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BEVATRON OPERATION AND DEVELOPMENT. 42

April through June 1964

Berkeley, California

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Research and Development

UCRL-11737

UC-28 Particle Accelerators
and High Voltage Machines
TID-4500 (35th Ed.)

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

BEVATRON OPERATION AND DEVELOPMENT. 42

April through June 1964

Kenneth C. Crebbin and William L. Everette

November 19, 1964

Printed in USA. Price $2.00. Available from the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U. S. Department of Commerce, Springfield, Virginia.

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ABSTRACT

The Bevatron beam was on for 82% of the scheduled operating time. There were two scheduled shutdowns. The first was to inspect the bearings and journals of the main motor generator sets. The second shutdown was to relocate the K^- beam channel to the 72-inch hydrogen bubble chamber, to provide a lower-energy K^- beam. Four primary experiments were continued through this quarter. Four emulsion runs were made on primary time. Radiation detection and control studies continued. Decay-measurement studies of internal activation in the Bevatron were made during the shutdowns. Some viewing ports and pole-face-winding clamps were removed for studies of radiation damage. General building background and shielding studies were continued.

I. OPERATION

The Bevatron operation record is shown in Fig. 1. The beam was on for 82% of the scheduled operating time. The beam was off 11% of the time because of component failure, and 7% of the time for setup and routine checks.

II. SHUTDOWNS

There was a 2-day shutdown on May 4 and 5 to inspect the bearings and journals on the main motor generator sets. This inspection routinely occurs after 1.3×10^6 magnet pulses, or about every 3 months. The bearings are checked for tarnishing and scraping. The shaft journals are given ultrasonic and "Magnaflux" inspection.

Routine maintenance was done on the Bevatron and related equipment. The "astrodome" on the south tangent tank and the glass viewing ports on the east tangent tank were replaced. They had become discolored from radiation. This is discussed in more detail in Section VI of this report.

The "B"-type gate at the east was replaced with a labyrinth and an "A"-type gate.[1] This provided controlled access to the center of the Bevatron pit through the radiation shielding from the east. There are now two access routes to the center of the pit, one from the east and one from the west.

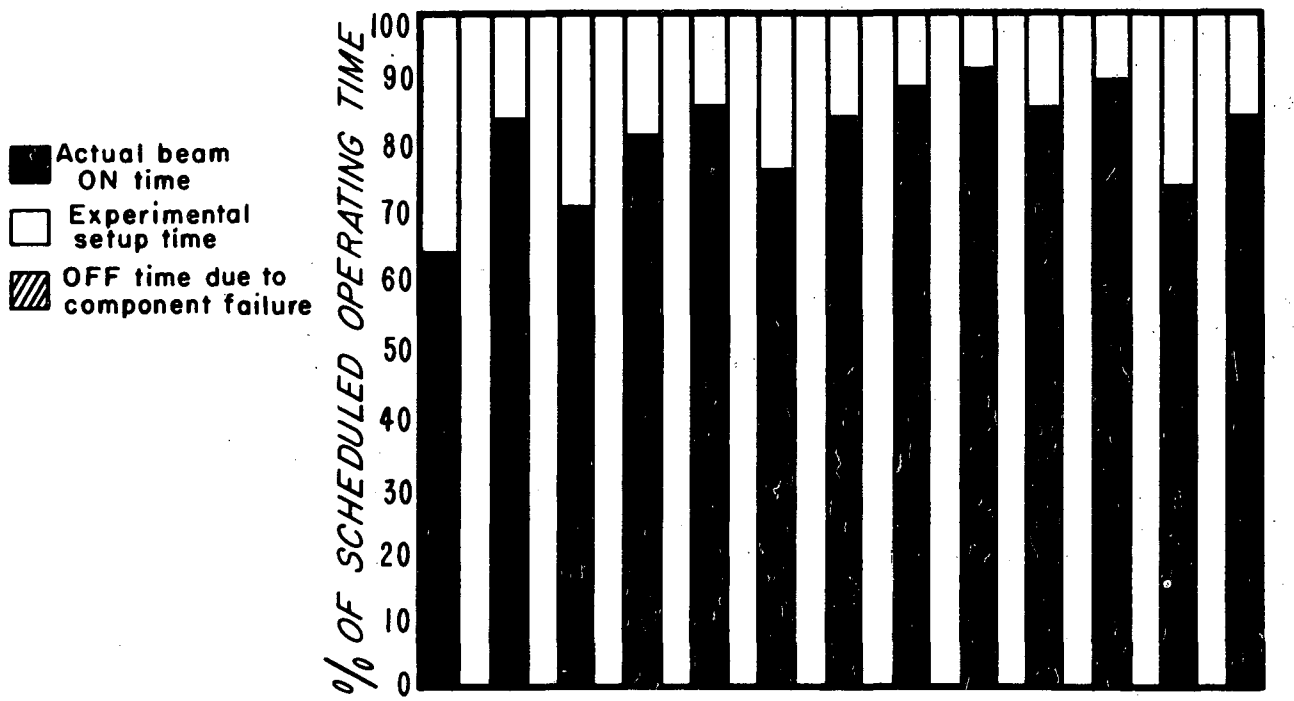
There was a second shutdown on June 15 and 16 to change the K^- beam line to the 72-inch hydrogen bubble chamber. This change allowed tuning the channel to a lower-energy K^- beam for a University of California at Los Angeles experiment by Harold Ticho.

A collimator was installed on the M_2 plunging magnet in the external proton beam (EPB). The collimator is adjustable from outside the vacuum tank by means of a sliding shaft through a vacuum seal. With plunging magnet interlocked in the back position, the shaft is pushed in to engage the slit-adjusting mechanism. After the slit adjustment, the shaft is withdrawn and the interlocks removed. The slit is vertical and adjustable from 0 to 3-in. wide. This allows radial clipping of the EPB to provide better optical quality of the EPB when it is needed.[2]

III. BEVATRON STUDIES

Beam-loss studies continued, with studies of injection parameters and coasting beam.

Tests were made on spilling beam by controlled rf turnoff, using feedback loops. Preliminary results looked very good. A detailed report will be issued after the results are observed on a more operational type of electronic circuit.



Week of	3/29	4/5	4/12	4/19	4/26	5/3	5/10	5/17	5/24	5/31	6/7	6/14	6/21
Crew hours	168	168	168	168	168	168	168	168	168	168	168	168	168
Turn on & maintenance time (h)	10	10	10	10	10	10	10	10	10	10	10	4	10
Scheduled operating time (h)	148	146	147	151	144	118	148	143	150	148	152	115	149
Scheduled Bevatron test time (h)	10	12	11	7	14	6	10	15	8	10	6	8	9
Scheduled shutdown time (h)	0	0	0	0	0	14	0	0	0	0	0	41	0
Holiday (h)	0	0	0	0	0	0	0	0	0	0	0	0	0

MUB-4942

Fig. 1. Bevatron operating schedule, April through June, 1964.

IV. EXPERIMENTAL PROGRAMS

The four primary experiments continued through this quarter. There were four emulsion runs on primary time for a total of 114.25 hours. A summary of the experimental program is given 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. Format

At this date the format for reporting results of studies of radiation detection and control problems appears to have reached suitable maturity. In general, we will attempt to show by plan-view sketch all future experimental arrangements as they appear on the magnet room and building annex floor (as, for example, in Fig. 2 of this report). The principal features of all secondary beam transport systems will be shown, and the facility will be labeled according to group usage. Major components in the external beam transport system are to be shown and labeled. Radiation-detection surveys and pertinent beam conditions are to be listed, as in Table III, where references to detection results generally will appear in the last column. Target locations in the EPB and in the circulating beam will be either shown on the sketch or stated explicitly in the table. All acknowledgments will be placed in footnotes.

B. Radiation Detection While Accelerating Beam

1. Modes of Operation

As the operation schedule will show, the principal experiment groups using beam in this period were those designated as Trilling-Goldhaber, Powell-Birge, Alvarez (K-72), and the University of Washington (Masek). Some work continued, on a noninterference basis, in setting up secondary beams and counter calibrations for future runs. These participating groups were the Elioff (Segrè-Chamberlain) group, using target EPB-F_2, in building bay 3 (annex); and the Arens (Segrè-Chamberlain) group, using an IPB target, section H-Q III, in bay 6 (see Fig. 2).

The K-beam facility in bay 2 was used alternately by the Trilling-Goldhaber (25-inch hydrogen bubble chamber) and the Powell-Birge (Freon bubble chamber) people. The target for this work was EPB-F_1, which is located just inside the 10-foot shield enclosure. To provide an adequate shielding arrangement for the external proton beam "beam stop," EPB BS-1 (in the wall) was used during all K-25 and Freon chamber experimental runs.

Table I. Summary of Bevatron experimental research program, April through June 1964

Group	Start of experiment	End of experiment	Experiment	Beam time: This quarter (Apr-June) 12-hour periods	Beam time: This quarter (Apr-June) Hours	Beam time: Start of run through June 1964 12-hour periods	Beam time: Start of run through June 1964 Hours	Pulse schedule	Primary or Secondary Experiment
Internal groups									
Alvarez (#16)	3-23-63	In progress	Study of π^- interactions in the 72-inch bubble chamber, using hydrogen, deuterium.	23	254	168	1763	1:1	P
Powell-Birge (#14) 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.	76	779	211	2204	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		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.	38	430	70	797	1:1	S
Trilling-Goldhaber (#29)	2-18-64	In progress	Study of K^+-nucleon interactions, using 25-inch hydrogen bubble chamber.	33	399	72	799	1:1	P
Powell-Birge (#18)	3-24-64	In progress	Investigation of Y_1^* interactions in K^--nucleon reactions, using 25-inch bubble chamber.	68	684	79	793	1:1	P
Powell-Birge-Frye	4-21-64	In progress	Study of hyperfragments produced by K^- mesons in the 30-inch Freon bubble chamber.	40	420	40	420	1:1	S
Lofgren-Segrè	5-14-64	In progress	Study $K^+ - \mu^+ \pi^0 + \nu$, measuring polarization as a function of energy.	4	44	4	44	1:1	S
	6-23-64	In progress		1	11	1	11	1:1	P
Barkas	6-9-64	6-9-64	Emulsion exposure in a 800-MeV/c K^--meson beam in preparation for a future series of emulsion exposures.	1	10	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.	--	5	--	5	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	Experiment to investigate the magnetic moment of the Σ^+ hyperon, using a spark chamber in a 200-kG pulsed magnetic field.	42	454	74	819	1:1	S
				28	282	28	282	1:1	P
	4-12-64	In progress		14	161	14	161	1:3	P
Tufts University Schnepps, Kang, Kwak	4-13-64	4-15-64	Emulsion exposure in a 1.1-BeV/c K^- beam.	2	26	2	26	1:1	P
Delhi, India Bhowmik	4-15-64	4-18-64	Emulsion exposure to stopping K^- mesons.	4	42	4	42	1:1	P
Univ. Washington Lord, Piserschio	4-18-64	4-20-64	Emulsion exposure to stopping K^- mesons.	3	36	3	36	1:1	P
Stanford-Michigan Perl-Longo	5-6-64	In progress	Tests in preparation for a future n-p scattering expt.	2	27	2	27	1:1	S

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	Faults[a] 26	Pulses	Faults[a] 14	Pulses	Faults[a] 14	Faults[a] 26	Pulses	Faults[a] 14	Pulses	Faults[a] 14	Faults[a] 26	Pulses	Faults[a] 14	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	

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

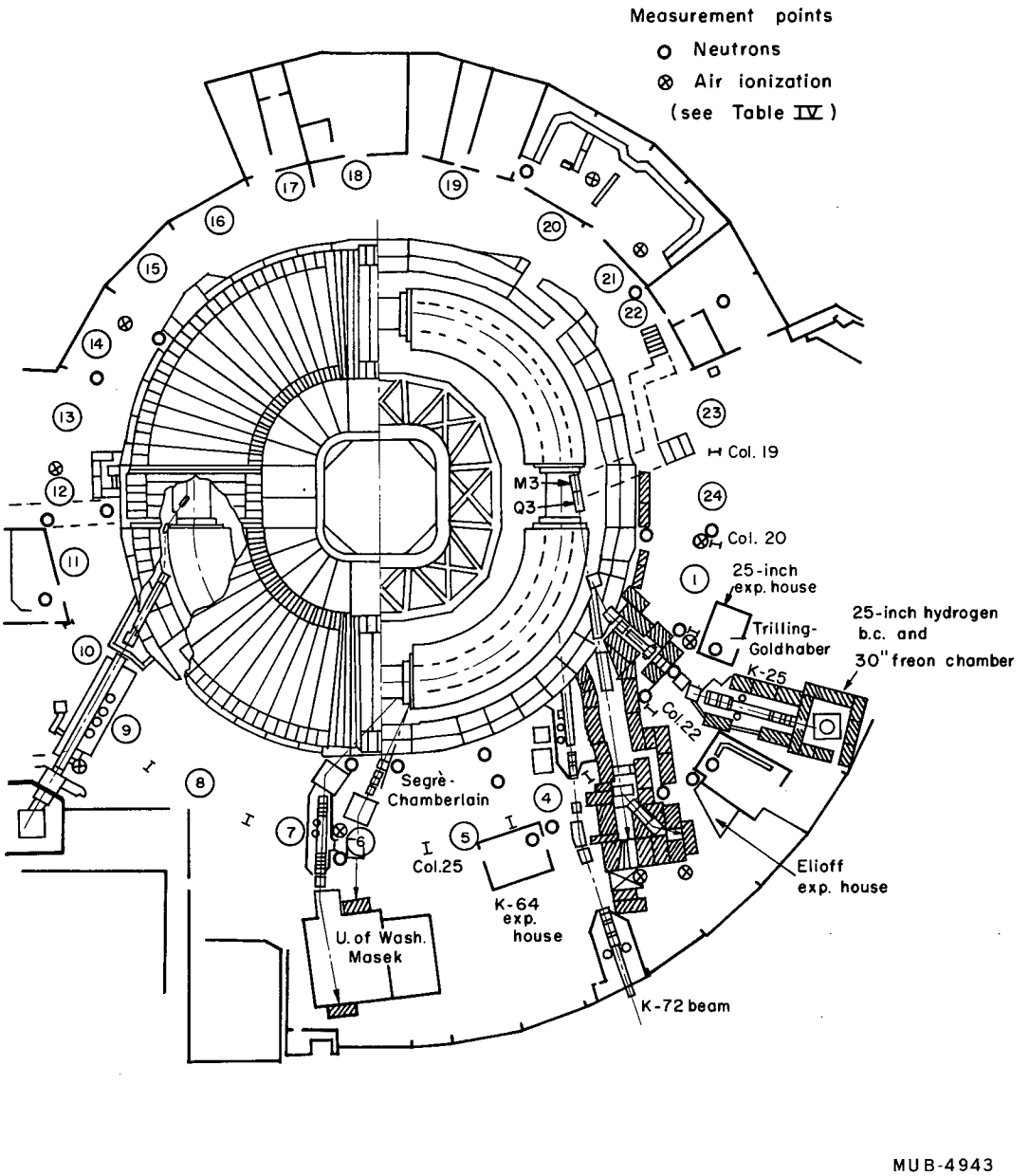


Fig. 2. Plan view of magnet room and annex, showing experimental arrangements and location points for neutron detection and air ionization measurements (see Table IV).

Table III. Summary of building radiation surveys - April through June, 1964

Date of survey	Survey		Beam intensity (a) (protons per pulse)		Targets				Data reference
	Area	Detector	Internal	External	Designation	Location	Spill (%)	Spill (BeV)	
4-22	Building floor	Cary ion chamber	2.5×10^{12}	10^{11}	1. Alvarez 2. Masek 3. Powell-Birge	Sect. E-Q III EIM - Now SIW(b)	60% of IPB 10% of IPB 30% of IPB	5.8 4.5 6.2	Table IV, Col. 4 and Figs. 2, 3
4-23	Building floor	Ag(n, γ)-GM	2.5×10^{12}	10^{11}	1. Alvarez 2. Masek 3. Powell-Birge				Table IV, Col. 5, and Figs. 2, 3
5-12	Floor area adjacent to east straight section	Ag(n, γ)-GM	2.5×10^{12}	2×10^{10}	1. Alvarez 2. Trilling-Goldhaber	Sect. E-Q III SIW(b) EPB F, and BS-1	80% of IPB 20% of IPB 100% of EPB	5.8	Fig. 4
6-30	Floor area outside EPB cave	Ag(n, γ)-GM		4 to 5×10^{10}	Elioff-(Segrè-Chamberlain)	SIW(b) EPB F_2 and BS-2	100% of EPB	6	Fig. 3

(a) Pulse rate 10.9 ppm

(b) Energy loss target

For this condition it was determined that the number of recoil events from stray particles with sufficient energy to cause noticeable obliteration of pictures in the K-25 bubble chamber was about 3 to 5 per 90-liter volume, with EPB approximately 1.5×10^{10} ppp.

2. Detection of Neutrons and Air Ionization

Figures 2, 3 and 4 and Tables III and IV present data from radiation detection work performed in regions about the building floor which could be occupied by workmen. The accumulated doses to operational personnel, integrated in film dosimeters, are shown by bar graph in Fig. 5. The solid part of each bar represents the first 3-month period, the white or the shaded portion the second 3 months, in the first 6 months of 1964.

About the data, one may say in general that the air-ionizing species contributed negligibly to radiation dosage. The major portion of the proton-sensitive film dosage, shown by the bar graph, came from residual activity in beam channels. The neutron data must be interpreted in the light of three empirically derived facts. These are: (a) the energy spectrum of stray neutrons about the Bevatron resembles the cosmic-ray neutron spectrum; (b) approximately 80% of the biological dose delivered by cosmic-ray neutrons is deposited by particles in the energy interval from 50 keV to 20 MeV [3] (our detectors have maximum energy sensitivity in this interval); and (c) the established exposure count rate (for neutrons in this energy range) required to deposit 0.1 rem per 40-hour week is 18 to 20 neutrons $cm^{-2}sec^{-1}$.

The following conclusions are evident. The fast neutron flux in some regions of the building is greater than the established tolerance rate by factors of 3 to 4. Yet the accumulated biological dose to building personnel remained lower than the maximum permissible level by a factor of 2.5 in the worst case. In the past, duration of occupancy has worked in our favor to give a safety margin of a factor of approximately 8. However, this method of control is not reliable, and in some cases warning signs are unheeded. Thus plans must be made to circumvent the chance that someday a workman may decide to stay in a high-flux region for a long time.

Figure 4 exemplifies one situation that is presently being treated. The region adjacent to the east straight section has long been plagued with excessive neutron counts, as indicated by the encircled flux numbers, caused by interactions of the high-energy beam with the EPB plunging magnet, M_1. It has been shown by measurement[4] that these numbers are sums of various components being contributed in approximate ratios of 22% from the roof, 7% through the wall, and 71% from the utilities tunnel (dashed lines) and the trench (solid lines). The more recent flux numbers, enclosed in squares, were obtained during similar beam conditions but after a 4-ft section of clay brick had been stacked across the trench and tunnel under the 10-foot wall. At least 90% of the remaining flux is from the roof, for which additional shielding is being planned.

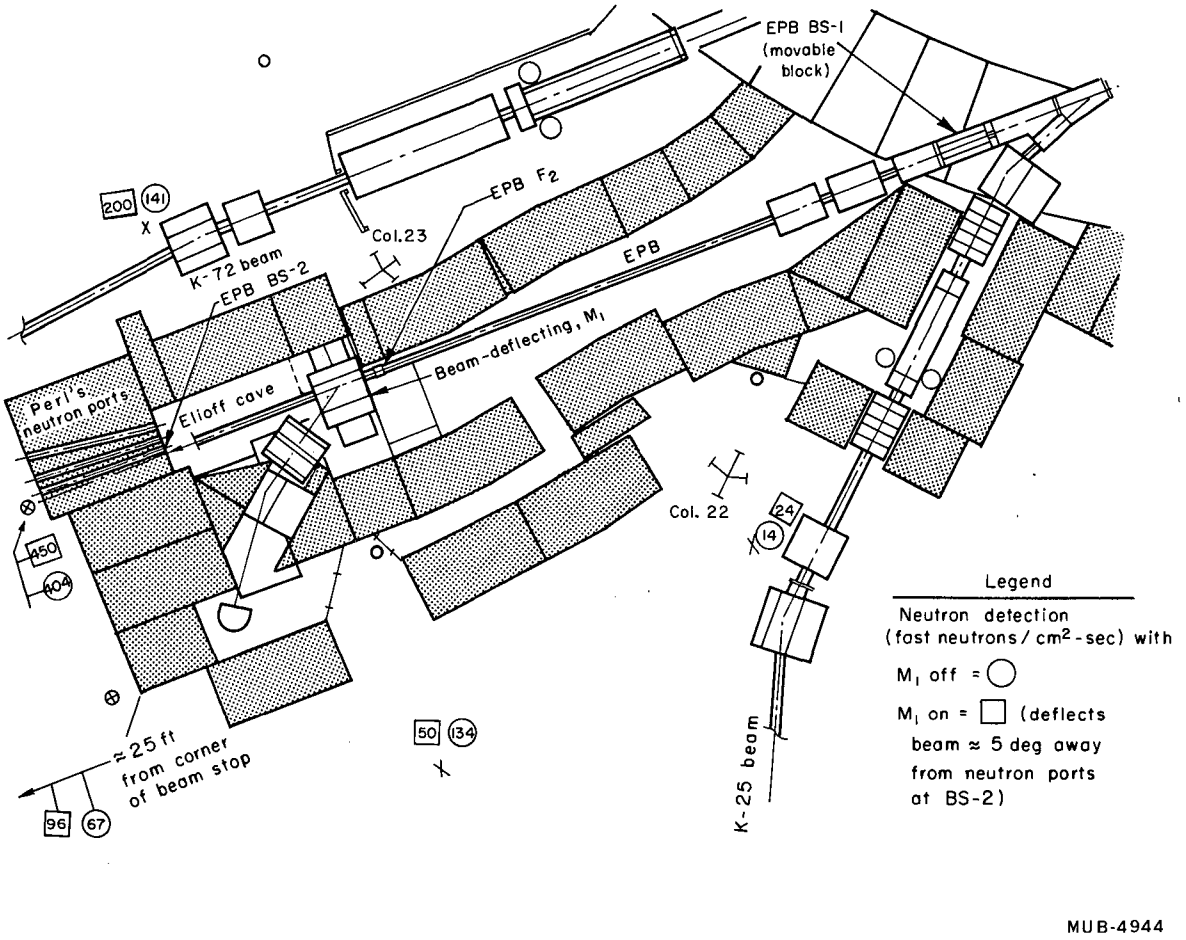


Fig. 3. Neutron detection results in the vicinity of the EPB shield channel.

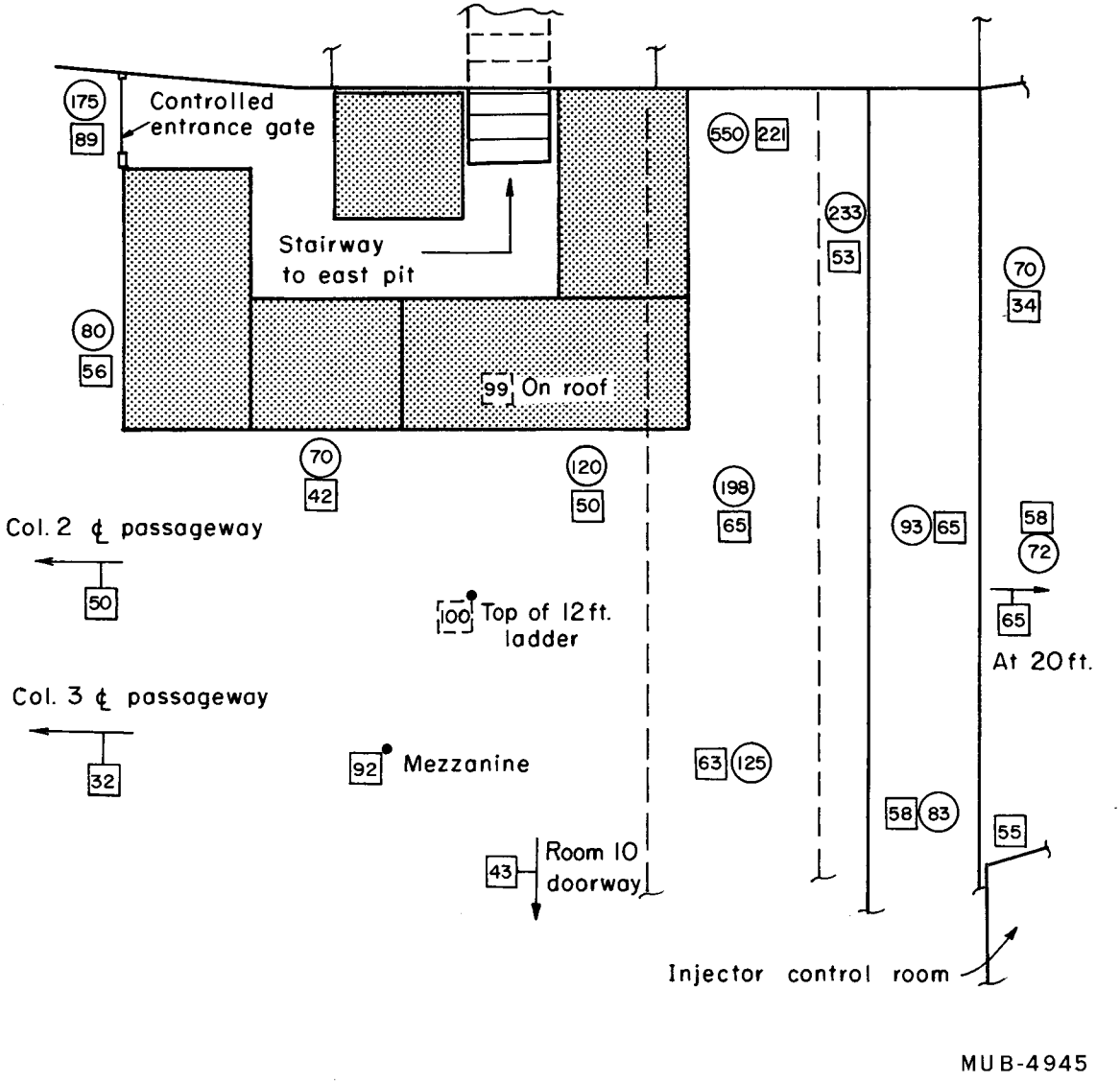


Fig. 4. Neutron detection results at east straight section, building bay 12. (Values are in fast neutrons/cm^2-sec; see Table III for operating conditions under which measurements were taken.)

Table IV. Building survey data.

Note: See Fig. 2 for building plan, and Table III for operating conditions under which measurements were taken.

Building bay Nos.		Locale	Neutron Flux (a) ($n/cm^2 sec$)	Air Ionization (b) (mR/hr)
2	-	North side, Col. 21	22	0.38
	-	Passageway under K-25 beam	14	
	-	Inboard, Col. 22	65	
	-	Inside K-25 experimenter house	6	
3	-	Inside 25-inch B. C. control room	3	
	-	Outside 25-inch B. C. control room	8	
	-	Entrance maze to EPB channel	5	
	-	S. W. corner of EPB BS-2		0.040
4 (Annex)	-	Centerline, front of EPB BS-2		0.070
	-	Inside K-72 experimenter house	4	
	-	Outside K-72 experimenter house	18	
	-	Col. 24, 25 ft from wall	20	
	-	Col. 24, 5 ft from wall	19	
6	-	Near Segrè-Chamberlain secondary beam	16	
	-	Masek secondary beam	26	
	-	Col. 26	16	0.060
9	-	Right rear of linac		2.2
11	-	Injector control room	74	
	-	Col. 31, over utilities tunnel	159	
	-	5 ft. from wall over utilities tunnel	523	3.4
13	-	20 ft from wall	55	
14	-	Entrance maze to Q-I	280	0.75
20	-	Bevatron control room	15	0.10
21	-	Col. 16	26	0.13
22	-	Machine shop	6	
24	-	Col. 20, 50 ft from wall	37	
	-	Col. 20, 5 ft from wall	38	0.60

(a) Position marked by O in Figs. 2 and 3

(b) Position marked by ⊕ in Figs. 2 and 3

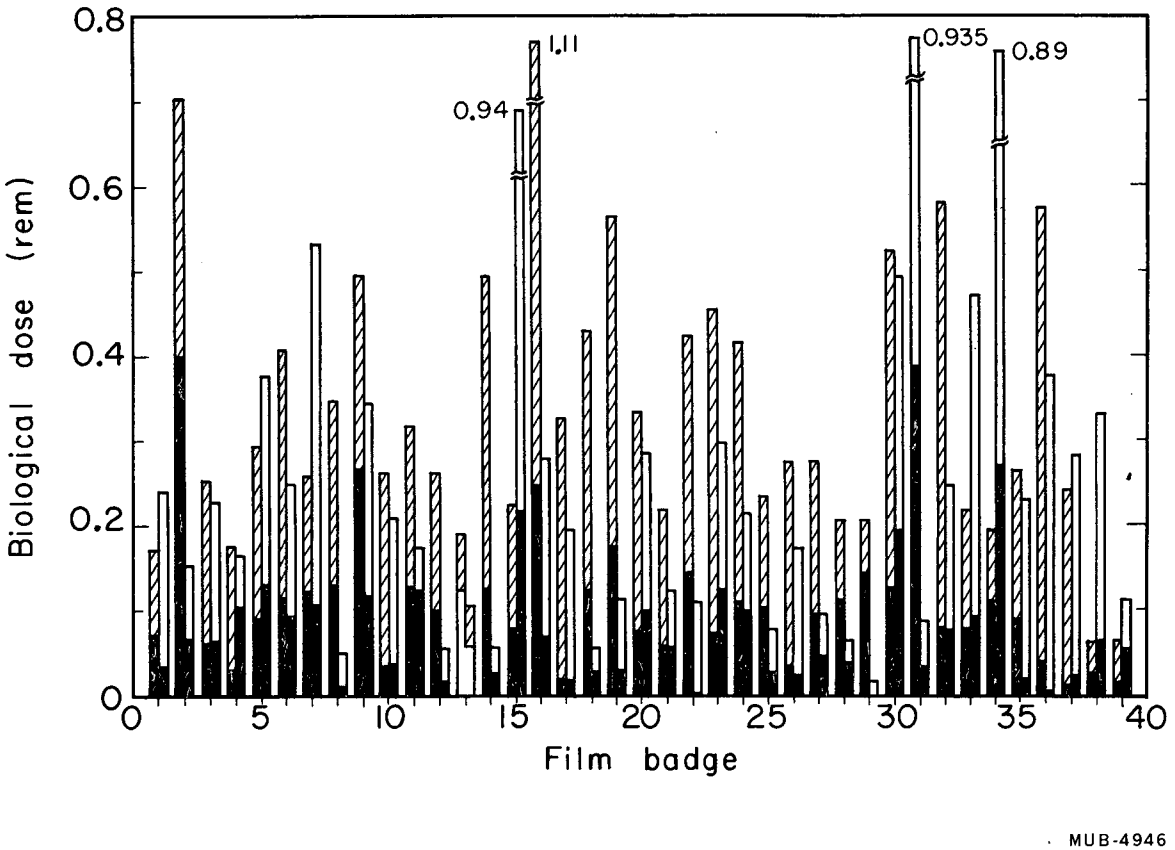


Fig. 5. Integral dose in rem for persons carrying neutron (left-hand column) and gamma (right-hand column) dosimeter film in the Bevatron building, January through June, 1964.

C. Special Studies

1. Evaluation of Roof Shielding Over External Beam Targets

Shielding design dimensions have generally been taken from Burton Moyer's analysis.[5] The method is illustrated in Table V, where it is applied to the EPB roof shielding geometry (Fig. 6). Measured and calculated values are compared in Fig. 7.

An EPB of 1.5×10^{12} ppp at 11 ppm was incident on a 4-in. copper target. The roof shielding consisted of 20 in. of iron followed by 48 in. of ordinary concrete. Measurements were made by using paraffin-moderated indium foils which were calibrated in the interval 30 keV to 14 MeV. Aluminum foils (having 6.7 MeV threshold and calibrated at 14 MeV) were also used, and gave a reading about one-half of the indium foil readings at the maximum-intensity location over the target.

2. Decay of Residual Radioactivity in the Bevatron Environs

Since the radioactivity about the machine in general has become more prominent, our shutdown periods have been rather short, lasting at most up to 48 hours. Consequently no good set of data has been collected to determine in detail just how the radioactivity is decaying. Two sets of measurements were taken recently 24 hours apart, and indicated rather broadly that the remaining radioactivity was from 30% to 50%.

D. Radiation Damage

Some interest was expressed by various operations people in knowing the extent of the radiation damage to plates and domes covering the vacuum-tank viewing ports, after a 1-year period of operation following the Bevatron-modifications shutdown. A survey was made to determine which, if any, of the viewing-port cover plates should be replaced. Discoloration of both glass and Plexiglas types was very evident, but it was difficult to discern whether or not physical deterioration had set in. It was thus decided to remove sample plates, which could be selected on the basis of maximum discoloration and with which stress tests could be performed. The results[6] were gratifying.

Four circular plates, 10 in. in diameter by 1 in. thick (two each of Plexiglas and laminated glass), were removed from the outside east tank. A hemispheric Plexiglas dome was removed from the south outside. All pieces were water-pressure-tested in fixtures which permitted stress from one surface only. The two Plexiglas plates, showing average light transmissions (as observed from the more diffuse side) of 46 and 24%, were tested at 500 and 480 psi, respectively. The 500-psi test resulted in a fracture, whereas the 480-psi test did not. Interestingly enough, however, the two irradiated glass plates, plus a similar unirradiated plate, fractured under tests at 100 psi. The light transmission of the irradiated glass was less than 1%. (All transmission values were referenced to clear samples of the same thickness. An ordinary light bulb source was used.)

Table V. EPB roof shielding evaluation.

We consider here only $0.150 < E \lesssim 6$ BeV resulting from proton interactions at BeV energies with 1-mfp copper target. For this energy range the neutron yield is stated to be (see reference 5)

$$I = 2\pi \int_{\Delta}^{\pi} f(\theta) \sin\theta \, d\theta = 8 \text{ neutrons/proton.}$$

To obtain $\phi_n{}^n/\text{cm}^2$-sec in $d\Omega$, calculate $\left(\frac{dI}{dA}\right)_i \phi_p = \frac{2\pi \, \bar{f}(\Delta\theta_i) \sin\theta \, \phi_p}{2\pi R_i^2 \sin\theta} = \frac{\bar{f}(\Delta\theta_i)\, \phi_p}{R_i^2}$,

where $\bar{f}(\Delta\theta_i)$ may be read from the curve, Fig. 2 of reference 5.

θ_i (deg)	$\bar{f}(\Delta\theta)$	For 126-in. wall R_i (cm)	R_i^2 (cm)	$\bar{f}(\Delta\theta)\,\phi_p$ [a] / X^2	Ordinary concrete T (cm)	T/λ [b]	Iron T	T/λ [c]	Sum T/λ	Attenuation $0.3\,T/\lambda$	$10^{0.3\,T/\lambda}$	$\bar{f}\,\Delta\theta\,\phi_p$ [d] / $A\,X^2$
15												
16	3.7	734	5.4×10^5	1.01×10^6	171	9.5	54	9.8	19.3	5.79	6.15×10^5	1.64
30	2.4	413	1.7×10^5	3.9×10^6	96	5.32	40	7.3	12.62	3.79	6.1×10^3	638
45	1.5	297	8.8×10^4	4.7×10^6	68	3.8	29	5.3	9.1	2.73	5.4×10^2	8700
60	0.74	236	5.6×10^4	4.12×10^6	56	3.12	23	4.2	7.32	2.2	1.56×10^2	26,000
75	0.38	214	4.6×10^4	2.3	50	2.78	21	3.82	6.60	2.0	95.5	23,900
90	0.20	200	4×10^4	1.37	48	2.67	20	3.64	6.31	1.9	78.2	17,600
105	0.13	214	4.6 -	7.7×10^5	50	-	-	3.82	6.60	2.0	95.5	8100
120	0.09	236	5.6 -	4.45×10^5	56	-	-	-	7.32	2.2	156	2850
135	0.075	297	8.8 -	2.33 -	68	-	-	-	9.1	2.73	540	432

(a) $\phi_p = 1.5\times10^{12}$ ppp $\times \frac{11}{60} = 2.75\times10^{11}$ protons/sec.

(b) $\lambda_{1/2} = 18$ in. for ordinary concrete, $p = 150$ lb/f^3.

(c) $\lambda_{1/2} = 5.5$ in. for iron; $p \approx 490$ lb/f^3.

(d) n/cm^2 sec - surviving neutrons.

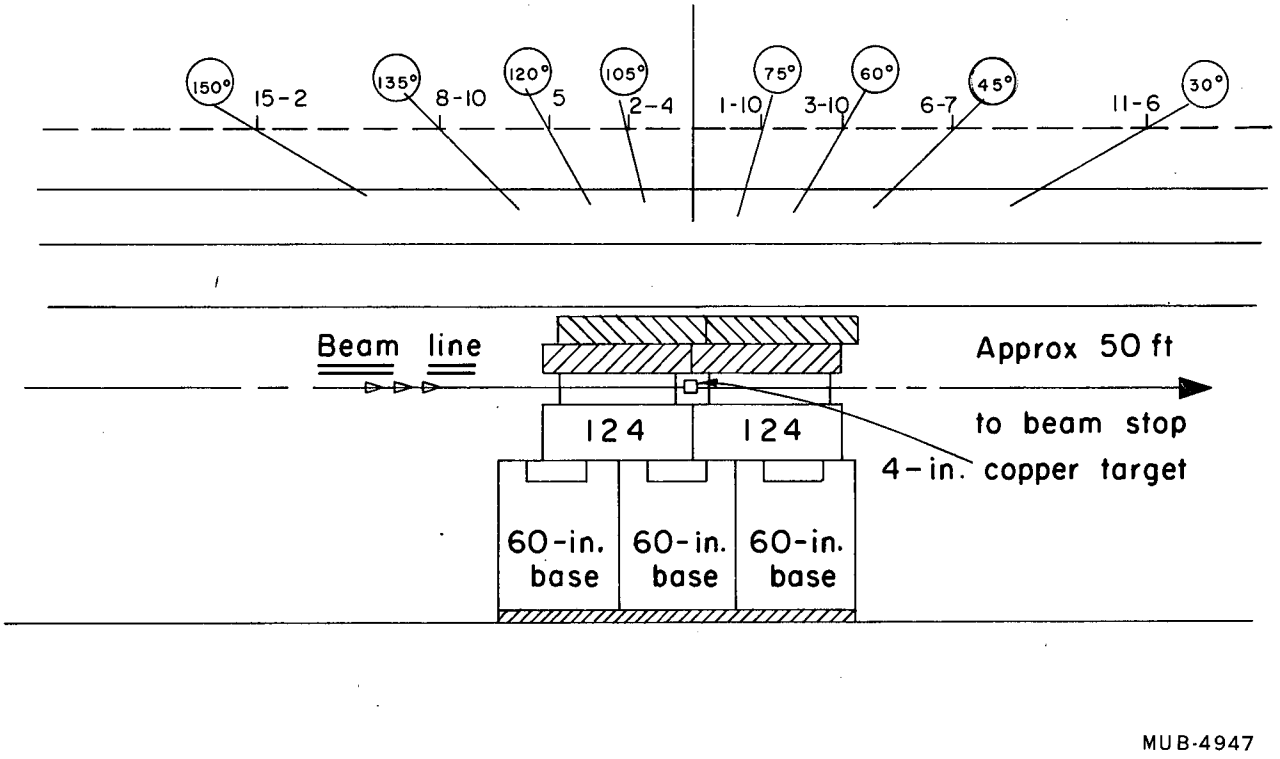


Fig. 6. Target and shielding arrangment for external beam study.

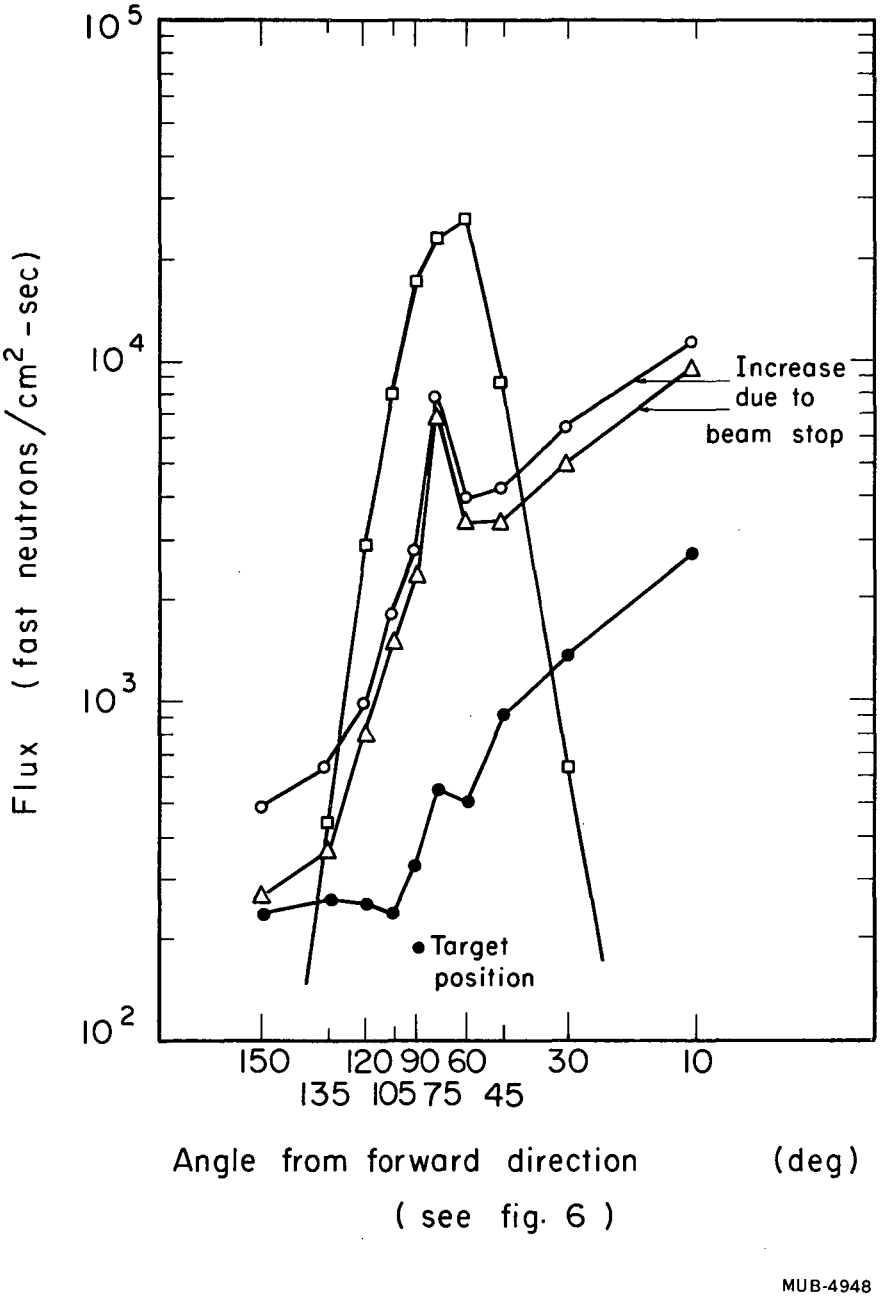


Fig. 7. Angular distribution of neutron flux around Cu target in EPB.

The conclusions to be drawn from these tests are quite simple. Absorption bands in the irradiated and discolored glass are in the visible region, and thus label the glass as a poor observation-port cover material. Plexiglas is generally better than glass, plus the fact (as the tests show) that it does not rupture as easily. Tests for radiation damage were negative, i.e., there was no evidence that the effect was important.

Several pole-tip-winding clamps were replaced in Quad III 29° target area. The clamp material is epoxy-glass laminate. Slight discoloration of the clamps was apparent but no physical damage was detected.

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