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Ernest O. Lawrence Radiation Laboratory

BEVATRON OPERATION AND DEVELOPMENT. 39

July through September 1963

Berkeley, California

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Kenneth C. Crebbin, William L. Everette,
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ABSTRACT

The Bevatron provided beam for 86.8% of the scheduled operating time this quarter. There was a 4-day shutdown period, including a 24-h vacuum shutdown. The studies of the beam loss just after injection continued with no conclusive results. A new primary experiment started this quarter, using the external proton beam.

There were some changes made in the main ac power distribution for the Laboratory, to try to correct for line fluctuations caused by pulsed equipment at the Bevatron.

I. OPERATION

The Bevatron operation record is shown in Fig. 1. Beam was on for 86.8% of the scheduled operating time. Of the scheduled operating time, the beam was off 11.8% of the time because of equipment failure, and 1.4% of the time for experimental setup.

II. SHUTDOWN

The Bevatron was shut down from 8 am, September 3 to 5 pm, September 6. The vacuum shutdown lasted from 8:30 am, September 3 until 6:30 am, September 4. The primary job during shutdown was to change the external-proton-beam collimator.[1] There was some misalignment of the beam in the initial installation. This was corrected, and a positioning control was installed that provided an angular adjustment of 1 deg in the angle between the collimator and the nominal 6-BeV external-beam line.

The tracks on the external-beam plunging magnets $M_1 Q_1$ again showed damage. This was again repaired by honing the tracks. A new guide was ordered and should be ready for installation at the next vacuum shutdown. This should correct the problem of damaged tracks.

General maintenance was done on the magnet power supply and auxiliary equipment.

A 30-min vacuum shutdown occurred on September 5 to repair a cracked glass vacuum port.

III. IMPROVEMENTS

A. Beam Loss

1. rf Accerleration Voltage

Calvin F. Hansen

The beam loss reported in the preceding quarterly report[1] is still under study. One phase of this study involves the rf system. Further tests[1] were made by changing the shape of the rf voltage at the start of the acceleration cycle. The accelerated beam was increased to 3×10^{12} protons per pulse (ppp) from the previous maximum of 2.4×10^{12} ppp. However, when the test equipment was removed and normal operating rf wave shape was restored, the accelerated beam was still 3×10^{12} ppp.

Increased rf "dee" voltage indicated that even higher dee voltage was desirable. The rf automatic gain control (AGC) system was modified to allow higher dee voltage. Operation indicated that the normal operating conditions allowed the rf voltage to peak out for maximum accelerated beam.

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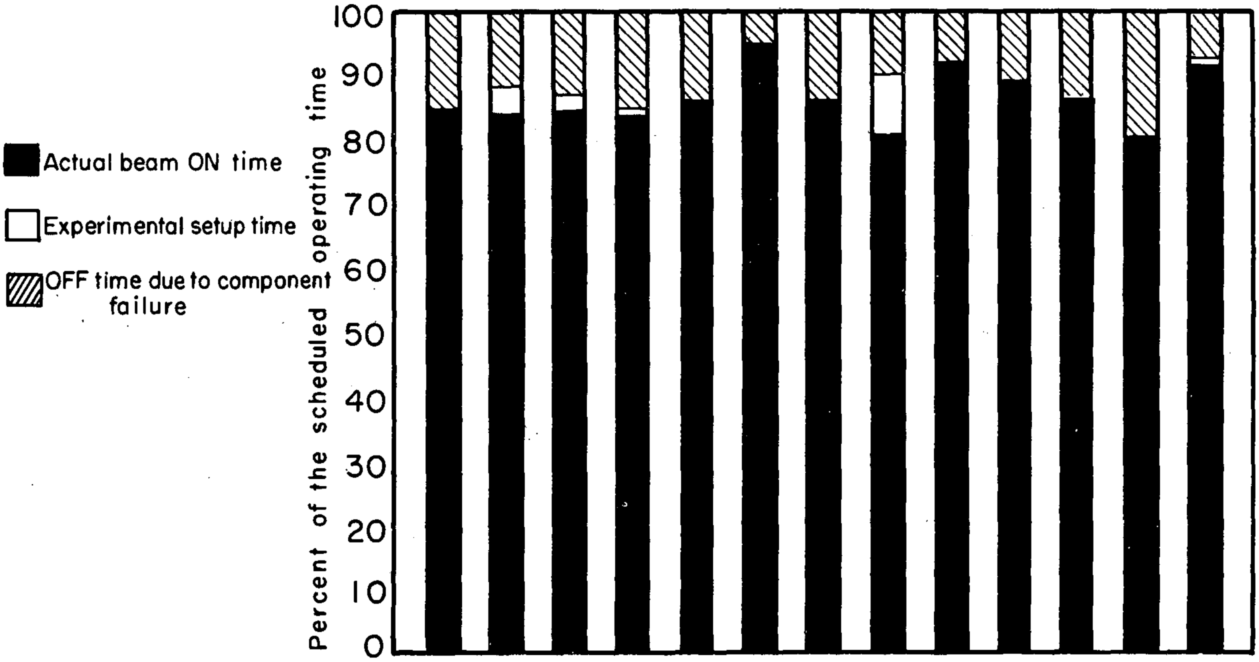
* Preceding quarterly reports: UCRL-11278, UCRL-10863.



Week of		6/30	7/7	7/14	7/21	7/28	8/4	8/11	8/18	8/25	9/1	9/8	9/15	9/22
Crew hours		112	128	128	128	128	128	128	128	128	104	128	128	128
Turn on & maintenance time	(h)	8	10	10	10	10	10	10	10	10	12	10	10	10
Scheduled operating time	(h)	96	96	96	96	97	97	98	98	98	0	106	109	108
Scheduled Bevatron test time	(h)	8	22	22	22	21	21	20	20	20	12	12	9	10
Scheduled shutdown time	(h)	0	0	0	0	0	0	0	0	0	84	0	0	0
Holiday time	(h)	24	0	0	0	0	0	0	0	0	24	0	0	0

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Fig. 1. Bevatron operating schedule, July through September 1963.

2. Beam Capture and Survival Studies

A second phase of study of the beam loss at high injected currents is the initial capture and survival under various conditions of Bevatron magnetic field shape and aperture. The aperture studies were made by clipping the beam at injection with either vertical or radial clippers. The beam intensity was then studied as a function of time for various vertical and radial apertures. These studies showed an apparent growth of vertical beam size in time. This is shown in Fig. 2.

It was thought that the higher injected beam currents might be causing an apparent lowering of the n value and therefore be going through a resonant point. The n value was therefore lowered by changing the pole-face-winding currents to give an n value below the resonant point. No change was observed in the high current beam loss.

3. Self-Excited Pole-Face-Winding Test

When the Bevatron resumed operation in February 1963 the pole-face windings were driven by a dc supply.[2] The currents in these windings provide the necessary correction to the radial-magnetic-field gradient for Bevatron operation. Previous to the 7-months shutdown, the pole-face windings had been driven by a five-turn loop around the inner magnet yoke of the Bevatron. There are some dynamic differences in the gradient correction as a function of time between the two methods of driving the pole-face winding currents. To check if this difference had any effect on the beam loss during the first 100 msec of acceleration, we reconnected the pole-face windings to the five-turn loop. There was no appreciable difference in beam capture and loss. The pole-face windings were therefore reconnected to the dc power supply.

B. Multiple-Target Compatibility Studies

With external proton beam (EPB) as a new mode of operation, it was necessary to conduct some compatibility studies to determine operating conditions for simultaneous operation of targets for EPB and targets for normal secondary beams. The external proton beam is brought out by the following method. The beam is spilled on an energy-loss target. The energy loss causes a betatron oscillation about a smaller-radius orbit. The minimum-radius point occurs about three-quarters of a turn around the Bevatron. At this point the beam goes through a deflection magnet M_1, which deflects the beam to a still-smaller radius. A quarter of a turn later it enters the second deflection magnet M_2, where it is deflected outward. It leaves the Bevatron a quarter of a turn after M_2, at the west outside straight section.

Normal external beam requires operation of the energy-loss target and deflection magnets M_1 and M_2. There are additional bending and focusing magnets outside of the Bevatron vacuum system to transport the EPB to the experimental area. We found, during the compatibility studies, that we could get beam down the EPB channel without the energy-loss target or M_1 and M_2 operating. The rest of the beam transport system was in operation. This beam was not of good optical quality. It had not gone through the two internal focusing quadrupoles located with M_1 and M_2. Because the beam was scattered out in some fraction of a turn around the Bevatron it

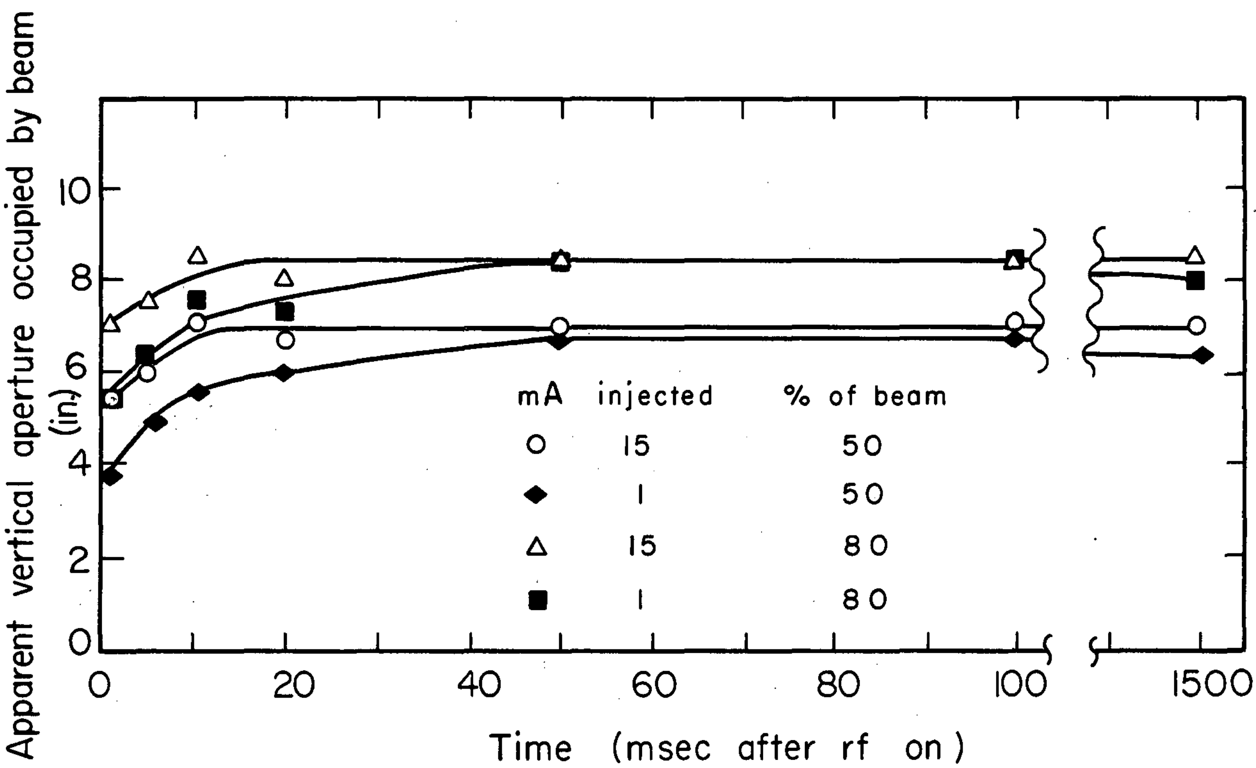

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Fig. 2. Apparent vertical growth of beam in Bevatron after injection.

also had rf structure. This spurious EPB came from three different sources. Just having 10^{12} protons circulating in the Bevatron gave between 5×10^6 and 10^7 protons down the EPB channel. If the string spiller was in use for the production of long beam spills, we got 3×10^7 protons down the EPB channel for 5×10^{11} protons onto the strings. If the internal proton beam is lost after being accelerated past peak magnetic field, it goes to the outer radius. Beam lost in this manner puts about 3×10^8 protons down the EPB channel for 10^{12} protons circulating.

The Segré-Chamberlain group, using the EPB, required low beam intensity of the order of 10^7 ppp. It is apparent from the above numbers for spurious EPB that low-intensity EPB experiments are not compatible with any high-intensity runs.

This spurious EPB required a change in the safety-chain operation for access to the EPB cave. The EPB cave access gate was placed in the control chain for the external deflection magnet M_3 as well as the internal deflection magnet M_2. The turning off of M_2 and M_3 allows operation of internal beam in the Bevatron while maintaining a safe background level for occupancy in the EPB cave.

IV. EXPERIMENTAL PROGRAM

A summary of the Bevatron experimental research program is shown in Table I. One new primary experiment was started this quarter by the Chamberlain group. It is a study of proton-proton interactions at energies of 1.7, 2.85, 3.99, 5.05, and 6.19 BeV. This experiment uses a polarized liquid-hydrogen target in the EPB. The runs were made with beams of from 5×10^7 to 10^9 ppp. Normal operation was at a level of $(1 - 3) \times 10^8$ ppp in the EPB.

V. MAGNET POWER SUPPLY

A. Magnet Pulsing

The magnet pulsing record is shown in Table II.

B. Power-Distribution Voltage Disturbance

Harold W. Vogel

The 12-kV ac electrical power-distribution system for the Laboratory is illustrated in a simplified form in Fig. 3. Prior to March 1963 the 88-inch cyclotron experienced difficulty in maintaining a beam of consistent intensity because of the voltage variations associated with the ac power distributed to their building (Fig. 4). The voltage disturbance was correlated with the operation of the Bevatron magnet power supply, and specifically, the step control of the two 3600-hp wound-rotor motors. The 12-kV ac regulated line was transferred to a spare feeder line from the campus to ameliorate the transient line voltage variation on the feeder to building 88.

After the transfer of the 12-kV ac regulated feeders to the campus line, the operation schedules for the Bevatron included more time for the EPB

Table I. Summary of Bevatron experimental research program, July through September 1963

Group	Start of experiment	End of experiment	Experiment	Beam time: This quarter, 12-hour periods	Beam time: This quarter, Hours	Beam time: Start of run through Sept. 1963, 12-hour periods	Beam time: Start of run through Sept. 1963, 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.	30	303	104	1071	1:1	P
Trilling-Goldhaber				0	0	3	41	1:1	S
Powell-Birge	3-23-63	5-27-63	Study of the decay of stopping K^+ mesons in a freon bubble chamber (750-MeV/c K^+).			64	656	1:1	P
						5	66	1:1	S
Lofgren	3-25-63	5-26-63	Study of the related Σ-Λ Parity (1.1- to 1.3-BeV/c π^-).			62	625	1:1	P
	3-25-63	7-3-63		7	44	32	336	1:1	S
Alvarez	4-26-63	In progress	Study of K^--p interactions in the 72-inch hydrogen bubble chamber.	34	366	55	588	1:1	P
Barkas	5-27-63	5-27-63	Emulsion exposure (750-MeV/c K^+).			3	43	1:1	P
Moyer	6-7-63	In progress	Study of inelastic π-p scattering in the range 500 to 1000 MeV/c, and elastic charge-exchange scattering in the range 500 to 1600 MeV/c.	70	752	91	984	1:1	P
					4	1	23	1:1	S
Segré-Chamberlain	8-6-63	In progress	Study of polarization of protons in high-energy p-p scattering as a function of momentum and angle.	19	214	19	214	1:1	P
				18	197	18	197	1:1	S
External groups									
Institution and experimenter									
Argonne Marcowitz	4-1-63	5-16-63	Counter tests			41	425	1:1	S
Univ. Washington Masek	4-10-63	Continuing	Spark-chamber and counter tests.	7	83	10	106	1:1	S
Philco Space Div. Rinehart	5-24-63	Continuing	Test of solid-state counters and spark chambers.		7	3	33	1:1	S

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

Month (1963)	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.	5055	16	1684	5									6739		21	21	320	Startup from long shutdown: 27
Feb.	2550		1152	2 4	4030	3 5	7385	5 11	7933	5 1	50387	25 36	73437	40	57	97	757	Not operating: 21-24 Shutdowns: 27, 28
March									11279	1	177283	49 55	188562	49	56	105	1796	Shutdowns: 1, 3, 7, 10, 17, 24, 31
April					504		12178		8698	1 1	259492	32 87	280872	37	88	125	2247	Shutdowns: 7, 14, 21, 28
May	1291		153		191		3859	2	6130		296222	16 36	307846	16	38	54	5701	Shutdowns: 5, 12, 19, 31
June									63896	5 4	179044	21 17	242940	31	26	57	4262	Repairs: 1-5 Shutdowns: 9, 16, 23
July	792		34				17020	2	174076	7 1	120461	3 22	312383	10	35	45	6941	Shutdowns: 4, 14, 21, 28
Aug.									18200	1	280775	15 47	298975	16	47	63	4745	Shutdowns: 4, 11, 18, 25
Sept.					28982	5 3	67950	5 12	104862	4 4	16776	4	218570	14	23	37	3834	Shutdowns: 1, 2, 3, 4, 5, 8, 15, 22, 29 Ignitron changed: 2A5

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

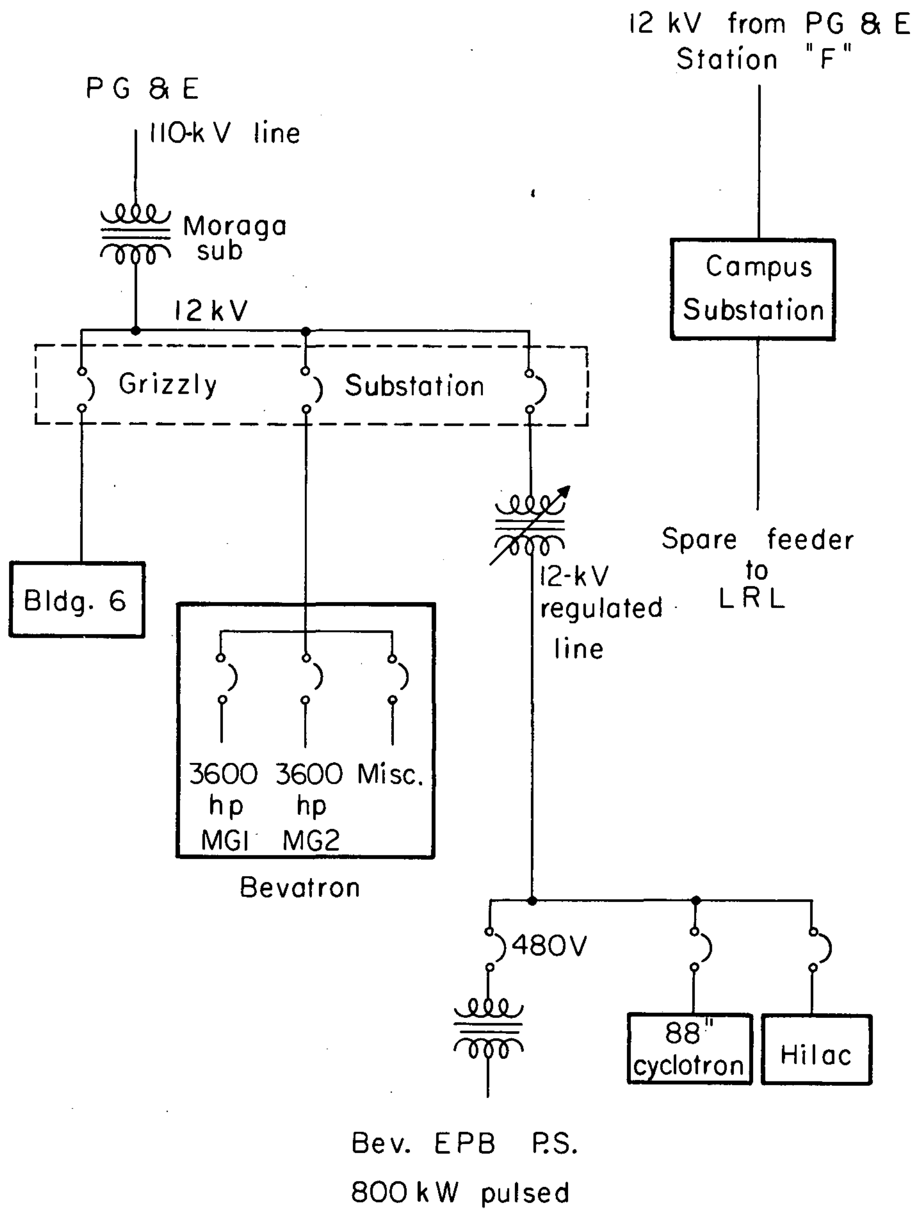

Fig. 3. Simplified Laboratory power distribution.

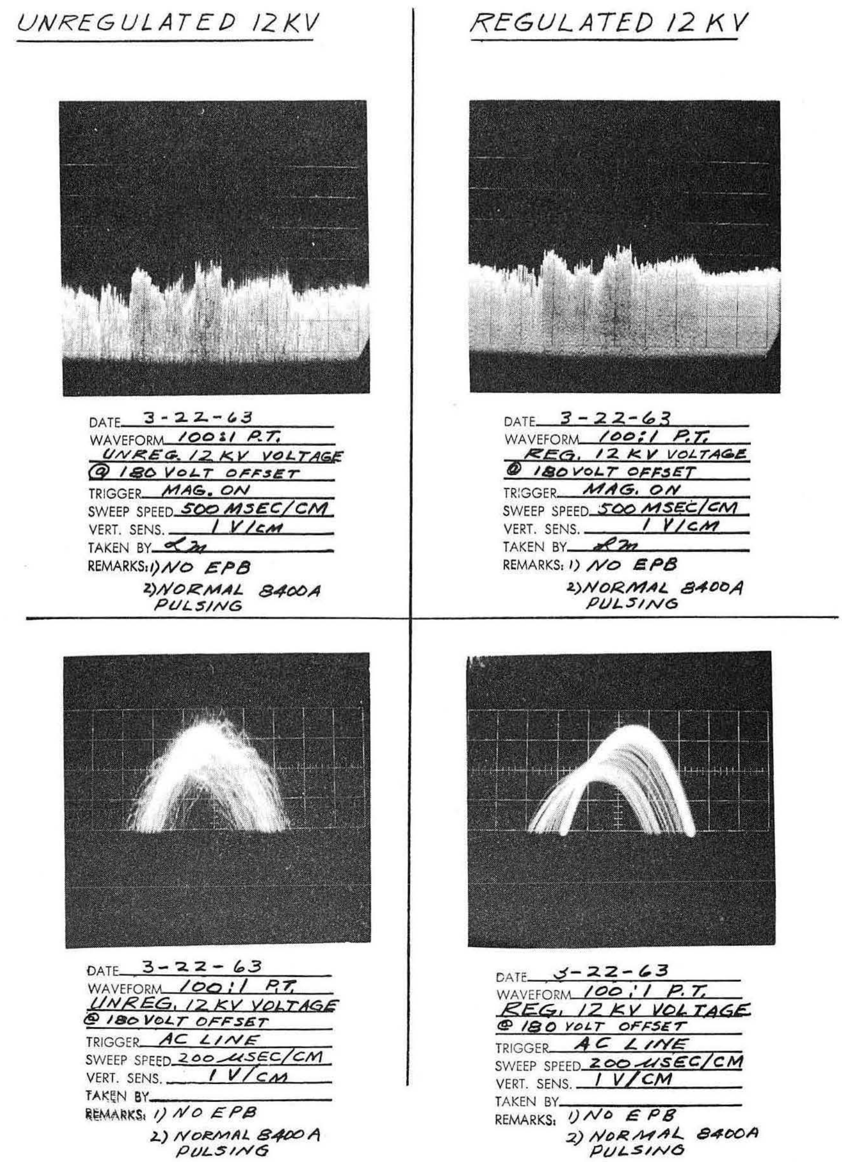

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Fig. 4. Wave forms of regulated and unregulated 12-kv lines (March 1963); no EPB magnets.

program. The EPB magnets require 800 kW of pulsed power from SCR phase-controlled rectifiers supplied from the 12-kV ac regulated line (Fig. 5). The operation of the 88-inch cyclotron again was affected, as their beam intensity varied between 10 and 90% of normal, thus making the accelerator unusable. The Bevatron 12-kV regulated line was returned to the Grizzly Substation feeder while the 88-inch cyclotron remained on the campus feeder.

An investigation is now under way to determine a long-term solution to line disturbances and system stability as related to present and future loads.

VI. BUILDING RADIATION SURVEYS

William L. Everette

The shield for the Bevatron proper was finished in April 1963. Once the 10-ft wall and the 7-ft roof shields were in place, neutrons constituted the only residual flux contributing significantly to biological dose. The areas of most concern were adjacent to targets stationed at, or slightly upstream from, tangent tanks. Considerable shielding advantage is lost here since the magnet iron is absent. The wall shielding has proved to be adequate, and these areas at floor level are left open for continual occupancy. However, the roof shield is a bit thin for target operation near tangent tanks, and generally these regions are excluded from normal public occupancy. These conditions were illustrated in Fig. 8 of the second quarterly report of 1963. [1]

After a specific mode of operation is established, involving fixed target arrangements and procedures for spilling beam onto these targets, the residual neutron flux exterior to the shield is constant. For the major portion of the third-quarter period, the mode of operation established in the month of June was continued. Thus, the building radiation intensities reported in the second quarterly report are generally valid for this period. Some changes were made involving the extraction—and some experimentation with—the external proton beam. These results are reported here.

Table III is a summary of the more pertinent area radiation measurements made by Health Physics personnel. Figure 6 is a plan view of the building showing the current shielding arrangment for the Bevatron and EPB. Figure 7 is a presentation of general area flux values; Fig. 8 shows positions of measurement and the neutron flux around the EPB shield for the stated conditions of operation and shielding.

One must realize that the flux values given in area surveys indicate only the possible exposure dose rate existing at the indicated locations. True biological, or absorbed dose is dependent on rate of exposure and time of occupancy. Significant knowledge of biological dose was acquired from neutron and gamma-ray dosimeter films carried by all personnel. Figure 9 is a compilation of these readings summed over the 3-months period. Each point along the abscissa represents a person. The left- and right-hand columns indicate gamma-ray and neutron dose readings, respectively. The ordinate is the integrated dose in rem units.

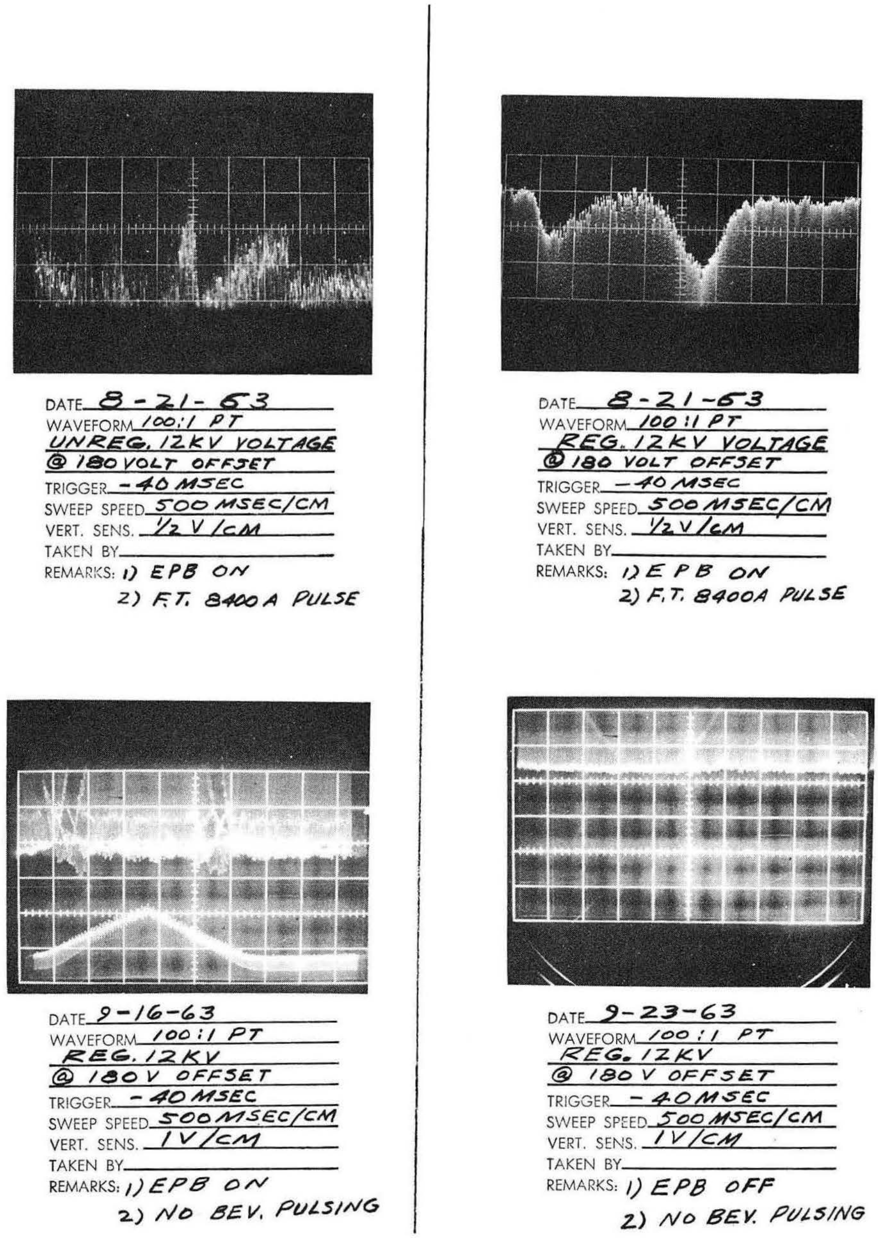

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Fig. 5. Wave forms of regulated and unregulated 12-kv lines (August 1963); with pulsed EPB magnets.

Table III. Summary of neutron-survey data for July through September 1963

Date	Survey		Beam intensity (p/pulse)		Targets				Shielding	Information reference
	Area	Dectector	Internal[a]	External	Designation	Location	Spill (%)	Spill E(BeV)		
7/1	Linac injector blockhouse roof	BF_3— fast neutrons	Linac: 16 mA; two 500-μsec pulses/sec	----	4J4 Catcher	Downstream end of blockhouse	75 25	0.0192	Complete	Downstream end: 3.9 n/cm^2-sec Upstream end: 2.1 n/cm^2-sec
					4J3 Catcher	Upstream end Downstream end	99 1			Upstream end: 14 n/cm^2-sec Downstream end: 6.5 n/cm^2-sec
7/2 - 7/3	Building floor	BF_3— fast neutrons	5×10^{11} [a]	----	Moyer Lofgren	76°, QIII 80°, QII	90	4	Complete	Fig. 7, curve 1
					Alvarez	17°, QIII	10	3.6		
7/24	Building floor	Ionization chamber (gamma ray)	1.5×10^{11} [a]	----	Moyer Alvarez	80°, QIII 20°, QIII	75 25	4 6	Complete	Fig. 7, curve 3
9/17 and 10/3	Building floor	BF_3— fast neutrons	$\approx5\times10^{10}$ [a]	$\approx5\times10^{7}$ [a]	Chamberlain	EPB channel	--	--	Bevatron shield and EPB blockhouse	Fig. 7, curve 2
8/22	Building floor around EPB blockhouse	Ag(n, γ)— fast neutrons	$\approx10^{12}$ [a]	$\approx4\times10^{11}$ [a]	EPB extraction studies	S.I.W.[b]	100% of internal beam		Bevatron shield and EPB blockhouse	Fig. 8, column A
					EPB backstop	Main Bev. shield wall	100% of EPB			
9/24		Ag(n, γ)— fast neutrons	$\approx8\times10^{11}$ [a]	$\approx10^{11}$ [a]	EPB extraction studies	S.I.W.[b]	100% of internal beam		Bevatron shield and EPB blockhouse	Fig. 8, column B
					EPB backstop	End of EPB blockhouse	100% of EPB			

[a] Measured in protons per pulse; normal pulse rate is 11 pulses per minute.

[b] South inside west (EPB energy-loss target).

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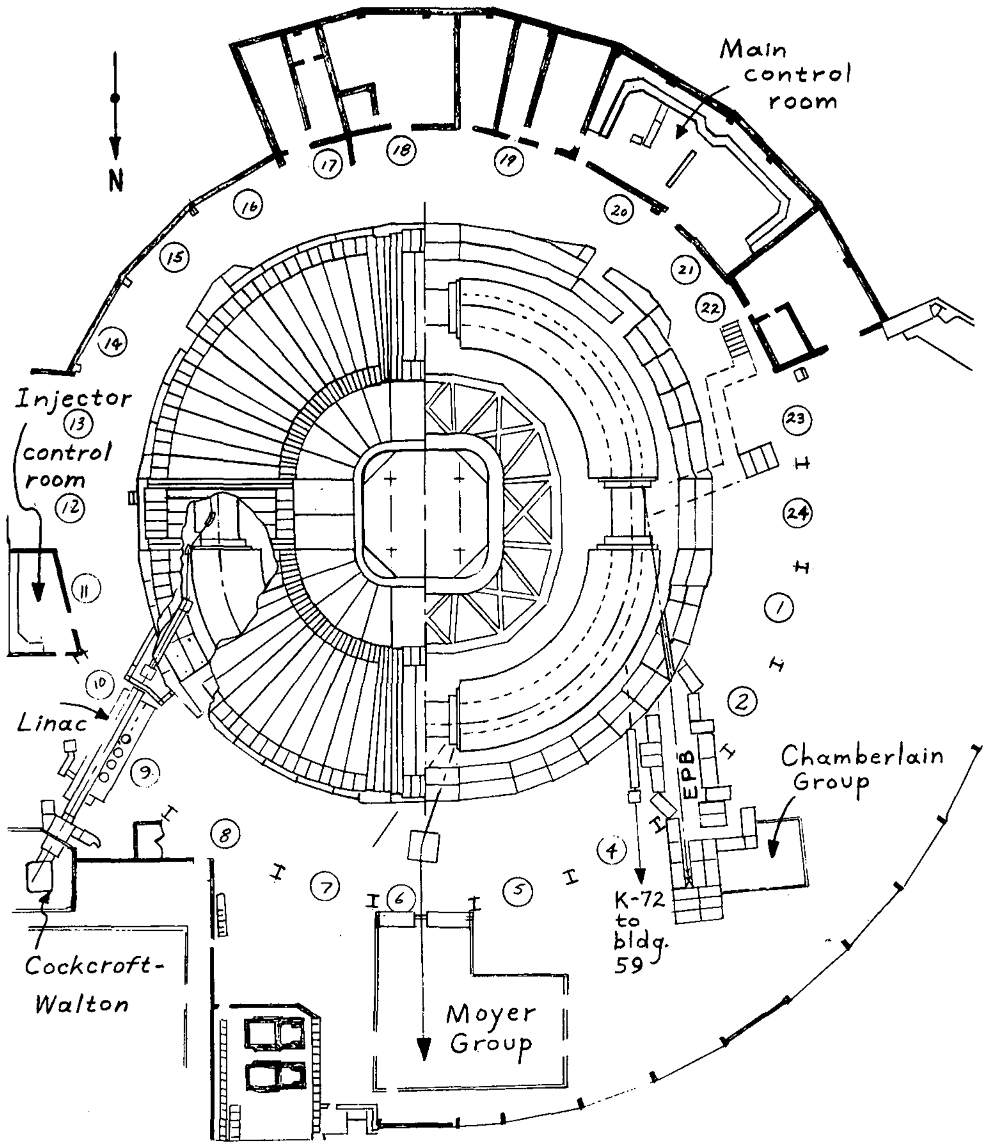

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Fig. 6. Plan view of Bevatron building.

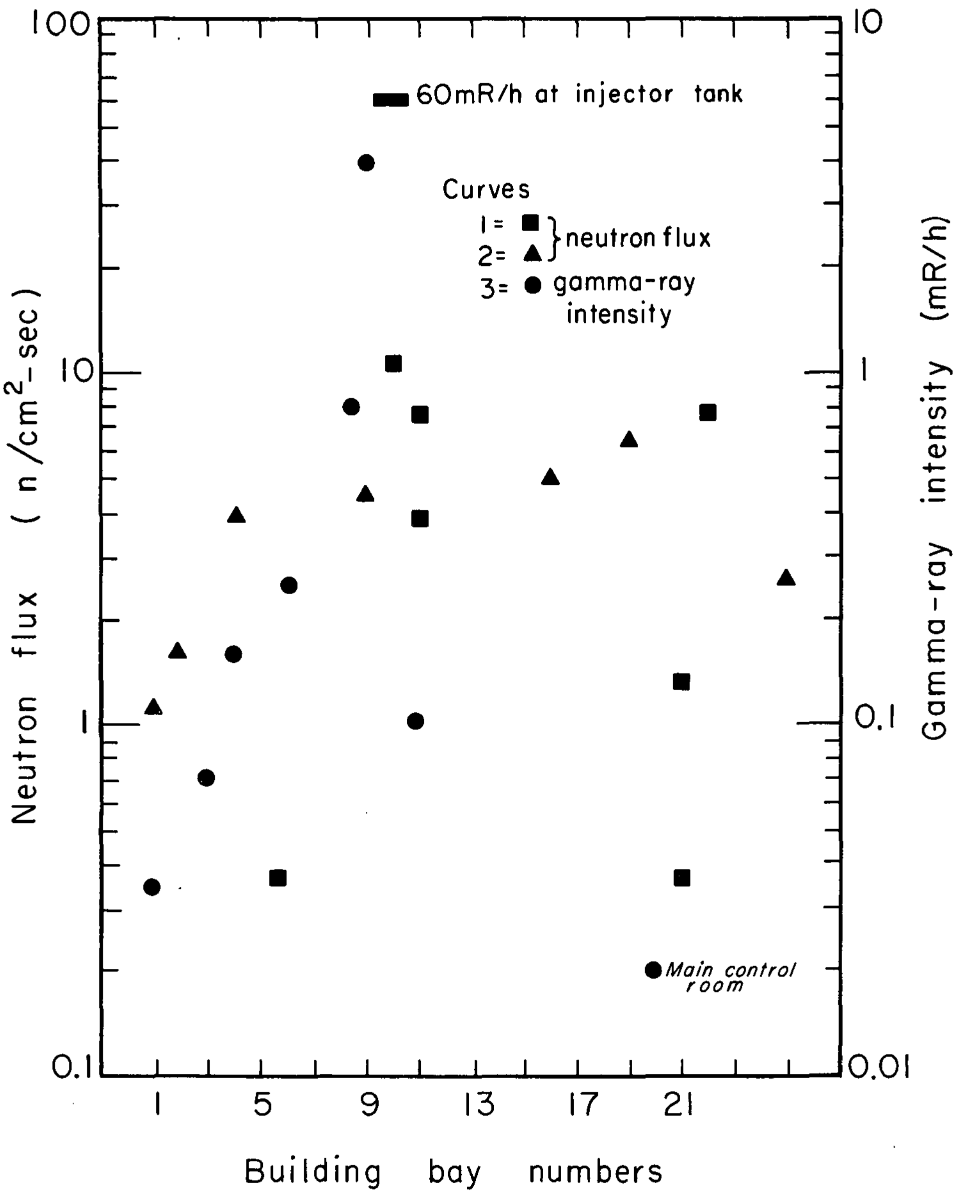
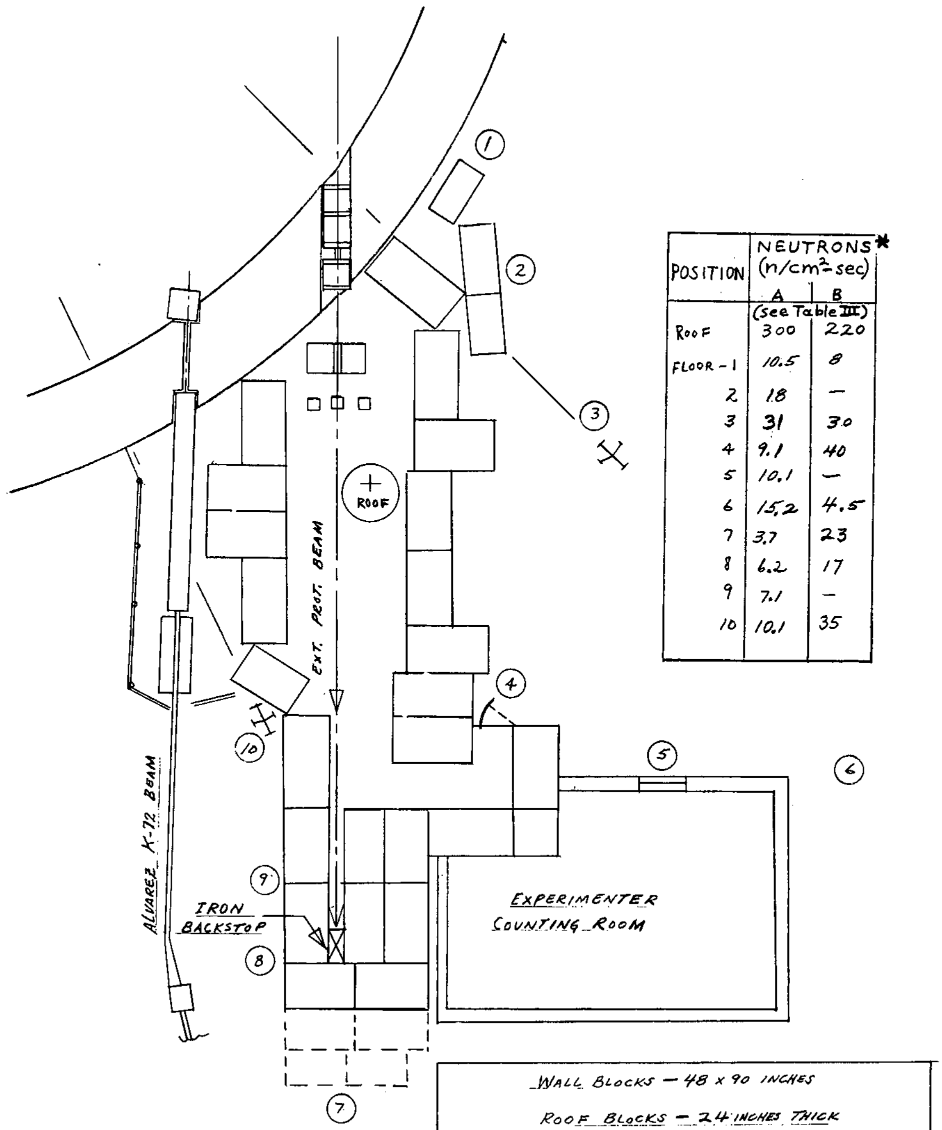


Fig. 7. Building radiation surveys, neutron and gamma rays.



POSITION	NEUTRONS* (n/cm²-sec) A	B
	(see Table III)	
ROOF	300	220
FLOOR - 1	10.5	8
2	18	—
3	31	30
4	9.1	40
5	10.1	—
6	15.2	4.5
7	3.7	23
8	6.2	17
9	7.1	—
10	10.1	35

WALL BLOCKS — 48 x 90 INCHES

ROOF BLOCKS — 24 INCHES THICK

*Reported flux values are normalized to 10^{10} p^+/pulse -- the maximum allowed value for continuous operations.

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Fig. 8. External-proton-beam blockhouse in building bay-3 for Chamberlain Group p^+ polarization run.

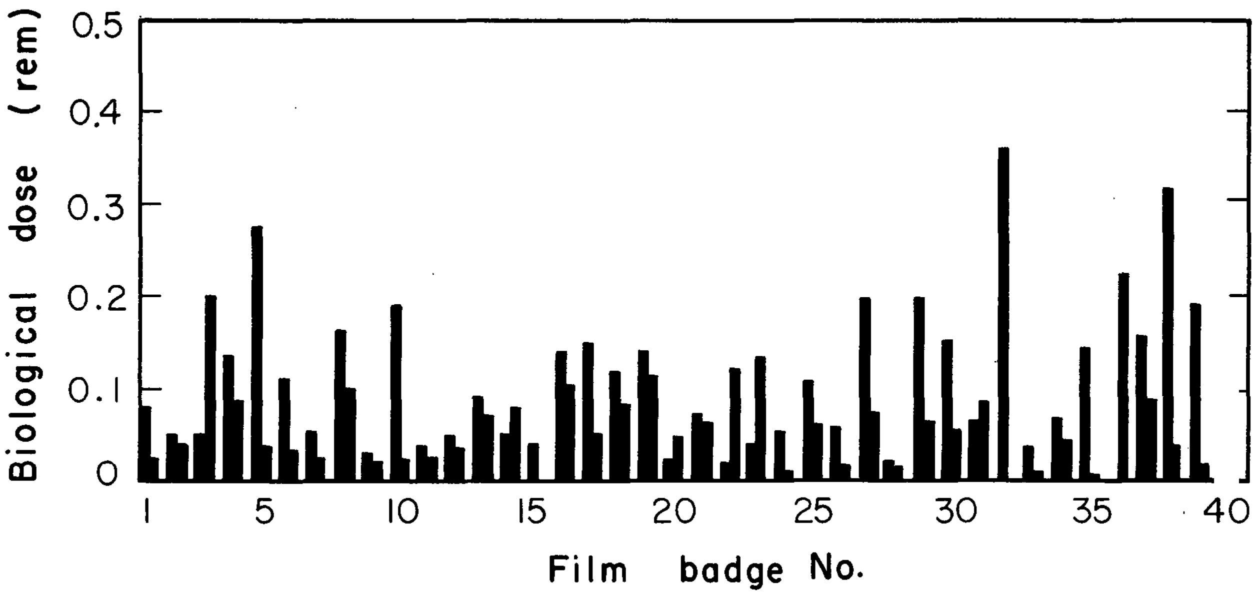

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Fig. 9. Integral dose in rem for personnel carrying neutron (left-hand column) and gamma (right-hand column) dosimeter film in the Bevatron building, July through September 1963.

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2. Kenneth C. Crebbin, Rudin M. Johnson, and William L Everette, Bevatron Operation and Development. 37, January through March, 1963, Lawrence Radiation Laboratory Report UCRL-10863, February 1964 (unpublished).