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RADIATION EXPOSURES OF PERSONNEL AT THE 60-INCH CYCLOTRON

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ABSTRACT

A study has been made of the radiation received by staff members of the 60-inch cyclotron for the period from 1953 to 1957 and of the radiation environment in the target area. The nature of the operations has caused workers to receive an average amount of radiation that was within the formerly accepted limits and in addition is less than the present maximum recommended by the AEC. Namely, the Maximum Permissible Dose (MPD) to the most critical organs, accumulated at any age, shall not exceed 5 rems multiplied by the number of years beyond age eighteen and the dose in any thirteen consecutive weeks shall not exceed 3 rems. There has been a yearly decrease in average exposure however, and constant improvement of techniques lessens the amount of radiation received.

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Because of the normal concern for personnel radiation and the recent decrease in recommended tolerance level, an investigation was made of exposures received by members of the 60-inch cyclotron crew. Film-badge readings for the years 1953 to 1957 were totaled for the men doing the actual work on the cyclotron. A comparison was made between the findings at the 60-inch cyclotron and the findings at other accelerators, as shown in Table I.[1] A summary was made of the total radiation received in performing various cyclotron operations.

Figure 1 shows the cyclotron area. A wide-range beta-gamma dose-rate meter is placed as close to the target as possible, at A, which is about 3 feet from the target plate and on the same level as the target.[2] This indicates the level of exposure to which a crew member is subjected when he must enter the target area. Every effort is made to keep the time of exposure as short as possible. The average time required for setting up a target is usually about 3 minutes, and the average time for removing the target assembly from the cyclotron is about 1 minute. The assembly is then dismantled, which takes less than a minute. The dismantling is done from behind a shield which consists of a 2-inch lead glass front and 2-inch lead base, the sides of which are open to allow access for tools. For transuranic elements, a special cart is used which supplies the target and assembly with cooling water, air, and helium. This takes about 5 minutes to set up, and less than a minute to remove from the area. Targets from the dismantled assembly are placed in shielded containers for transportation or storage.

Alpha-Particle Bombardments

Alpha bombardments accounted for 73% of the total bombardments for the years 1953 to 1957.

During an average alpha bombardment, the radiation level recorded by the meter is 10 to 20 roentgens per hour. One minute after the bombardment, the level has dropped to about 1.0 r/hr. The radiation level after 5 minutes varies with different target materials because of their different

[1] Solon, McLaughlin, and Blatz, Stray Radiation Measurements at Particle Accelerator Sites, NYO-4699, Jan. 1956, p. 25.

[2] Kenneth D. Jenkins, Wide-Range Beta-Gamma Dose-Rate Meter, in Physics Division Quarterly Report, UCRL-3689, Jan. 1957, p. 40-44.

Table I

Summary of radiation exposure cases reported at various accelerators (from Solon, McLaughlin, and Blatz, NYO-4699).

Site[a]	Accel[b]	Particle	Energy (Mev)	No. of badges	Dates, months frequency[c]	No. of exposures at stated factor of MPE: 0.25 to 0.5	0.5 to 1	1 to 2	2 to 3	> 3	Number of persons accounting for stated percentage of exposures	
CIT	syn	p	440	51	5/53-1/55 (20) W	253	116	58	19	6	10	50
Col	cyc	d	10	27	11/53-1/55 (13) W	12	-	1	-	-	14	100
	syn	p	385	-	3/53-1/55 (22) W	48	35	28	9	7	8	50
MIT	cyc	d	15	6	4/53-1/55 (21) B	46	16	-	1	-	2	83
	syn	e	340	11	4/53-1/55 (21) B	13	4	-	-	1	8	100
Pitts	cyc	d	16	10	7/53-1/55 (18) B	67	25	17	8	-	6	73
Prin	FMcyc	p	18	32	3/53-1/55 (22) B	4	4	-	-	-	14	100
Roch	syn	p	250	60	6/54-1/55 (7) B	24	6	1	-	-	9	26
Yale	cyc	d	4	11	11/53-1/55 (13) B	1	1	-	-	-	3	100
Calif	cyc	α, d, p	40, 20, 10	22	7/52-6/54 (23) W	150	147	68	13	5	10	93
	cyc	α, d, p	48, 24, 12	14	1/55-7/56 (18) W	85	102	56	3	1	5	90

[a] CIT = Carnegie Institute of Technology; Col = Columbia Universtiy; MIT = Massachusetts Institute of Technology; Pitts = University of Pittsburgh; Prin = Princeton University; Roch = University of Rochester; Yale = Yale University; Calif = University of California, Crocker Laboratory

[b] syn = synchrocyclotron; cyc = cyclotron

[c] W = weekly; B = biweekly

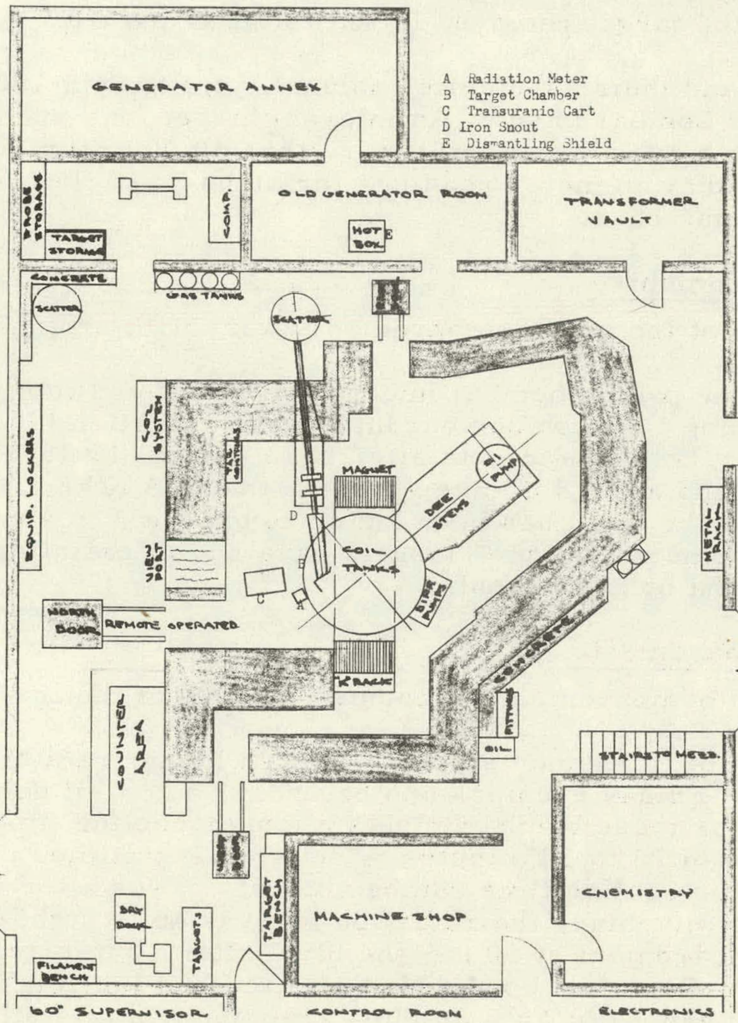

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Fig. 1. Arrangement of the 60-inch cyclotron area.

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activities. In some cases, a target is removed from the cyclotron to a shielded enclosure as soon as possible -- i.e., from 1 to 5 minutes after the bombardment. Five minutes from beam cutoff and after target removal, the level of radiation at the meter is usually about 0.3 r/hr. In other cases, while a target is still in place, the level may exceed 1.0 r/hr. Most targets are removed from 5 to 10 minutes after the bombardment. After 10 minutes, the level with the target removed is still slightly over 0.2 r/hr.

Targets and their assemblies normally emit about 100 to 500 r/hr 5 minutes after bombardment. An internal target (one that has been inserted into the tank on a probe) may emit more than 10,000 r/hr. Figures 2 and 3 show typical radiation meter readings for alpha-particle bombardments taken from a Speedomax chart.

Proton Bombardments

About 7% of the total bombardments were with protons.

Most of the proton bombardments are on a beryllium target for neutrons. During a proton bombardment, the radiation level at the meter is about 50 to 60 r/hr. One minute after beam cutoff the level is usually more than 1.0 r/hr, and after 5 minutes greater than 0.5 r/hr. For prolonged bombardments, the level has been known to exceed 3 to 4 r/hr after 1 minute. Proton bombardments on other targets have shown radiation levels similar to those for alpha bombardments.

Deuteron Bombardments

Deuteron bombardments accounted for 20% of the total bombardments.

Deuteron bombardments create a much higher radiation level. They are run only on Friday evenings and Saturday, and -- if demands are high -- on Sundays. For these bombardments a longer cooling time is required. A nominal time of 25 to 30 minutes is set, but sometimes the radiation meter indicates that the cooling time can be shorter. Even after very short bombardments on a cool machine, the radiation level is quite high; e.g., for a 10-minute bombardment at 60 μa, the level after 10 minutes' cooling is more than 1.0 r/hr. For most bombardments, the level during the irradiation is over 100 r/hr, and 2.0 r/hr 5 minutes after the beam is off. Following long deuteron bombardments, the radiation level 5 minutes after cutoff is sometimes 8.0 r/hr. Following bombardment of a beryllium target for neutrons with 70 μa of beam, the radiation level has been 1.5 r/hr after 30 minutes. A prolonged uranium bombardment with 30 μa of beam has resulted in a radiation level of more than 1.0 r/hr after 1 hour of cooling. Figure 4 shows a typical radiation meter reading for a deuteron bombardment taken from a Speedomax chart. Radiation meter readings of various bombardments are shown in Table II.

Setting up "cart" runs in the evenings after deuteron bombardments presents a problem, as the cart is usually about 5 feet from the target chamber.

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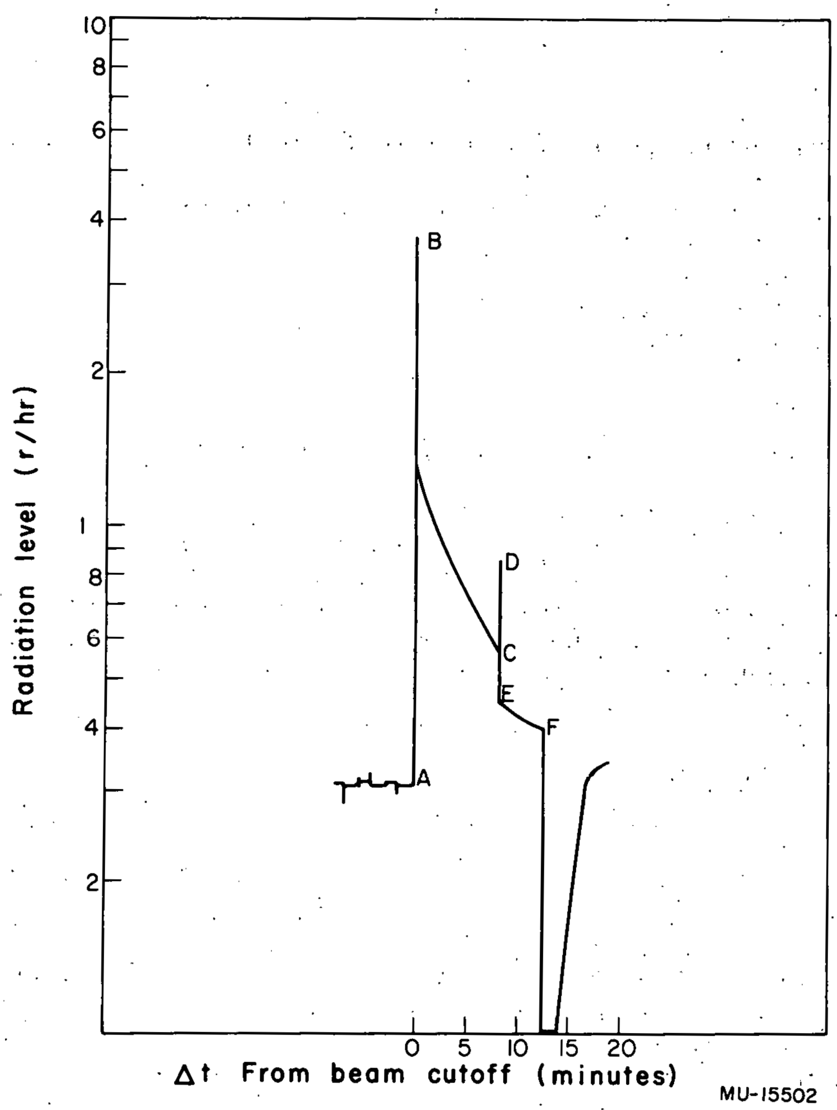

Fig. 2. Typical radiation decay on Speedomax chart.
Alpha particles on Ni and Au; 7.5 μa on target (5/8" diam); 38.0 μa on collimator; 2-hr bombardment.
A= beam off. 1,000 R/hr full scale
B= scale change 10 R full scale
C= target being removed
D= target passing meter
E= target removed, setting up next target
F= oscillator on

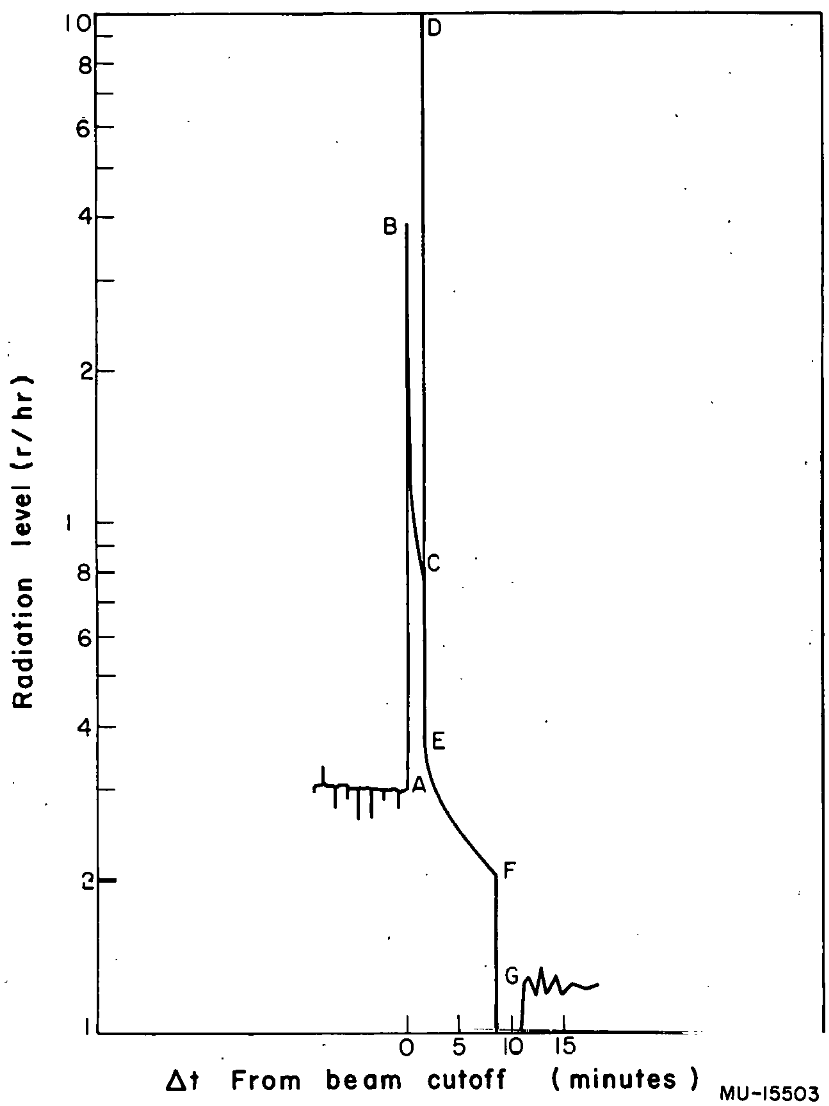

Fig. 3. Typical radiation decay on Speedomax chart.
Alpha particles on U; 15 μa on target; 20 μa on collimator; 1.6 hr bombardment.
A=beam off 1,000 R full scale
B=scale change 10 R full scale
C=target being removed
D=target passing meter
E=target removed, setting up next target
F=oscillator on
G=beam on next target

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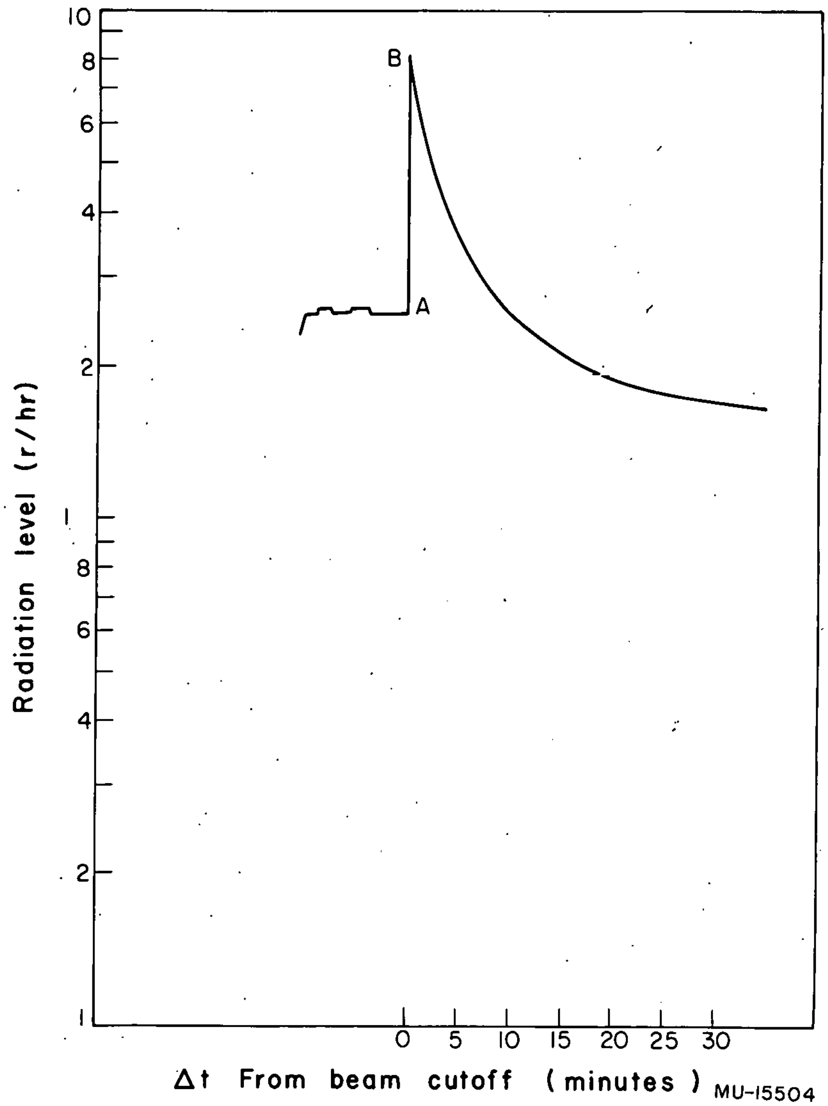

Fig. 4. Typical radiation decay on Speedomax chart.
Deuteron particles on Be; 70 μa on target; 3.4 hr bombardment; after 8 hr 0.400 R .
A=beam off 1,000 R full scale
B=scale change 10 R full scale

Table II

Typical radiation levels (r/hr) following bombardment of various targets (meter 3 feet from target chamber)

Bombardment Conditions		Be	Re	U	Ni & Au	Np	Fe (on probe)[a]	Ag (on probe)[a]	Be	Be	Re	Pu	Hg	Be	Be
		Target Material													
Beam particles		α	α	α	α	α	α	α	p	p	p	d	d	d	d
Total beam (μa)		57	40	30	42.5	44	50	80	50	50	40	43[b]	35	65	70
on target		57	40	.4	7.5	8	50	80	50	50	40	8	35	65	70
on collimator		...	...	.6	35	36	...	...	...	...	...	35	...	...	...
Duration of bombardment (hr)		0.4	0.9	..8	2.4	6.3	2.9	2.9	2.0[c]	2.9[d]	8.5	1 min[e]	3.3[e]	0.2[e,f]	3.2[e]
Radiation level recorded at meter (r/hr)	0	65	24	26	31	27	10	20	50	60	18	120	95	210	250
Δt after cutoff (min)	1	1.000	0.850[g]	0.960[g]	1.300	1.000	0.200[g]	1.200	1.250	1.600	0.450	0.670[g]	3.400	4.000	6.500
	5	0.600	0.360	0.320	0.710[g]	0.600	0.130	1.000	0.600	0.950	0.320	0.300	1.700	2.000	3.400
	10	0.360	0.270	0.220	0.420	0.450	0.100	0.900	0.440	0.650	0.280	0.200	1.100	1.150	2.500
	15	0.300	0.240	...	...	0.400	...	0.850[g]	0.380[h]	0.550	0.250	0.140	0.900[g]	0.870[h]	2.100
	20	0.260	0.210	...	...	0.370	...	0.160	...	0.520	0.240	0.120	0.640	...	1.700
	30	0.230	...	...	...	0.350	...	0.140	...	0.470	0.210	...	...	...	1.590[h,i]
	40	0.200[h]	...	...	...	0.330[h]	...	...	...	0.450[h]	0.190[h]	...	...	...	...

[a] Low-level internal beams

[b] Cool cyclotron; beam was off for 2 hr.

[c] Eleven 10-min bombardments

[d] Twenty 8-min bombardments

[e] All these bombardments on the same day in order given

[f] Machine "hot" following 3-hr deuteron bombardment

[g] Target removed after this reading

[h] Target left on cyclotron

[i] 8 hr after "beam off" radiation level was 0.400 r/hr.

Heavy-Ion Bombardments

During the last 5 years, heavy-ion experiments and bombardments have averaged 35 days per year. Most of the heavy-ion work has been with beryllium and carbon ions. The radiation background during operations is not known, but target-area radiation level should be fairly low, as the beam intensities are very low. Internal carbon beam currents are very seldom over 0.2 μa; consequently, most of the radiation emitted is from the background of the cyclotron itself. Though most of the targets are relatively cool, some uranium targets taken off the machine have radiated 500 r/hr.

Scattering Experiments

Scattering setups (on the average, ten 9-day runs per year) usually take about 6 hours and require 20 different settings for "burn" patterns on emulsion plates. The crew members receive for each a total of about 0.3 r. For this setup the normal target snout plate is replaced with an iron snout plate, an operation which takes less than 5 minutes. Collimating slits are put in the probe port, and then a pattern is taken at the iron snout plate. Adjustments, if necessary, are made on the slits. A 5-foot iron snout is then placed in position at the end of the snout plate to bring the beam beyond the magnetic field. The mounting and adjusting of this section require from about 1 to 2 hours, but the crew is in the target area for a total of less than 1 hour. The level in the target area is 0.2 r/hr during this period, and the emulsion plates emit 8.0 r/hr 2 minutes after cutoff. Further work in the target room is required, but primarily about 10 feet away in a region of 0.04 r/hr.

Developmental Work

Cyclotron experimental and developmental work is done primarily with alpha particles. Usually more time is spent in the target area than for bombardments, as the setup is more involved. During the operation, it may be necessary to try many different parameters, and sometimes this requires that adjustments be made in the target area. The radiation received by personnel during this work varies appreciably.

Maintenance

Exposure doses during cyclotron replacements are also difficult to evaluate, since they depend on the job to be done. For deflector and exit-strip removals, 0.5 r exposure is to be expected. The intensity of radiation by the exit strip averages about 10,000 r/hr, and the deflector about 500 r/hr. The deflector is removed and taken to shielded storage in less than half an hour, and the exit strip in less than 5 minutes. With these two parts removed, most of the high-radiation parts are gone. They are replaced in about the same length of time. An average of three such changes a year was made during this 5-year period.

Operations Summary

During the 5 years covered, the cyclotron operated for an average of 83% of the available time: 7% for experimental and developmental purposes, and 76% for target bombardments. In 1956 and 1957, target bombardments accounted for 84% of the available time. In 1954, the cyclotron was down for more than 3 months for remodeling (increasing the energy from 10 Mev per nucleon to 12 Mev per nucleon). This remodeling brought about a higher radiation level, as the beam currents remained the same.

From 1953 to 1956, the average exposure was 0.165 r/man/week. The highest individual exposure during these years averaged slightly more than 0.2 r/week. In 1957, the average dropped to 0.1 r/man/week, and the "high man" received 0.13 r/week average. This is of interest, because during 1957 there were more than a thousand target changes, plus the scattering setups and cyclotron maintenance, whereas in 1956 there were approximately 780 target changes, and before that an average of 500 target changes. Exposures of more than 0.3 r/week accounted for one-third of the total radiation received, and exposures of more than 0.5 r/week accounted for 15% of the total radiation. A summarization of the radiation received by the personnel during this 5-year period is shown in Table III.

Finger films show that the hands receive about ten times as much exposure as the body for target operations; i.e., setting up and dismantling. In 1954 and 1955, a blood check was taken on a number of crew members.[3] The study showed a significant increase in incidence of binucleated lymphocytes in persons exposed to ionizing radiation at levels of the order of 0.2 r/week.

There may be reasons for the decrease in radiation received during 1957. One is the experience gained by the crew members in assembling and disassembling the targets, and setting them up for the bombardments. Time is one of the most important factors in the amount of radiation received, and familiarity with the targets added to the speed of target setups and disassemblies. The average duration of target bombardment during the year, excepting scatter work, was less than 3 hours. Another reason is use of a reliable radiation meter in the cyclotron near the targets, which informs the personnel of the radiation level during and after the bombardment. This takes much of the guesswork out of the question "How long should the target cool?" Thirdly, a great help in decreasing the radiation received is the target-dismantling shield; unfortunately, however, it is not known how much of the decrease is due to this shield.

A further survey is being made of the amount of radiation received during the various stages of operation and maintenance. We believe that additional knowledge gained from the study will make it possible to lower the radiation exposure still further by using better techniques.

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[3] R. Lowry Dobson and Mary M. Chupp, Effect of Small Measured Doses of Radiation on Lymphocyte Morphology in Man, Proc. Soc. Exptl. Biol. Med., 95, 360-361 (1957).

Table III

Summary of radiation exposures received by personnel at Crocker Laboratory

Year	Men: Full Time	Men: Part Time	Total radiation rec'd by workers (r)	Average (r/man/wk)	High-man average (r/week)	Target changes	Scatter setups	H-I work (days)	Cyclotron replacements
1953	6	1	44.449	0.163	0.225	450	17	56	9
1954	7	1	42.622	0.166	0.205	420	8	38	6
1955	6	1	47.679	0.166	0.248	600	10	20	2
1956	5	3	53.415	0.163	0.187	780	11	46	5
1957	5	2	30.165	0.101	0.132	1020	9	17	2

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