7.5 degrees away from the neutron port by magnet M4D, and the magnet current supply is interlocked in the EPB 1 safety chain. When neutrons are not required, but disposal of the beam at EPB F_3 is required, a plunged beam stopper (BS2) blocks the port and removes the M4D current interlock requirement in the safety chain. However, a finite chance remained that a lethal proton beam might escape the beam stop. For this reason and for purposes of shielding experimenters' detectors from stray particles (the shielding requirement for detectors being considerably more stringent than that for health purposes), a concrete enclosure was built downstream from EPB BS2 and labeled the EPB 2 region. A monitored entrance station is provided, but may remain open if the beam port has been blocked while the beam is disposed of at BS2.

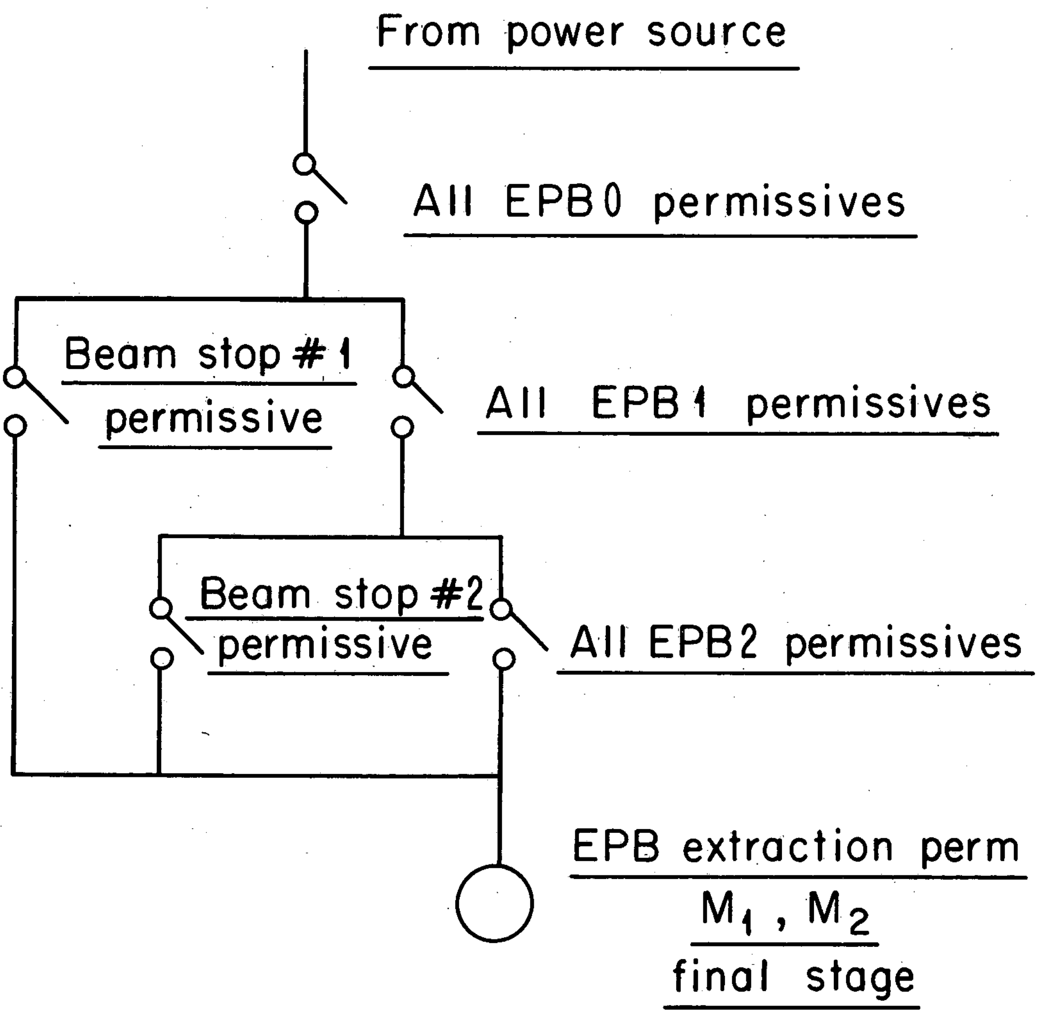

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Fig. 4. Simplified schematic diagram of the radiation safety chain for the external proton beam.

C. Residual Radioactivity--Machine Shutdown

A 3-week machine shutdown began 14 September and extended through 5 October. One task for the period was to substitute a new inflector magnet for the old one, in which a short had developed in a coil turn. The magnet, IM3, is located in the east straight section adjacent to the external beam magnets, MI-QI. The surface intensity of the residual radioactivity in the EPB magnets was measured and found to be 15 roentgens per hour 105 minutes after beam-off time. This residual activity decayed by a factor of three during the next 240 hours. Work in the tank was delayed by 12 hours during which a 33% decrease in activity from MI-QI was observed. The magnets were then enclosed in iron and lead shields, leaving IM3 as the major exposed source (reading 450 milliroentgens per hour at the downstream end). Radiation intensity in the working space was about 150 mR per hour when the process of removing IM3 began.

During the course of the shutdown, 75 man-hours were spent inside the Bevatron vacuum tank by 64 men. The number of hours per man varied from a maximum of 6.6 to as low as 0.06. Forty-six man-hours were spent in the east tank, but only six of these were required for radiation survey, shielding M1-Q1, and removing IM3 from the tank. The remaining 40 were used for clean-up, local repair jobs, and installing the new magnet. The largest integral dose to one man for the 3-week period was 450 millirem. The permissible dose for the period was 500 millirem.

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