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October through December 1963

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Contents

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Lawrence Radiation Laboratory
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Berkeley, California

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ABSTRACT

The Bevatron provided beam for 86% of the scheduled operating time this quarter. The Bevatron was shut down for 9 days over the Christmas and New Year holidays. This period included 4 days of maintenance on the Bevatron and some modifications to the external proton beam extraction system. Extraction efficiencies for the external proton beam were studied for various types of beam spill and energies.

Two primary experiments ended this quarter and a new experiment was started for studying elastic and inelastic p-p scattering, using the external proton beam.

The building radiation surveys continued and the results are given for the new operating conditions.

I. OPERATION

The Bevatron operation record is shown in Fig. 1. Beam was on for 86% of the scheduled operating time. The beam was off 11% of the time because of component failure, and 3% of the time for setup and routine checks.

II. SHUTDOWN

The Bevatron was shut down at midnight on December 22, 1963 and resumed operation for the experimental groups at midnight on January 1, 1964. This period included 4 days of scheduled holiday time, 2 days of vacuum shutdown, and 2 additional days of maintenance. The vacuum shutdown lasted from 8 AM on December 26 to 8 PM on December 27. The major jobs were on the external-proton-beam (EPB) equipment and are outlined below.

The center guide rail for the plunging magnets M_1, Q_1 was removed and a new hardened rail installed and aligned. The guide rollers were removed and polished. They were then washed, packed with vacuum grease, and reinstalled.

The exit collimator for the EPB was removed and reworked. The pivot point was changed to lower the collimator about 3/16 of an inch. Additional material was added to the outer radius edge of the collimator to provide more attenuation to the outer fringe of the beam.

A new air-operated flip target was installed at the transition-section entrance to quadrant II [South inside west (S.I.W.)]. The EPB energy-loss target was moved to this location from the south inside middle (S.I.M.) probe. This change made the S.I.M. lock facility available for Bevatron development projects without requiring probe changes each time we changed from development to normal operating conditions.

The Mark III plunging mechanism was installed at the S.I.M. with an adjustable copper collimator. This setup was used to test the effect of collimating the EPB in this region. These tests showed a much-better-defined beam spot in the experimental area at a reduction in beam intensity by a factor of about two. An adjustable collimator to do this job is being designed to mount on the plunging magnets M_2, Q_2.

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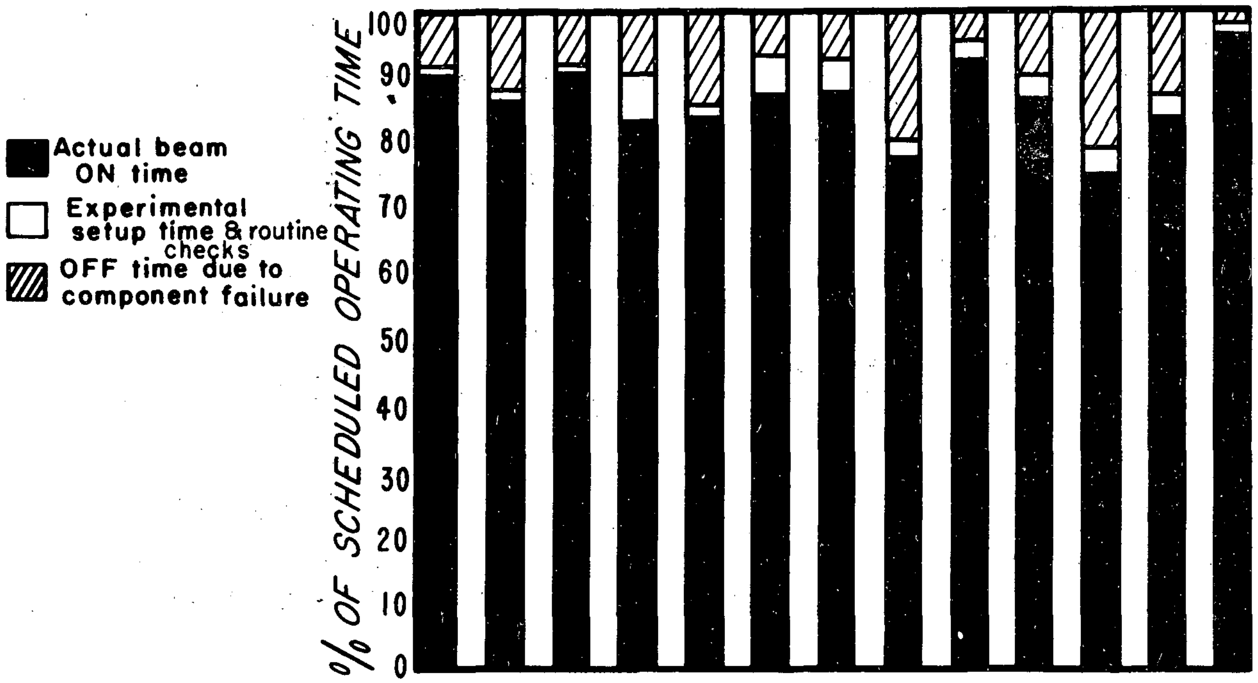
* Preceding quarterly reports: UCRL-11279, UCRL-11278.



Week of	9/29	10/6	10/13	10/20	10/27	11/3	11/10	11/17	11/24	12/1	12/8	12/15	12/22
Crew hours	128	128	128	128	128	128	128	128	56	128	128	136	56
Turnon & maintenance time (h)	10	10	10	10	10	12	10	10	3	10	10	10	0
Scheduled operating time (h)	108	96	108	93	118	94	104	80	53	94	104	111	24
Scheduled Bevatron test time (h)	10	22	10	25	0	22	14	14	0	24	14	15	0
Scheduled shutdown time (h)	0	0	0	0	0	0	0	24	0	0	0	0	32
Holiday (h)	0	0	0	0	0	0	0	0	72	0	0	0	112

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Fig. 1. Bevatron operating schedule, October through December 1963.

The old vertical clippers at the exit of quadrant IV were removed, and a new set of vertical induction electrodes installed. These electrodes are to be used to study vertical oscillations in the Bevatron as a possible beam-loss mechanism.

Elevation surveys of the magnet sectors and the tangent tanks were made as a continuing study of the Bevatron foundation settlement. The results showed a settlement of from 0.150 to 0.200 in. from the original plane the magnet was placed on in October 1963. In addition there is some differential settlement between the inner and outer radius foundations. This causes a twist in the sectors from the desired plane, varying about $\pm 0.4 \times 10^{-3}$ radians. To date these shifts have not caused any observed changes in orbit position or problems in beam steering and targetry.

In addition to the above jobs, routine maintenance jobs were done on the mechanical and electrical equipment associated with the Bevatron.

III. BEVATRON STUDIES

A. Beam-Loss Studies

Studies of the high-intensity beam loss continued. The major effort was directed toward a study of the vertical betatron oscillations, using vertical clippers and a simple set of vertical pickup electrodes. A new, improved set of vertical electrodes was installed during the December shutdown (Sec. II). These electrodes are in a shielded box and cover the full radial aperture of the Bevatron. To date there has been no new information gained as to the cause of the beam loss.

B. External Proton Beam

Extraction efficiencies, for EPB, were studied for various types of beam spill. At 6 BeV the following extraction efficiencies were measured: rf-off spill, 40 to 50%; rapid beam ejector (RBE), 20%; long string spill, 25%. At 2 BeV we measured: rf-off spill, 25%; string spill, 1%. The extraction efficiency is the percentage of the internal circulating beam that appears as usable beam down the EPB channel. The internal beam is measured on the beam induction electrode system (BIE). The external beam is measured with a secondary-emission chamber.

The Lofgren experiment, started this quarter, required EPB intensities of the order of 10^4 to 10^5 protons per pulse (ppp) to calibrate the counters. Both the internal- and external-beam monitors have a low-intensity limit of about 10^7 ppp. To reduce the beam level to this amount, the following method was used. The beam was reduced by a factor of about 200 by use of an orbit expander. A set of deflection electrodes in the injector system can be used to get a short burst of injected beam, in effect reducing the beam injected into the Bevatron in a well-controlled way. When there is a deflecting voltage on the plates, the beam is bent into a carbon block that stops the beam. With no deflecting voltage the beam misses the carbon block and is injected into the Bevatron. With three pulses, 0.7 μsec wide and 20 μsec apart, the beam was reduced by a factor of 60. This device is called the "chopper." These methods of reducing the beam were set up at a beam level where the reduced levels could be read on the induction electrode system. This gave us the reduction factor for each case. Both methods could be turned on or off by a simple on-off switch with no retracking of the beam. The beam was then reduced to about 3×10^7 ppp by using two sets of carbon slits in the injector system. Further reductions down to the 10^4 region were made by turning on the orbit expander, chopper, or both to get the desired beam levels. The Bevatron was tuned for operation without using the rf phase or radial feedback loops. At these low beam levels there is no signal to operate the feedback loops.

IV. EXPERIMENTAL PROGRAM

Two primary experiments ended this quarter: the Moyer group studying pion-nucleon scattering; and the Segrè-Chamberlain group studying p-p scattering, using a polarized target. One new primary experiment was started this quarter by the Lofgren group. A summary of the Bevatron Experimental program is shown in Table I.

The new Lofgren group experiment is for studying elastic and inelastic p-p scattering, using the EPB. This experiment is expected to improve considerably both the accuracy and extent of the p-p scattering measurements at Bevatron energies. Use of the external beam provides the means of measuring cross sections a factor of 10^9 down from the forward-scattering cross section, with a counting rate of one per pulse. Momentum transfers up to 6 BeV/c are available. Background will be considerably reduced with the use of a hydrogen target, and the facility with which the EPB intensity can be measured will lend considerable improvement to the absolute normalization of the measurements. Very small momentum transfer events (≈ 100 MeV/c) will be measured with a gas target. In this way the real part of the forward-scattering amplitude can be measured and, hopefully, the Coulomb-nucleon interference effects can be detected.

The need for better data in elastic scattering is emphasized by the fact that pion-nucleon scattering apparently does not show the same energy-dependent shrinkage of the diffraction pattern that appears in the p-p scattering. Because proton beams can exceed pion beams in intensity by perhaps six orders of magnitude, it seems likely that sophistication of the present models can best be tested by p-p scattering.

In the course of estimating the background in the elastic-scattering data at each energy and angle, a momentum spectrum of

Table I. Summary of Bevatron experimental research program, October through December 1963.

Group	Start of experiment	End of experiment	Experiment	Beam time: This Quarter, 12-hour periods	This Quarter, Hours	Start of run through Dec. 1963, 12-hour periods	Start of run through Dec. 1963, Hours	Pulse schedule	Primary or secondary experiment
Internal groups									
Alvarez Powell-Birge Trilling-Goldhaber	3-23-63	In progress	Study of π^- interactions in the 72-inch hydrogen bubble chamber.	21	224	125	1295	1:1	P
				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.	47	497	102	1085	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	11-7-63	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.	19	300	110	1284	1:1	P
				9	78	10	101	1:1	S
Segrè-Chamberlain	8-6-63	10-26-63	Study of polarization of protons in high-energy p-p scattering as a function of momentum and angle.	13	136	32	350	1:1	P
				12	116	30	313	1:1	S
Lofgren	10-2-63	In progress	Study of elastic and inelastic p-p scattering at large and small angles.	14	159	14	159	1:1	S
	11-12-63	In progress		33	376	33	376	1:1	P
Trilling-Goldhaber	11-8-63	11-19-63	Engineering tests of the new 25 inch hydrogen bubble chamber in a π^- beam.	1/2	10	1/2	10	1:1	P
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.	--	--	10	106	1:1	S
Philco Space Div. Rinehart	5-24-63	12-6-63	Test of solid-state counters and spark chambers.	1	13	4	46	1:1	S
La Jolla Piccioni	11-23-63	12-16-63	Investigation of albedo and coincidences from an iron target in the EPB. Preparation for a future experiment.	1/2	5	1/2	5	1:1	P
				4	45	4	45	1:1	S
Carnegie Inst. of Tech. Rayudu	12-10-63	12-10-63	Irradiation of a mock meteorite in the EPB.	--	3	--	3	1:1	P
Argonne A.B. Smith	12-17-63	12-17-63	Measurement of the neutron yield produced by 6-BeV protons striking thick targets.	--	5	--	5	1:1	P

secondary particles must be measured. In this data nucleon isobar formation will appear as bumps in the momentum spectrum of the scattered protons. In this way isobar formation can be studied as a function of energy and momentum transfer. A small increase in running time to extend these measurements is planned.

The beam required is a long spill, 100 msec or longer. This is achieved by using a string spill onto the energy-loss target.

V. MAGNET POWER SUPPLY

The magnet pulsing record is shown in Table II.

VI. RADIATION DETECTION AND CONTROL STUDIES

William L. Everette

Additional radiation-detection studies were made for several new operating and experimental conditions. A summary of these is presented in Table III. Plan-view sketches (Figs. 2 to 5) of building areas are used to better define shielding arrangements and survey points.

A. Building Surveys

Four major neutron surveys (Figs. 2 to 5) were made to assess exposure doses for persons working in accessible spaces about the building floor. Two surveys were made at the shield roof level: one over the Bevatron magnet and one over the external-beam channel. Results of two surveys using film sensitive to beta-gamma and neutron radiation are given in Table IV.

No problems were found except those attributed to the EPB. Some areas on the shield roof are not safe for occupancy when the primary beam is being extracted (Fig. 6). A barrier-and-sign method of isolation is provided until adequate shielding can be installed.

B. Control of Radiation Caused by External Proton Beam

We have, in fact, gained much radiation-control experience with the external beam during the past 6 months. Early in the year a concrete blockhouse was constructed in bay 3 to accommodate the p-p scatter and polarization experiment (Segrè-Chamberlain group). Fortunately, the proton demand for the experiment was low, 10^7 to 10^8 ppp at 3 to 6 BeV, and the shortage of blocks at the time caused little concern in constructing a suitable beam-stop and neutron shield. The real problem began when high-intensity extraction studies were tried, using this beam-stop. We made a study of the neutron problem (see Fig. 4) and resolved the predicament by using a second beam-stop.

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

Month (1963)	4 to 6 pulses per minute: 1500 to 6900 A Pulses	Faults[a] 14	26	7000 to 9000 A Pulses	Faults[a] 14	26	7 to 9 pulses per minute: 1500 to 6900 A Pulses	Faults[a] 14	26	7000 to 9000 A Pulses	Faults[a] 14	26	10 to 17 pulses per minute: 1500 to 6900 A Pulses	Faults[a] 14	26	7000 to 9000 A Pulses	Faults[a] 14	26	Totals: Pulses (P)	Faults: Arc-backs	Arc-throughs	Total (F)	P/F	Comments
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
Oct.										88101	5	7	94317	1	6	124782	4	16	307200	10	29	39	7876	Shutdowns: 6, 13, 20, 27 Ignitron changed: 4B2
Nov.										71841	6	7	61527	4	3	109347	4	7	242716	14	17	31	8090	Shutdowns: 3, 10, 17, 24, 25, 28, 29, 30 Ignitron changed: 4A1
Dec.										62610	3	5	113285	5	1	54203	2	5	230098	10	11	21	10957	Shutdowns: 1, 8, 15, 23, 24, 25, 26, 27, 28, 29, 30, 31

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

Table III. Summary of neutron-survey data for October through December 1963.

Date of survey	Survey: Area	Survey: Detector	Beam intensity (ppp): Internal	Beam intensity (ppp): External	Targets: Designation	Targets: Location	Targets: Spill (%)	Targets: Spill (BeV)	Data reference
10-3	Building floor	BF_3 and CH_2– fast neutrons	1.2×10^{12} 12 ppm[a]	--	1. Moyer	80°, QIII	20	6.2	Fig. 2
					2. Alvarez K-63	17°, QIII	80	6.2	
12-13	Building floor	BF_3 and CH_2– fast neutrons	7×10^{11}	8×10^{10}	1. Alvarez π-63	17°, QIII	15% of int. beam	5.3	
					2. Wenzel and beam-stop	S.I.M.[b]	85% of int. beam	6.2	Fig. 3
						EPB channel	100% of ext. beam	6.2	
10-10	Building floor, bays 1-4	Ag(n, γ) – fast neutrons	$\approx10^{12}$	10^{11}	1. Wenzel and beam-stops 1 and 2	S.I.M.[b]	100% of int. beam	5	Fig. 4
						EPB channel	100% of ext. beam	5	
11-15	Building floor, bays 1-4	BF_3 and CH_2– fast neutrons	7×10^{11}	8×10^{10}	1. Wenzel and beam-stop	S.I.M.[b]	100% of int. beam	6	Fig. 5
						EPB channel	100% of ext. beam	6	
12-13	Bevatron shield roof	Ag(n, γ)– fast neutrons	7×10^{11}	8×10^{10}	1. Alvarez π-63	17°, QIII	15% of int. beam	5.3	
					2. Wenzel and beam-stop	S.I.M.[b]	85% of int. beam	6.2	Fig. 6
						EPB channel	100% of ext. beam	6.2	
12-13	EPB shield roof	Ag(n, γ)– fast neutrons	7×10^{11}	8×10^{10}	1. Alvarez π-63	17°, QIII	15% of int. beam	5.3	
					2. Wenzel and beam-stop	S.I.M.[b]	85% of int. beam	6.2	Fig. 5
						EPB channel	100% of ext. beam	6.2	

[a] 12 pulses per minute; normal pulse rate is 11 pulses per minute.

[b] EPB energy-loss target.

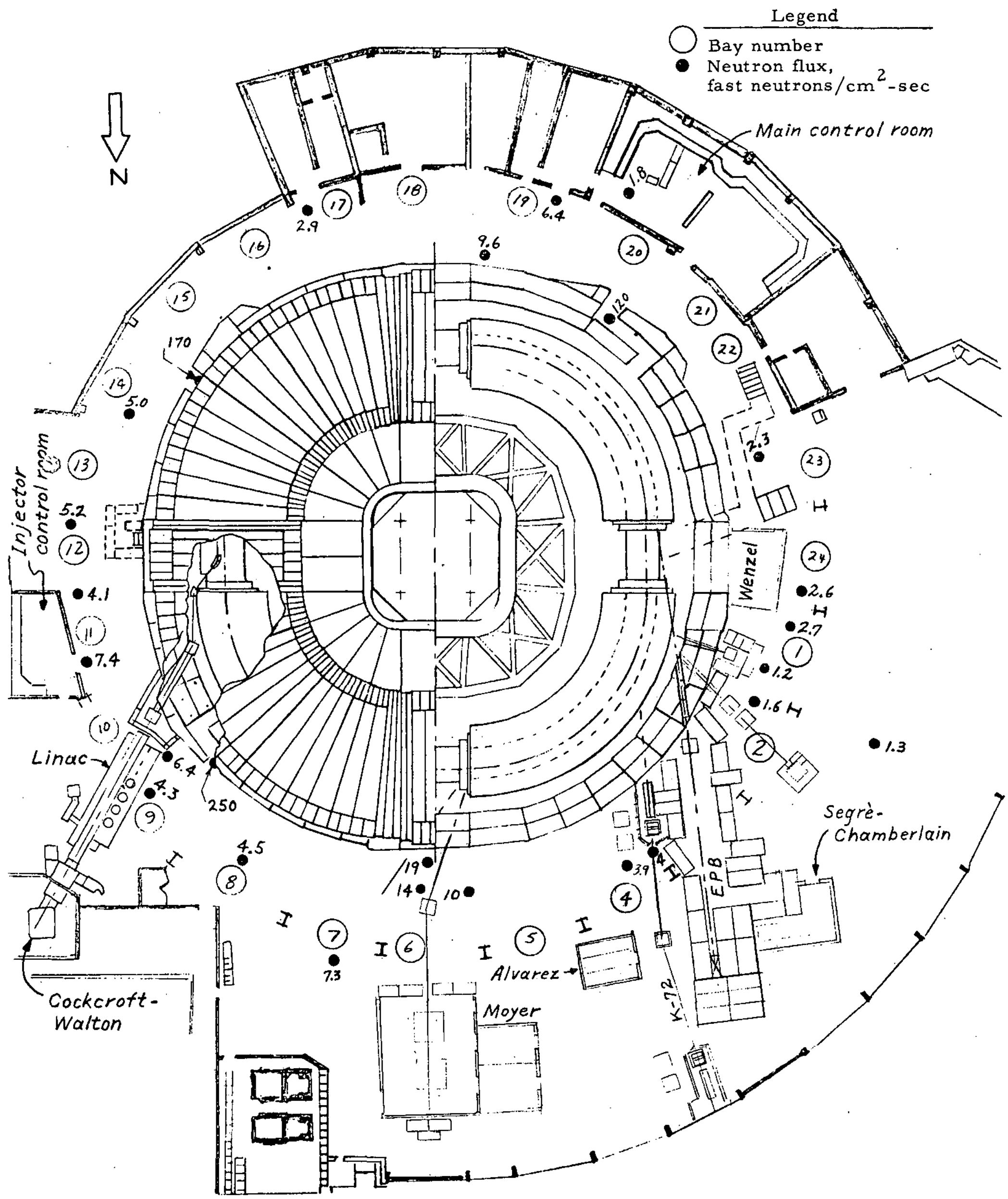

Fig. 2. Fast-neutron survey in building.

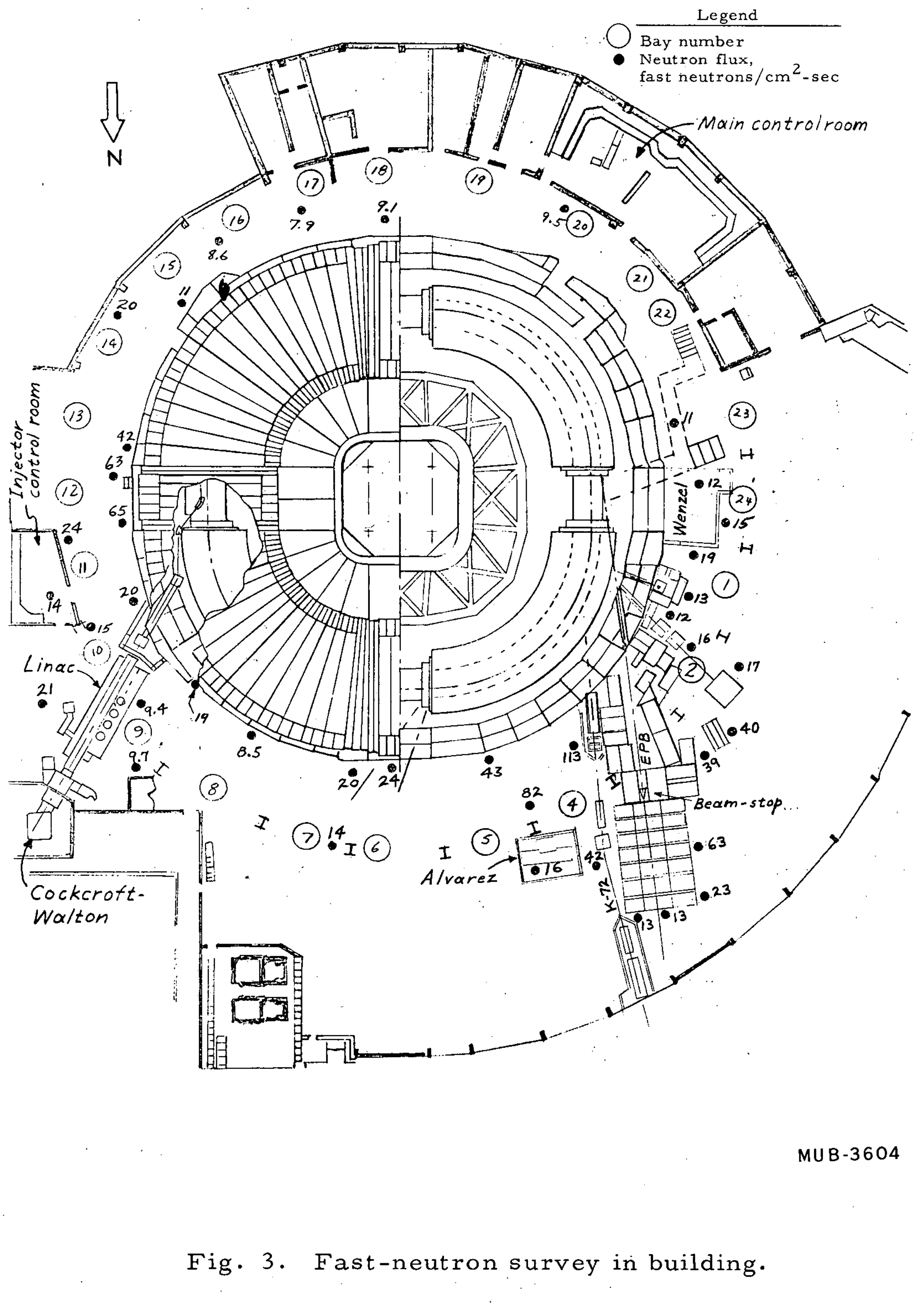

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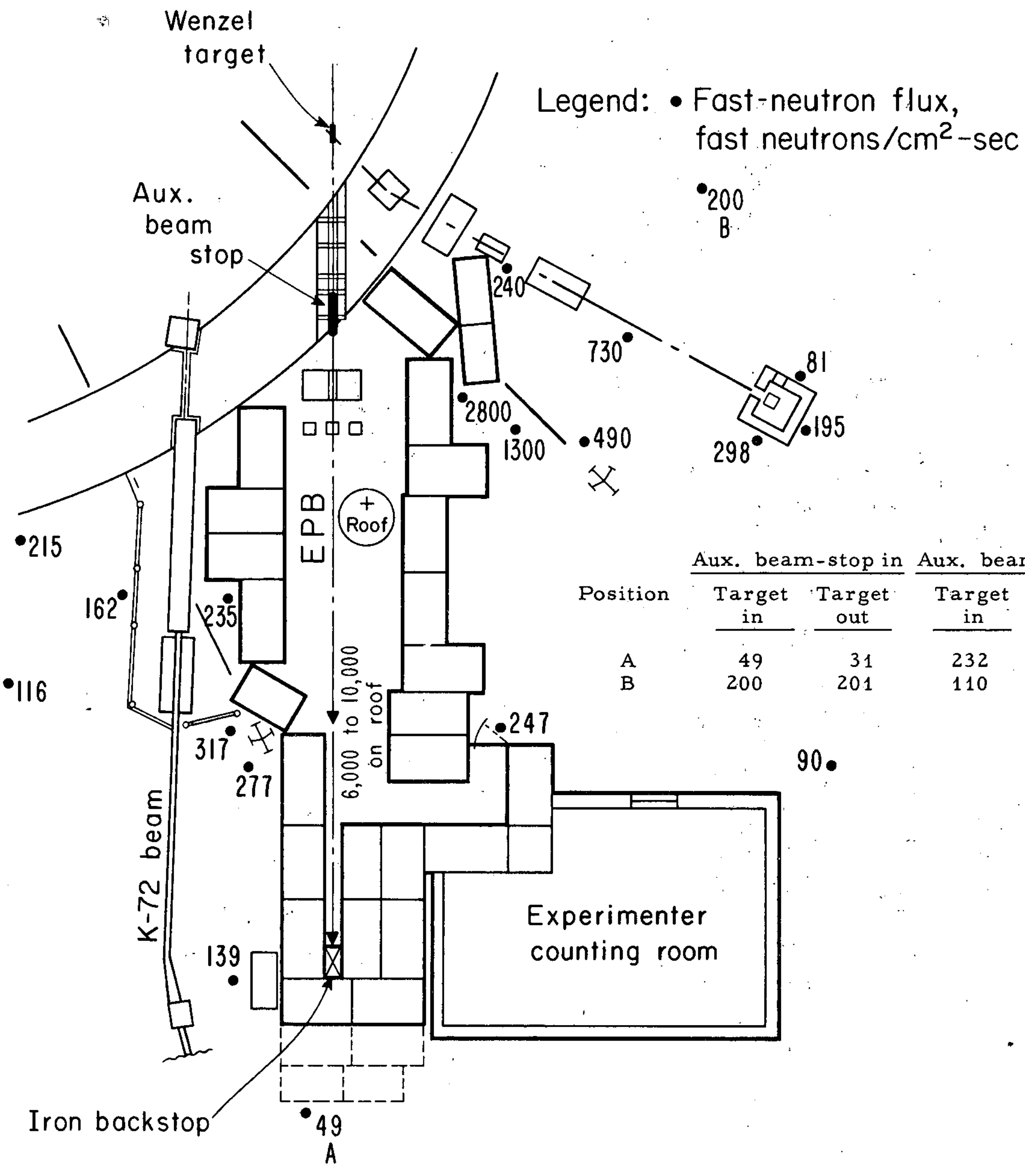
Fig. 3. Fast-neutron survey in building.



Position	Aux. beam-stop in: Target in	Aux. beam-stop in: Target out	Aux. beam-stop out: Target in	Aux. beam-stop out: Target out
A	49	31	232	370
B	200	201	110	2700

Fig. 4. Fast-neutron survey around EPB channel.

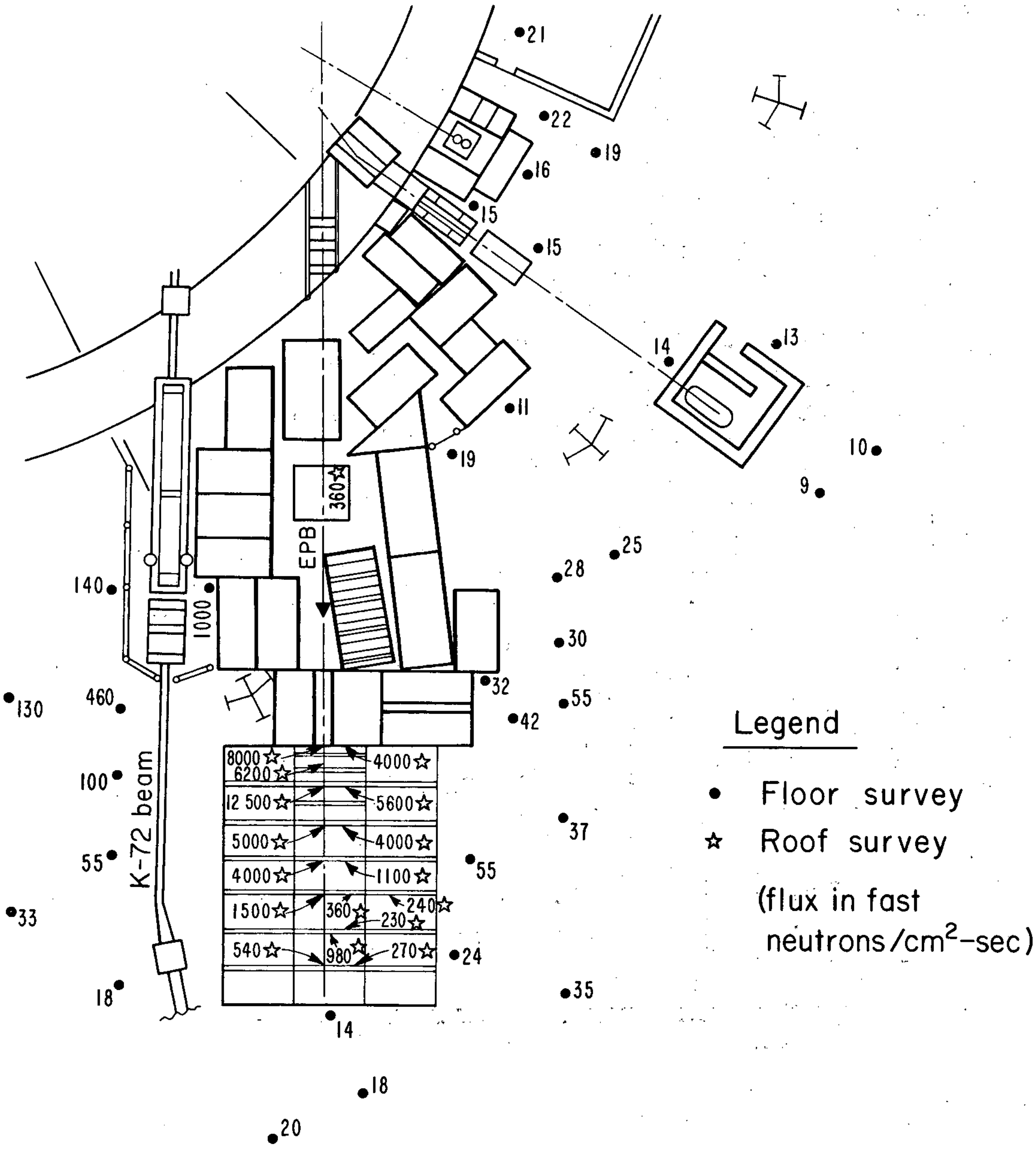


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Fig. 5. Fast-neutron survey at floor and roof levels around EPB channel.

Table IV. Survey with neutron- and photon-sensitive location film.

Location		Dose (rem)		
		Photons[a]	Photons[b]	Neutrons[b]
Top of beam-separator high-voltage supply.	"A"	0.156	--	--
	"B"	0.240	--	--
	"C"	0.130	--	--
K-72 beam-separator cubicle (inside)	No. 1	- 0.545	--	--
	No. 2	-23.0	0.375(0.22)[c]	--
Injector control room		0.460	0.138	0.036
Entrance to Cockcroft-Walton room		3.0	0.600	--
Bevatron shield maze entrance	QII	0.930	--	--
	QIV	--	0.194	--
On injector platform				
Upstream end		--	1.08	--
Downstream end		--	0.800	--
At building columns				
No. 30 - near injector		--	0.535	0.000
No. 23 - near K-72 beam		--	0.033	--

[a] 1000-h exposure (Aug. 7 - Sept. 24).
[b] 530-h exposure (Oct. 1 - 22).
[c] Outside.

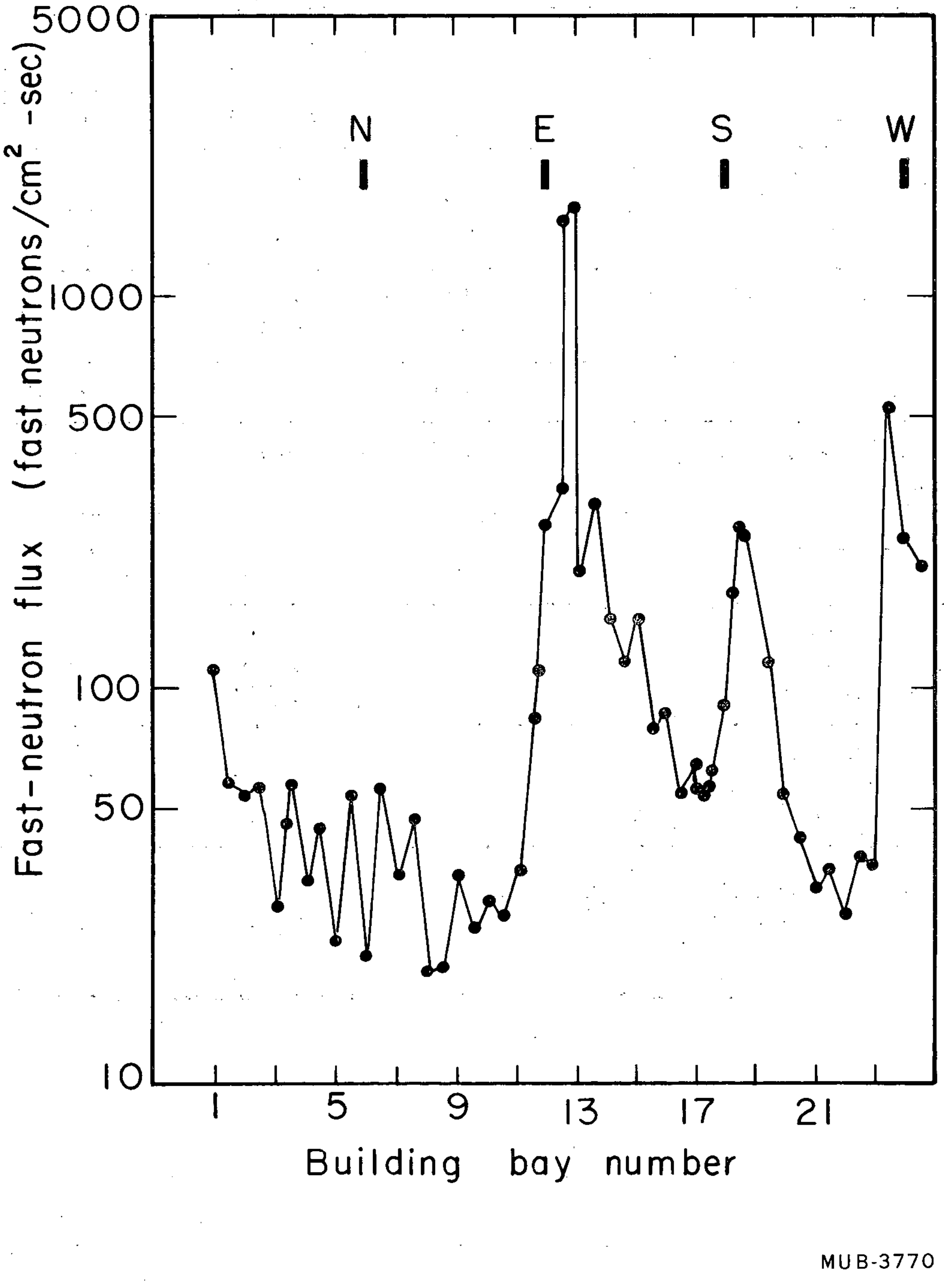


Fig. 6. Fast-neutron survey on Bevatron shield roof.

Four 1-ft iron slugs were placed in the beam port through the machine shielding wall whenever an extracted proton beam greater than 10^9 ppp was required.

At the conclusion of the Segrè-Chamberlain run, a second block structure was built for the Lofgren group (Fig. 5). The walls were thicker and the new arrangement provided some facility for parasitic work downstream from the Wenzel target. The beam-stop was built to permit narrow-beam attenuation studies in ordinary concrete. Detailed results of this work will be reported by the Berkeley Health Physics Group.

C. Special Problems

Some results obtained in a study of fast-neutron attenuation in the west access tunnels are reported in Figs. 7 and 8. The tunnel is 78 in. in height by 72 in. wide. Attenuation in the tunnel appears to be exponential with a relaxation length of about 6.5 ft.

An entry maze was improvised at the stairway to the east straight section pit by using 4-ft.-thick concrete blocks (dashed lines in Fig. 2). Neutron detection at 10^{12} ppp internal beam show that this shield is at least as adequate as the former method, which completely blocked the passage. The neutron flux was typically 5 to 10 n/cm^2-sec.

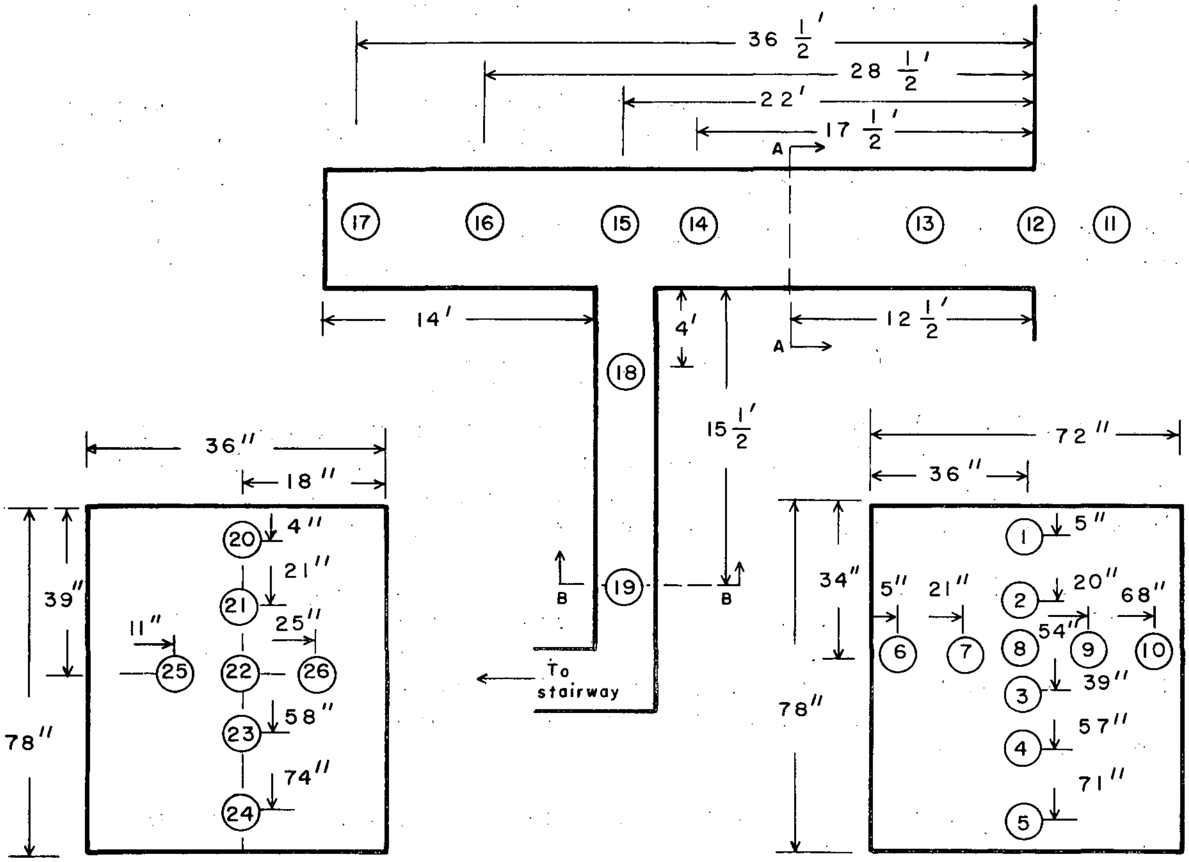
Preliminary studies were made for shielding the forthcoming 25-inch-bubble-chamber experiment.

Track films were taken in the 25- and the 72-inch bubble chambers and the events related to fast and thermal neutron flux measured by BF_3 proportional detectors. A tolerable neutron flux—approximately 1 n/cm^2-pulse—was established. Because the films have not been scanned, specific results are not yet available.

The study was extended by enclosing neutron-sensitive detectors in a 4-ft concrete blockhouse. Data are given in Fig. 9.

D. Residual-Radiation Studies

A vacuum shutdown occurred in December. Radioactivity measurements were made in the vacuum tank of the Bevatron. Typical values are reported here for comparison with similar numbers reported for the first quarter of 1963 [Lawrence Radiation Laboratory Report UCRL-10863, February 1964, pp. 10 and 11 (unpublished)].



Fast-neutron flux in fast neutrons/cm^2-sec (Au foils and BF_3).

Position	Reading	Position	Reading	Position	Reading
1	2820	11	42 600		
2	3020	12	20 400	21	3.7
3	3520	13	9320	22	3.6
4	2400	14	1680	23	3.5
5	3740	15	825	24	2.8
6	2780	16	527	25	4.0
7	3340	17	210	26	4.0
8	2560	18	42		
9	3060	19	5.5		
10	2780	20	3.3		

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Fig. 7. Neutron measurements in west access tunnel.

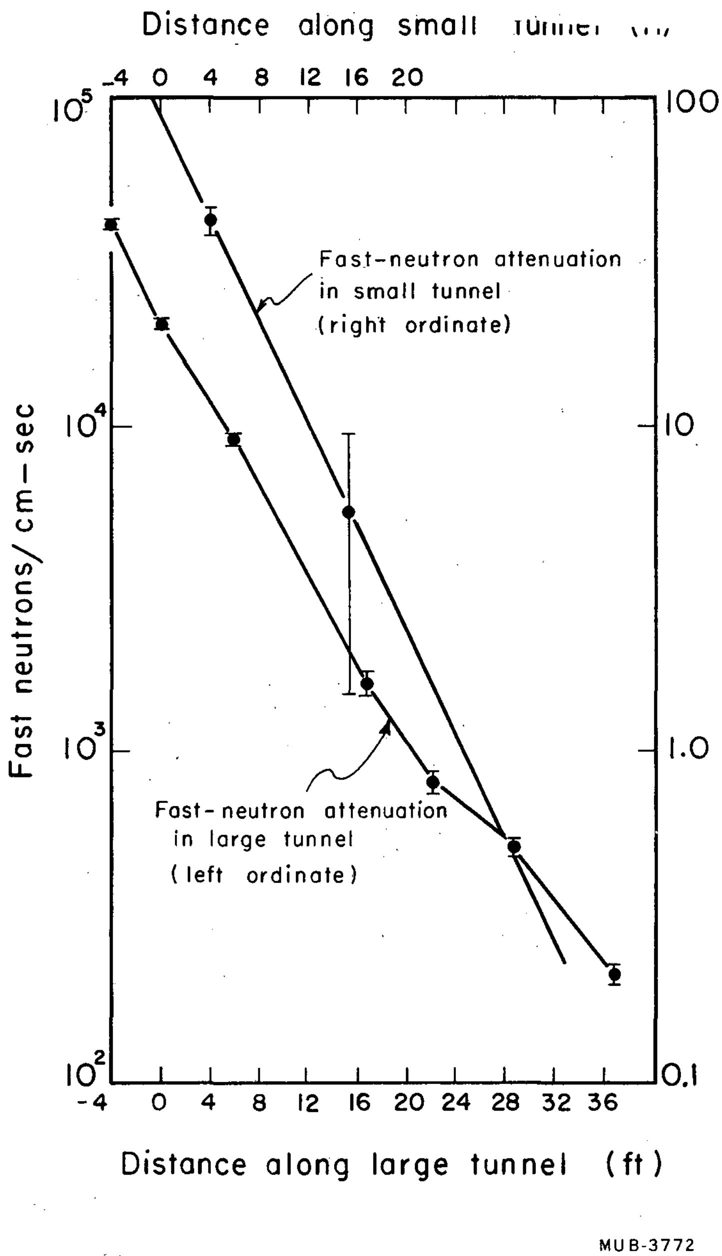

Fig. 8. Fast-neutron attenuation in the west access tunnel.

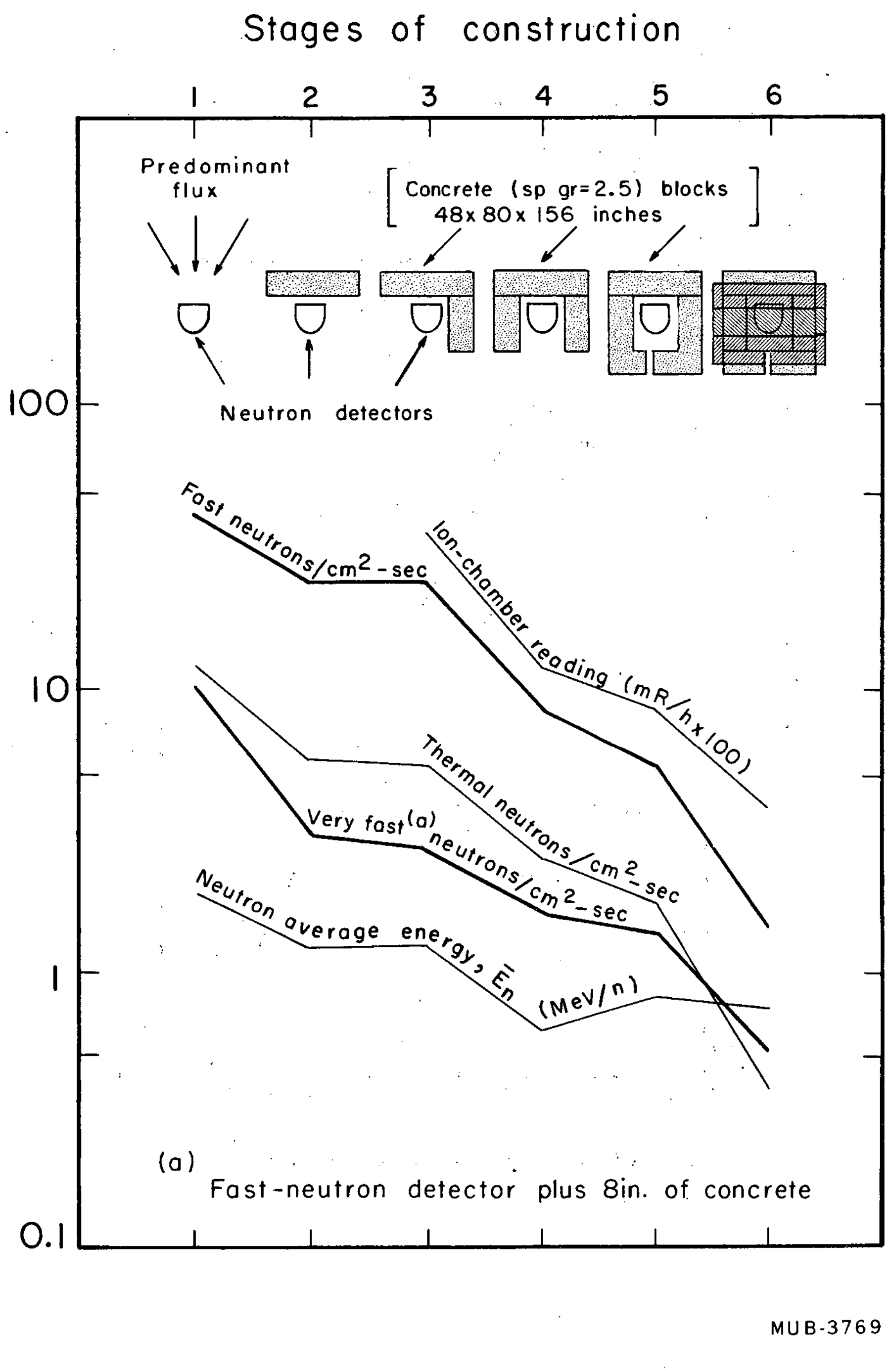

Fig. 9. Attenuation of neutrons by concrete-block enclosures.

(a) East straight section	
(1) Inflector magnet IM3	210 mR/h (max)
(2) Electrostatic inflector	150-200 mR/h
(3) EPB magnets M_1, Q_1	1.5-5 R/h
(4) General area, no shielding	200 mR/h
(b) South straight section	
(1) General area	25 mR/h
(2) Plunging magnets M_2, Q_2	150-200 mR/h
(c) Quadrant II	
(1) West tangential brace	35 mR/h
(2) EPB collimator	100-250 mR/h
(3) Magnet sectors 47 to 72	15-70 mR/h
(d) Quadrant III	
(1) Magnet sectors	20-40 mR/h (typical)
(2) Target areas	100-250 mR/h

ACKNOWLEDGMENT

The radiation-detection surveys were performed by the Health Physics Group.

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William L. Everette	Radiation control
Duward S. Cagle Frank W. Correll Robert G. Gisser	Operating Crew supervisors
G. Stanley Boyle Robert W. Brokloff Ashton H. Brown Norris D. Cash Ferdinand Dagenais Charles H. Hitchen Arthur K. Ikuma William H. Kendall William Lee Martin E. Scolnick Joseph F. Smith	Bevatron operators
Robert W. Allison Trancuilo Canton Warren W. Chupp Bruce Cork Kenneth Crebbin Lorenzo Eggertz Thomas Elioff Robert Force Leroy T. Kerth Fred G. H. Lothrop Donald Milberger Robert Richter Glenn White William Wenzel Emery Zajec	Development and support
Edward Hartwig Robert Force	In charge of Electrical Eng. Group
Marion Jones Harold Vogel Donald Milberger	In charge of Electrical Coord. Group In charge of Motor Generator Group In charge of Elec. Maint. Group

William Salsig Kenou Lou	In charge of Mechanical Eng. Group