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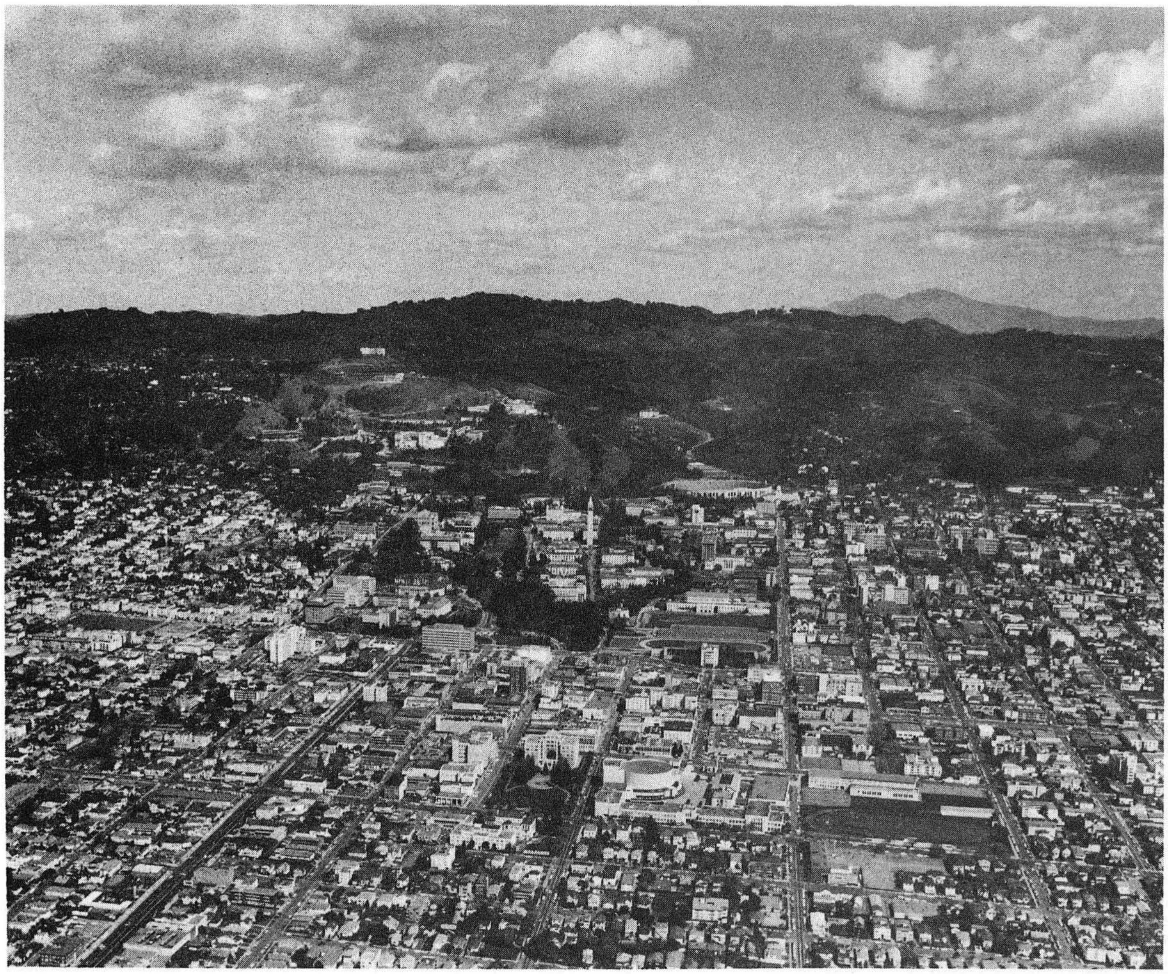

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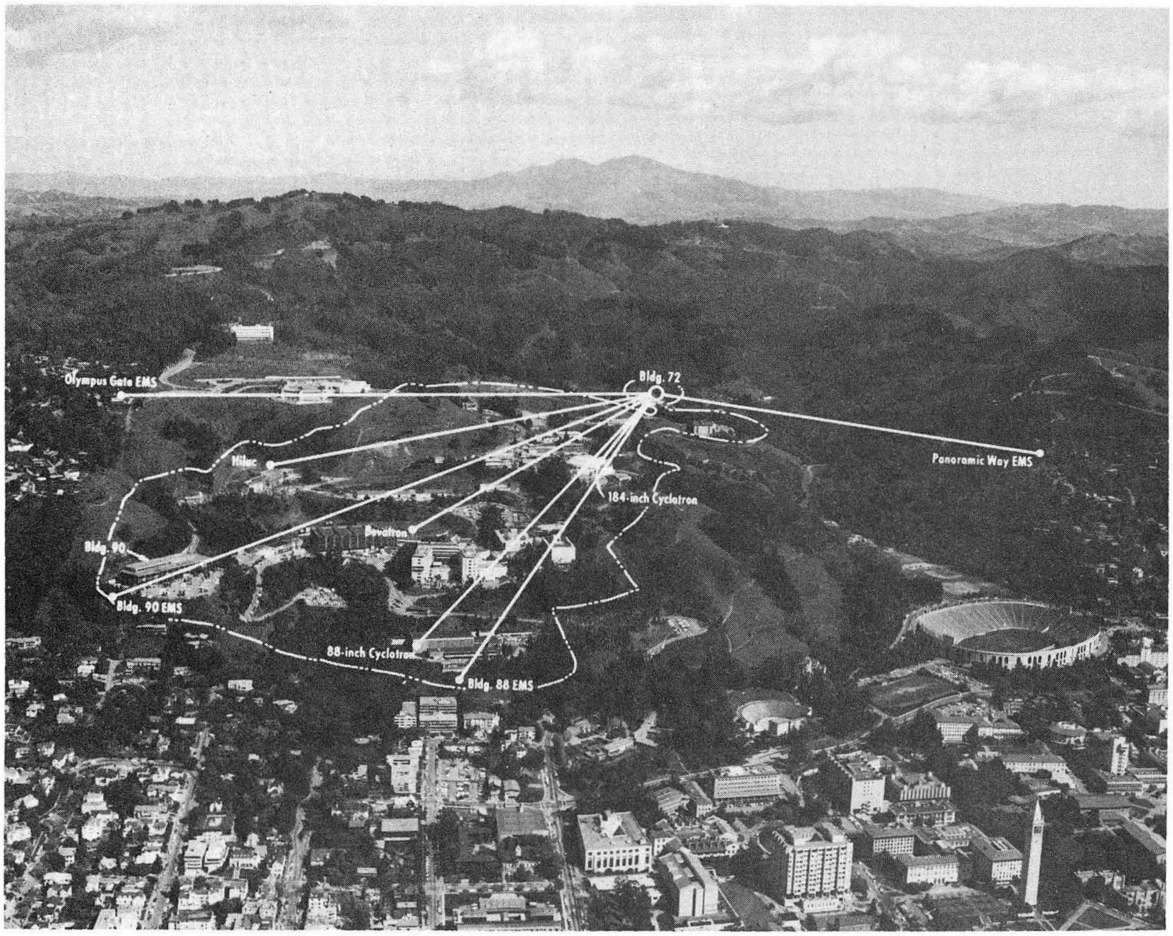
Frontispiece I: General View of the eastern half of Berkeley with the Lawrence Berkeley Laboratory site lying on the foot of the hills.



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Frontispiece II: View of the Lawrence Berkeley Laboratory and adjacent campus and city area. The fence line of the Laboratory is outlined. The location of the four Environmental Monitoring Stations and their relation to the accelerators and to Building 72, the Health Physics Building, is also shown.

ANNUAL ENVIRONMENTAL MONITORING REPORT -- 1974*

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ABSTRACT

The Lawrence Berkeley Laboratory, a large multi-disciplinary research institute, is located in the hills above the University of California and the City of Berkeley.

Nuclear Physics and Nuclear Chemistry research are the main contributors to the environmental radiation. In order to pursue this research effort, large particle accelerators have been built and are operated almost continuously. Other research may also involve the use of radioisotopes.

These research activities result in a small but finite population dose to the general population which works or resides in the area surrounding the Laboratory.

The annual maximum permissible dose equivalent (MPD) for members of the general population is recommended to be 500 mrem, however, Laboratory policy is to keep the population exposure as low as practicable at all times. In order to assure that this is done, several environmental monitoring stations are maintained which continuously telemeter radiation information to a central location. This information is presented here along with studies of the population distribution, in order to provide a total man-rem estimate. Using the data in this report the population dose due to laboratory operation ranges from 0.4% to 5.7% of the MPD.

*This work done under the auspices of the U. S. Energy Research & Development Administration.

INTRODUCTION

The Lawrence Berkeley Laboratory (LBL) of the University of California is situated between the 400 ft and 1000 ft levels on the western slope of the first range of hills parallel to the eastern side of San Francisco Bay. The Laboratory area is enclosed on the north and south sides by sparsely populated residential areas of the cities of Berkeley and Oakland. The major part of the Berkeley Campus of the University of California lies on the west side of the Laboratory. Higher up the hills to the east are the Lawrence Hall of Science and the Space Sciences Laboratory; beyond them lies uninhabited land of the Tilden Regional Park. The geographical setting is shown in the frontpieces and in Fig. 1.

A five-year[1] study of wind direction and speed collected by an anemometer located on top of Building 4 at the Laboratory gives a good indication of wind conditions to be expected. These data were averaged over one-hour periods. Table I gives the percent of time that the wind blows from various directions and speeds. These frequencies are also depicted by wind roses in Fig. 2.

This study shows that (1) no winds with a one hour average velocity greater than 27 knots were ever recorded; that (2) the most prevalent winds are westerly at 4 to 10 knots. These occur 6.5% for all hours but 15.5% from 1600 to 1900 hours. (3) The strongest winds are from the south-southeast (SSE) at 11 to 21 knots, occurring during periods of precipitation. This coincides with the cyclonic storms moving in from the Pacific during the winter rainy season. The average annual rainfall is 25 inches, almost all of which falls between November 1 and May 1.

The Laboratory carries on a wide-ranging program of general research in the fields of physical and biological sciences. Facilities include a number of large accelerators, and various physics, chemistry, biology, and medical research laboratories. The Laboratory is unique among high-energy accelerator laboratories in that it is contiguous with fairly densely populated areas.

There are four accelerators at Berkeley. Briefly, they are the 184-Inch Synchrocyclotron, used for physics studies requiring fairly large currents of protons or mesons in the energy range of 700 MeV and for biomedical studies and tumor therapy requiring alpha particles at an energy of nearly 1 GeV.

The Bevatron, a large proton synchrotron used for physics research requiring energies of up to 6.3 GeV.

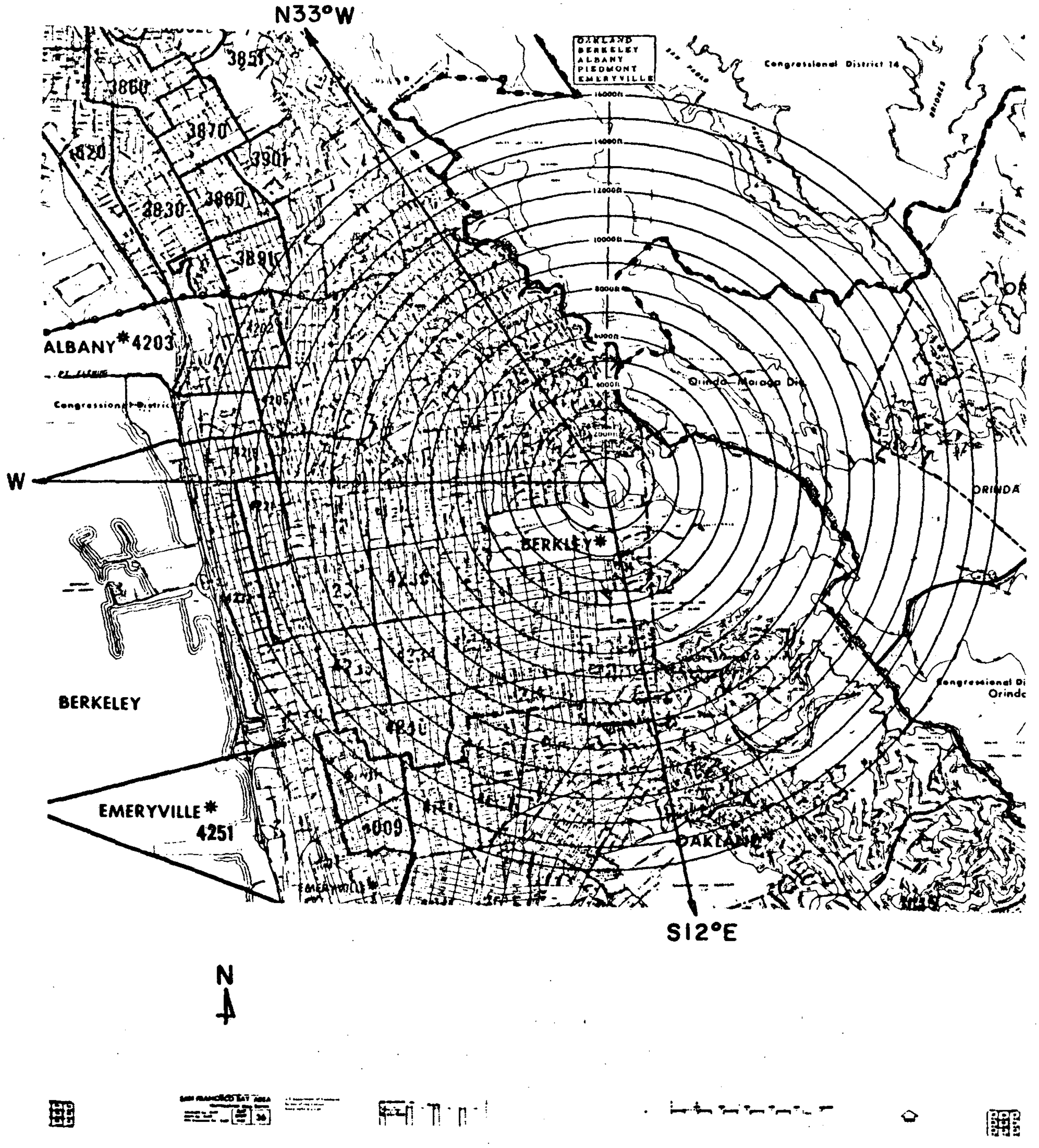

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Fig. 1. Map of the areas adjacent to the Lawrence Berkeley Laboratory. Dashed lines indicate profile cross sections as shown in Fig. 9.

TABLE I. Frequency of winds averaged over one-hour periods in percentages. Wind was calm 6.58% of time (40,705 observations taken in five-year period).

Direction	Speed (knots)				
	1-3	4-10	11-21	22-27	Over 27
N	.59	.97	.05	0.	0.
NNE	.61	.61	.01	0.	0.
NE	.89	1.10	.20	.00	0.
ENE	1.10	1.52	.59	.03	0.
E	1.97	1.68	.45	.03	0.
ESE	2.46	1.87	.17	0.	0.
SE	3.31	3.53	.39	.01	0.
SSE	3.59	4.76	1.13	.01	0.
S	3.12	4.44	.70	.01	0.
SSW	3.36	3.86	.18	0.	0.
SW	3.24	3.30	.03	0.	0.
WSW	3.17	4.28	.09	0.	0.
W	4.02	6.45	.14	0.	0.
WNW	3.65	4.86	.26	0.	0.
NW	3.33	3.19	.13	0.	0.
NNW	1.64	2.24	.08	0.	0.
Totals (all directions)	40.05	48.66	4.60	0.09	0.0

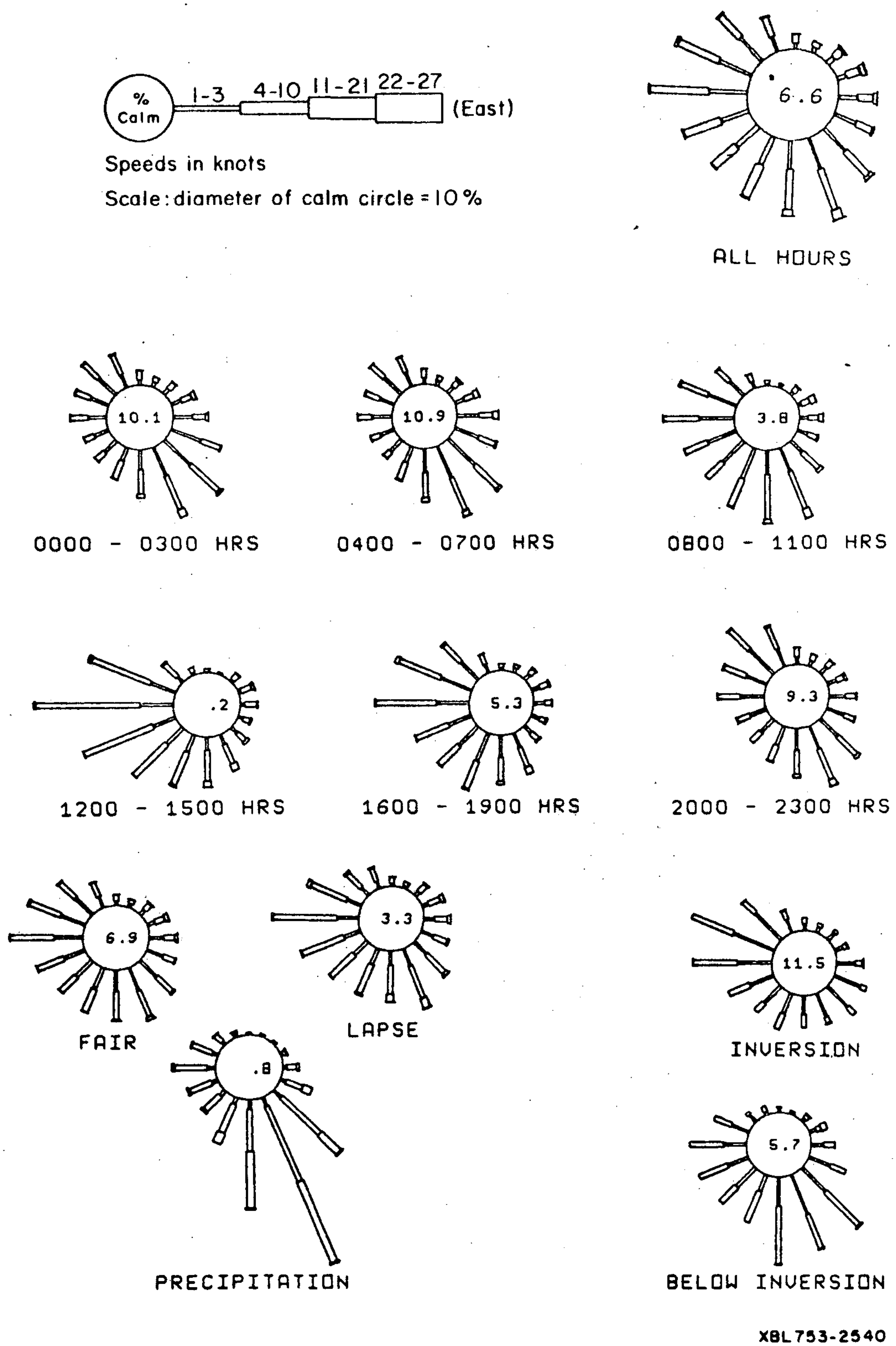

Fig. 2. Winds roses for LBL site, showing a) percent of time wind is calm (figure in circles) and, b) percent of time (relative length in diameters) wind in speed ranges given in legend is from various directions.

The SuperHILAC is a linear accelerator unique in the world, capable of ultimately accelerating all natural elements up to and including U to energies of approximately 8 MeV per nucleon or a maximum energy of nearly 2 GeV per particle. Binding forces and new transuranic element studies are carried out at this accelerator.

The Bevalac is a hybrid accelerator, using the SuperHILAC as an injector for the Bevatron. The result of this combination is an accelerator capable of producing extremely high energy heavy ions, useful for study and treatment of cancer, cell damage and many areas of nuclear physics.

Finally, the 88-Inch Sector-Focused Cyclotron completes the picture. This accelerator is capable of accelerating light to medium nuclei to fairly high energies. The machine is capable of extremely fine energy resolution and very high currents. The primary purpose is the study of nuclear structure and isotope production.

Studies of the possible environmental impact of the Laboratory may broadly be divided into the two categories of radiological and nonradiological impact. In turn, the radiological impact may be divided into two subcategories: the possible release of radionuclides to the environment and the potential gamma and neutron exposures resulting from accelerator operation. It is the exposure to accelerator-produced radiation that presents the largest potential source of population exposure. This radiation is continuously monitored around the LBL site and at four environmental monitoring stations (EMS), whose locations are shown in Figs. 3 and 4. Data obtained at these stations is telemetered back to a central location and recorded.

PART I. ISOTOPE MEASUREMENTS AND RELEASES

A study of the various paths by which radionuclides can be discharged from the Lawrence Berkeley Laboratory and measurements of the concentrations of radionuclides in these pathways allows close control at possible locations where radioactive material might be released. In addition, the background concentration of air- and water-borne activity is measured at several selected sites around the boundary of the Laboratory. These measurements and the techniques by which they are made will be briefly described in the following sections.

The use of radionuclides in the various individual research laboratories is the principal potential source of radioactive isotope pollutants. Work using

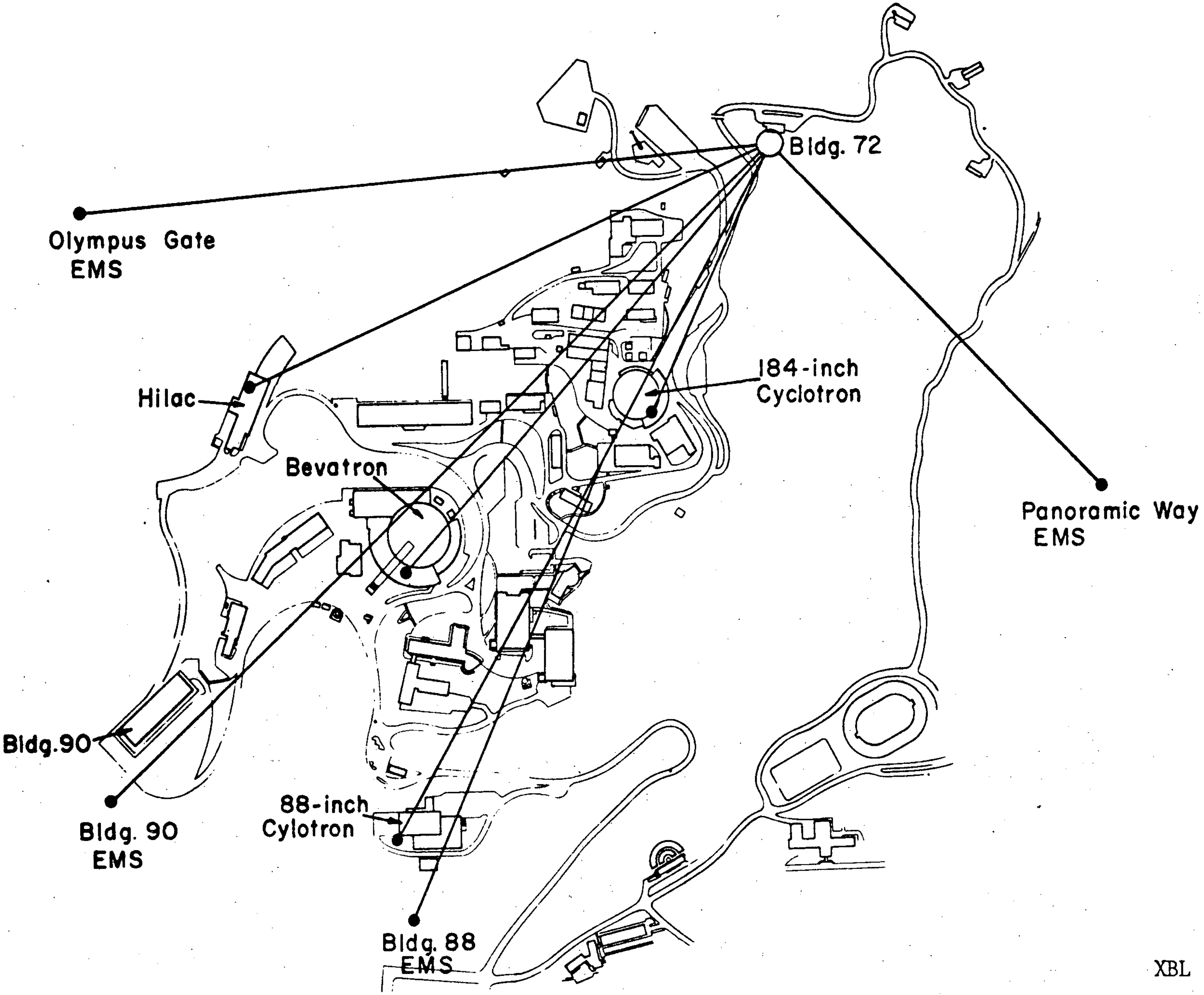

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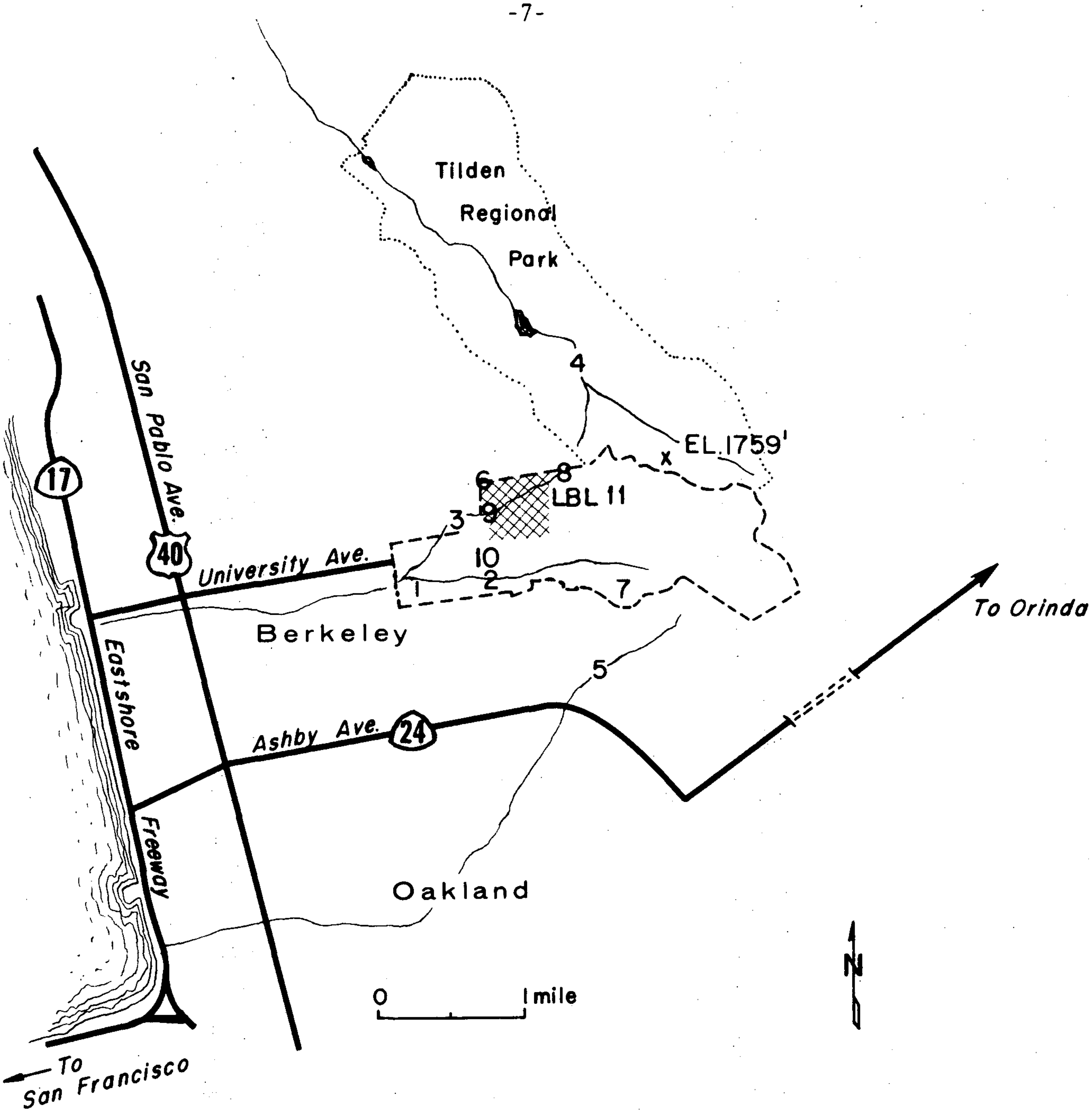
Fig. 3. Plan view of the Lawrence Berkeley Laboratory, showing the location of the four accelerators and of the four Environmental Monitoring Stations.



SURFACE WATER SAMPLING SITES

1 = Lower Strawberry
2 = Upper Strawberry
3 = Blackberry
4 = Wildcat
5 = Claremont

AIR AND ATMOSPHERIC DEPOSITION

6 = Bldg. 90
7 = Panoramic Way
8 = Olympus Gate
9 = Bldg. 88
10 = Bldg. 3
11 = Lawrence Hall of Science

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Fig. 4. Plan view of the University of California campus and the Lawrence Berkeley Laboratory, showing their relation to the cities of Berkeley and Oakland.

quantities of radioactive materials, which if released could result in a concentration greater than 1% of the radiation protection standard off site, are confined to glove boxes which exhaust through high efficiency particulate air (HEPA) filters. Every chemical laboratory room has its own locally controlled exhaust system, discharging individually into the atmosphere. Over 100 such exhaust points exist, located on a number of different buildings throughout the site, all of which are sampled and analyzed to determine the quantity of radioactive material released. During 1974, there were no releases which could result in a concentration > 1% of the appropriate radiation protection standard.

Sampling Methods: Atmospheric Sampling

Details of sampling methods and techniques of analysis are presented in Table II. Our basic policy has been to prevent, as far as possible, any release of radioactive material, no matter how small, into the environment. No deliberate releases are sanctioned, except where no practical method for containment has yet been developed and quantities are small compared with standards established by the International Commission on Radiological Protection (ICRP) and the U.S. Energy Research and Development Administration (ERDA).

From our stack sampling program we are able to determine the total quantity of radionuclides discharged to the atmosphere. Except for the volatile compounds of carbon-14 and tritium, we came close to our goal of zero release. The total quantities released are listed in Table III.

In addition to the careful sampling of stacks, an environmental air sampling program is carried on to provide a direct measurement of possible exposure to the nearby population should an accidental release occur. Results from these samples are shown in Table IV. The sampling stations designated "on-site" are outdoor locations within the site boundaries, and provide samples of the on-site atmosphere. The "perimeter" samples are taken at the boundary line of University property, in the direction of populated areas. From these samples, it is apparent that there has been no significant exposure from radioactive materials released by LBL.

Since the normal environmental air sampling will detect neither tritium nor carbon-14, special samplers are operated for these two nuclides. These samplers are located in the areas most likely to be affected, should a significant release occur. As shown in Table V, the concentrations of these two nuclides were a small fraction of the appropriate standard for uncontrolled areas.

TABLE II. Sampling methods and techniques of analysis.

Air Samples (perimeter and on-site)	Four cfm through 4" × 9" HV-70 paper. Sampling is continuous and the paper is changed weekly. 10 ml/min through silica gel and NaOH solution for HTO and $^{14}CO_2$.
Deposition Samples	Fifteen-inch diameter cylindrical container. Sample taken monthly. If there has been no rain the container is rinsed with 1 liter of water.
Sewer Samples	Both sewers have continuous automatic samplers. Assays are made weekly. Sampling rates are 10 to 20 parts per million.
Surface Water and Tap Water	1 quart "grab" samples taken weekly.
Assay Methods	*Air samples* are counted directly with a thin-window large area flow counter for alpha activity and 30 mg/cm² GM tubes for beta activity. The limit of detection for alpha emitters is 0.002 pCi/m³, and the limit for beta emitters is 0.08 pCi/m³. HTO and $^{14}CO_2$ samples are assayed by methods described in ref. 2. Detection limit: 0.7 and 0.2 nCi/m³, respectively. *Water samples* are evaporated into 2" planchets and counted for beta radiation in a low background thin-window GM flow counter and for alpha emitters in an internal-flow proportional counter. Sewer samples are run in duplicate, one being specially treated to retain halogens; the higher of the two counts is recorded. Limits of detection for these samples vary, depending on the solids content and the size of the sample assayed. Conditions are always chosen such that a concentration of 10 pCi/liter, either alpha or beta, can be detected.
Counting Efficiencies	With the "thick" samples involved, self absorption as well as absorption in counter windows is important. The counting efficiencies normally used are based on the assumption that alphas have 5.15 MeV and betas have 1 MeV.

TABLE III. Experimental Results: Total quantities discharged into the atmosphere (1974).

Nuclide(s)	Quantity Discharged
Alpha emitters	1×10^{-6} Ci
Unidentified beta-gamma emitters	1×10^{-4} Ci
Carbon-14	0.15 Ci
Tritium	30 Ci

TABLE IV. Summary of air samples (1974).

	No. of samples	Concentration, 10^{-15} μCi/ml						% of Standard	
		Alpha average	Min.	Max.	Beta-Gamma average	Min.	Max.	Alpha average	Beta average
On Site									
(Average of 10 locations)	469	0.5 ± 0.1	< 2	5	73 ± 4	< 80	340	3	0.7
Perimeter Stations									
Bldg 88 (A)	50	0.5 ± 0.3	< 2	3	76 ± 12	< 80	240	3	0.8
Bldg 90 (B)	50	0.5 ± 0.3	< 2	3	77 ± 12	< 80	300	3	0.8
Panoramic Way (C)	50	0.5 ± 0.3	< 2	4	87 ± 12	< 80	370	3	0.9
Olympus Gate (D)	43	0.5 ± 0.3	< 2	4	78 ± 13	< 80	320	3	0.8
Average	--	0.5 ± 0.2	< 2	--	80 ± 6	< 80	--	3	0.8
Standard for Comparison		20.			10,000				
AEC Appendix 0524 MPC for off-site breathing zone air									

Note: All minimum concentrations are below detectable limits for individual samples, i.e., $< 2 \times 10^{-15}$ μCi/ml for alpha and $\leqslant 80 \times 10^{-15}$ μCi/ml for beta-gamma.

TABLE V. Summary of special air sampling (1974) - samples for tritium in air (as water vapor).

	No. of Samples	Concentration 10^{-9} μCi/ml Average	Min.	Max.	% Standard
On Site					
Bldg 3 Roof	51	< 0.1	< 0.7	1	<.05
Perimeter					
Lawrence Hall of Science	51	< 0.1	< 0.7	1	<.05
Perimeter Station D	50	< 0.1	< 0.7	10	<.05
Standard for Comparison		*200*			
Samples for Carbon-14 in Air (as CO_2)					
On Site					
Bldg 3 Roof	51	.04 ±.02	< 0.2	0.2	.04
Standard for Comparison		*100*			

Note: Minimum concentrations are below detectable limits.
^{3}H detection limit = $\sim 0.7 \times 10^{-9}$ μCi/ml
^{14}C detection limit = $\sim 0.2 \times 10^{-9}$ μCi/ml

At each of the environmental stations, rain or dry "fallout" is also collected in 15-inch diameter containers. If no rain has fallen, the containers are rinsed out with water to obtain a sample. Table VI shows a summary of atmospheric deposition. There is no indication that any of this originated at LBL.

Although no radioisotopes have been detected in the environment that could be identified as originating from LBL, some releases have occurred. The significance of these small quantities released to the large population of the Bay Area has been investigated. During the course of the year, 30 Ci of tritium were released. This was the most significant isotope released, in terms of possible exposure to the public. The total dose to the entire population within a radius of 80 kilometers from the 30 curies of tritium released is estimated to be less than 0.04 man-rem. The basis for this estimate is described in Part III.

Experimental Methods: Water Sampling

All liquid waste known to be radioactive is collected, solidified, and shipped away. Other liquid wastes are discharged directly into the municipal sewer system. There are two outfalls, each of which is monitored by a continuous sampling system, to insure that no significant quantities have been discharged accidentally. The average concentrations observed for the year are shown in Table VII. The total concentration (alpha plus beta) in sewage is less than 1% of the ERDA standard for discharges to sewers.

During the year there were periods when the sewer samplers were not functioning. The Strawberry sampler was out of order 16% of the time, and the Hearst sampler was out of order 39% of the time. (A new sampler has been installed at the Hearst location in an attempt to improve this record.) The quantities discharged, as shown in Table VII, have been adjusted upward to account for the "down time".

The storm drainage from the Laboratory flows into the surface streams which discharge into San Francisco Bay. For the most part, these streams travel in underground conduits, but are exposed as they run through the University property and are sampled in three places. Results from these samples are listed as "On-Site Streams" in Table VIII. Two nearby off-site streams are also sampled to provide a comparison. All are well below the standard for drinking water. Results from samples of incoming tap water are also shown for comparison.

TABLE VI. Summary of atmospheric deposition (1974).

	No. of samples	Total Deposition, 10^{-3} $\mu Ci/m^2$			
		Alpha		Beta	
		Average	Max.	Average	Max.
On Site (8 locations)	96	.05	< .2	7.3	96 ± 0.4
Perimeter (4 locations)	47	.04	.06 ± 0.04	5.9	8.3 ± 0.3

Note: Minima not available.

TABLE VII. Summary of sewage sampling data (1974).

Total Quantities Discharged

	Total Volume 10^6 liters	Total Alpha, μCi		Total Beta, mCi	
Hearst Sewer	217	95	48	2790	130
Strawberry Sewer	203	70	41	2840	110
Total	420	165	63	5630	170

Net Concentrations

	No. of samples	Concentration, 10^{-9} μCi/ml				% of Standard	
		Alpha		Beta			
		Average	Max.	Average	Max.	Alpha Average	Beta Average
Hearst Sewer	31	0.44±0.22	3.6	12.8±0.6	147	0.1	0.4
Strawberrry Sewer	43	0.35±0.20	8.0	14.0±0.5	106	0.1	0.5
Overall Average	--	0.39±0.15	--	13.4±0.4	--	0.1	0.4
Standard for Comparison		*400*		*3000*			
AEC Appendix 0524 MPC for Sewer Discharge							

Note: Minima not available.

TABLE VIII. Surface water and tap water samples (1974).

	No. of samples	Concentration, 10^{-9} μCi/ml				% of Standard	
		Alpha		Beta			
		Average	Max.	Average	Max.	Alpha Average	Beta Average
On Site Streams							
Blackberry	51	0.24	4.2	3.0	28	0.8	3.0
Lower Strawberry	51	0.40	2.3	5.7	29	1.3	5.7
Upper Strawberry	50	0.49	5.3	3.9	29	1.6	3.9
Average	--	0.38	--	4.2	--	1.3	4.2
Off Site Streams							
Claremont	51	0.82	8.2	3.0	16	2.7	3.0
Wildcat	51	0.14	2.6	2.4	16	0.5	2.4
Average	--	0.48	--	2.7	--	1.6	2.7
Tap Water	49	0.01	0.5	1.9	15	0.03	1.9
Standard for Comparison		*30*		*100*			
(AEC Appendix 0524 MPC for off-site drinking water)							

Non-Radioactive Pollutants: Air

All stationary heating devices at LBL utilize clean burning natural gas (propane for emergency use), and there are no production processes which generate pollutants which warrant constant monitoring. Therefore, LBL does not conduct any environmental monitoring for SO_2, particulate matter, CO, hydrocarbons, photochemical oxidants, or nitrogen oxides.

A small beryllium shop is operated in the main machine shop building (77). All machines are totally enclosed and vented through high efficiency filters. Because of the rigorous controls over all aspects of this operation, the Environmental Protection Agency has granted this shop a waiver from environmental monitoring.

Non-Radioactive Pollutants: Water

All effluent from laboratory processes, cooling towers, and industrial-type processes is discharged to the municipal sanitary sewers. The regional sanitary sewer works states that there have been no problems with handling our wastes.

No wastes are discharged to the two surface streams which run through LBL property. Therefore, no sampling for non-radioactive contaminants is done.

PART II. ACCELERATOR-PRODUCED RADIATION MEASUREMENTS

Since the late 1940's extensive experience has been obtained of the radiation environments of a variety of accelerators, including the various cyclotrons, a proton synchrotron, a proton linac, electron linacs, an electron synchrotron, and a heavy ion linac. Of these, the 88-inch and 184-inch cyclotrons, the Bevatron, SuperHILAC, and Bevalac are currently in operation. A significant fraction of the present understanding of accelerator radiation phenomena directly derives from studies made at LBL.[3-5]

In monitoring accelerator-produced radiation an analytic method is used by which the various components of the radiation field are identified. The intensity and energy distribution of those particles which are present in significant quantities are then determined. From these energy spectra the dose equivalent is then calculated. Such an approach has the advantage that sufficient information is obtained to implement many aspects of a health physics program -- the anticipation and prior estimation of radiation intensities, their measurement and field estimation, and the design of shielding and operational procedures which ensure adequate safeguards but permit experimental flexibility.

The work of the group in radiation detector development and shielding measurements has been extensively described in the literature -- most recently condensed in several review articles.[6-8] From this work a general rule has emerged. Outside of high energy accelerator shielding, neutrons between 0.1 and 20 MeV usually contribute more than half the total dose equivalent. Gamma-rays and low-energy neutrons together contribute 10 - 20%, with neutrons greater than 20 MeV making up the balance. In the past few years it has become possible to measure the neutron energy spectrum, which exists outside accelerator shielding, with adequate detail for radiation protection purposes. (For a more complete description, see ref. 7.)

Method of Monitoring and Sampling

Measurements of the small contribution to the total dose equivalent, made at the Laboratory boundary by the operation of our accelerators, have been made continuously for many years. The environmental radiation monitoring system now in use at LBL makes possible continuous measurements and permanent indications of both the rate and time-integrated intensity of radiation exposure. It also provides a means for rapid determination of the relative contributions of each of the several accelerators to the total radiation environment by making use of accelerator maintenance shutdown periods during which radiation levels at remote locations are studied under different combinations of accelerator operating conditions.

The map of the LBL site, referred to previously in Fig. 3,[9] shows the locations of the four fixed monitoring and recording stations. These locations were strategically selected to monitor the radiation output of the Laboratory's accelerators, both close to each accelerator and at the Laboratory perimeter. Two environmental monitoring stations (situated at the Olympus Gate and adjacent to the 88-inch cyclotron) are specifically located to record the highest radiation levels at the Laboratory boundaries, while two others -- those at Building 90 and at Panoramic Way -- respond to skyshine from the Bevatron and the 88-inch cyclotron and to direct radiation from the 184-inch cyclotron, respectively. The signals from these stations are telemetered to our main laboratory in Building 72, as described by Stephens and Dakin.[9] Under certain operating conditions, any one of the accelerators may have a stray radiation field which can be detected as a small addition to the natural background radiation at distances as far as a few thousand feet.[10] This small increased radiation intensity at a given location and time may consist of contributions from any or all of these accelerators.

Instrumentation

At each station, gamma measurements are made by a recording GM detector. These Geiger counter detectors are used in the scaling dosimeters in order to provide sufficient sensitivity to the very low levels of radiation present. The detector assembly consists of a thin window GM tube in a stainless steel cylinder and the associated transistorized circuitry and scaler units. Each dosimeter is packaged in a metal box 6" × 6" × 9", with the GM tube assembly, 6" × 1½", mounted on top of the box. The units, while normally a.c. powered, also contain a rechargeable battery which will run the detector for approximately six weeks, in the event of an a.c. power outage. The detector and scaler unit are designed to obtain a sensitivity of one microroentgen per register integer. Beginning in 1975, these units are to be connected to the telemetering network.

The scaler dosimeters were calibrated against an NBS calibrated 1.35 milligram radium source, taking into consideration their angular variation in sensitivity. The overall sensitivity, averaged over the 4π solid angle and adjusted for variation between the dosimeters, is 1.83 microroentgens per register integer. The accuracy of this calibration probably lies between 3 and 5%.

The primary neutron detector at each station is a BF_3 gas proportional counter in a 2½-inch-thick paraffin-lined moderator. This detector is sensitive to neutrons whose energies lie in the range from 0.1 to 20 MeV.

Results of Monitoring and Sampling

In general, the response of each monitoring station is a complex function of the mode of operation of each and all of the Laboratory's accelerators. With all accelerators operating simultaneously, it is not possible, at the present time, to accurately assign the relative contributions to the radiation level at each station to particular accelerators. Without more detailed study, only approximate assignments may be made.

At each station, total radiation levels for 1974 were well below the standards set for the general public. Table IX shows the data from each station, with the background subtracted. The maximum values are less than 6% of Chapter 0524 standards. The errors shown in Table IX largely reflect errors in the

γ measurements. Figures 5 through 8 show the annual dose equivalent reported from the environmental monitoring stations since these stations were established.

Radiation levels at the Olympus Gate Station have shown a steady decline since 1959, when estimates were first made. The Olympus Gate Station is in direct view of the Bevatron and most directly influenced by that accelerator. During late 1962 and early 1963, the Bevatron underwent a substantial modification and was out of operation for a significant time. This shutdown was, however, only partially responsible for the falling radiation level recorded. This falling trend continued through 1964 and 1965, and was partly caused by the addition of shielding and improvements in accelerator operation -- particularly the development of an extracted proton beam. Radiation levels through 1966 showed an increase, due to increasing circulating proton beam intensity. The decrease observed in 1967 was caused by the installation of extra shielding to the straight sections of the Bevatron. Since 1970, radiation levels have declined, due to increasing use of the Bevatron to accelerate heavy ions, and this trend is expected to continue.

The monitoring station adjacent to the 88-inch cyclotron responds to radiation from both the Bevatron and the 88-inch cyclotron. The 88-inch cyclotron was completed in 1961 and the first external beam obtained in 1962. During the period 1962 - 1966 the radiation levels observed at this station closely reflect the operations of the Bevatron (see Figs. 5 and 6). In 1967, however, increasing intensity at the 88-inch cyclotron is reflected in the higher radiation levels recorded at this station. The addition of new shielding to the cave roofs during the latter part of 1970 resulted in a dramatic reduction in the radiation levels for 1971, and the 88-inch cyclotron is now so well shielded that its adjacent monitoring station now principally responds to the Bevatron.

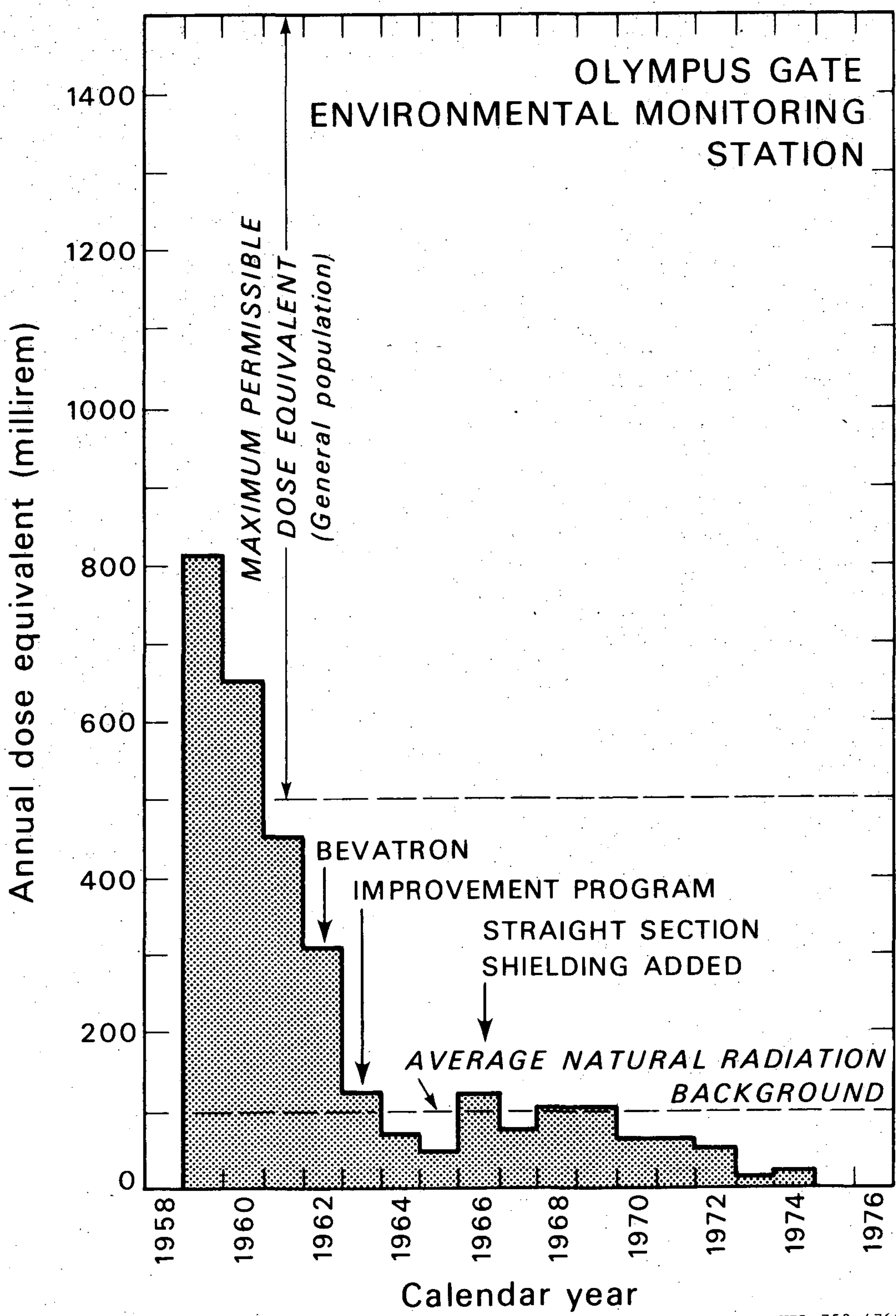
The station situated at Panoramic Way is in direct view only of the 184-inch cyclotron and responds principally to that accelerator. Elevated readings at this station may usually be directly attributed to unusual experimental conditions at the 184-inch cyclotron. Reduced use of this accelerator will result in a decline in readings at this station. The residual levels measured will be largely due to skyshine radiation from the Bevatron.

Radiation levels recorded at the Building 90 environmental monitoring station are principally due to skyshine from the Bevatron and 88-inch cyclotron (compare Figs. 5, 6 and 7).

TABLE IX. LBL site boundary levels (1974).

Location	Station	Total Beta-Gamma exposure, mrem (background subtracted) Jan - Dec.	Total Fast Neutron exposure, mrem (background subtracted) Jan - Dec.	Total Annual exposure, mrem due to LBL operation 1974
OGEMS	D	15.6	12.7	28.3^{+0}_{-10}
88 EMS	A	1.1	9.6	10.7^{+0}_{-10}
PAN EMS	C	BKG	2.2	$2.2^{+0}_{-0.7}$
90 EMS	B	BKG	5.2	$5.2^{+0}_{-1.8}$
Standard for Comparison:				*500*

Standards: 10 CFR, Part 20, Standards for Protection Against Radiation.
ICRP Publication 9, Recommendations of the International Commission on Radiation Protection (1965).
ERDA Manual, Chapter 0524.



XBL 753-4766

Fig. 5. Olympus Gate Environmental Monitoring Station annual dose equivalents.

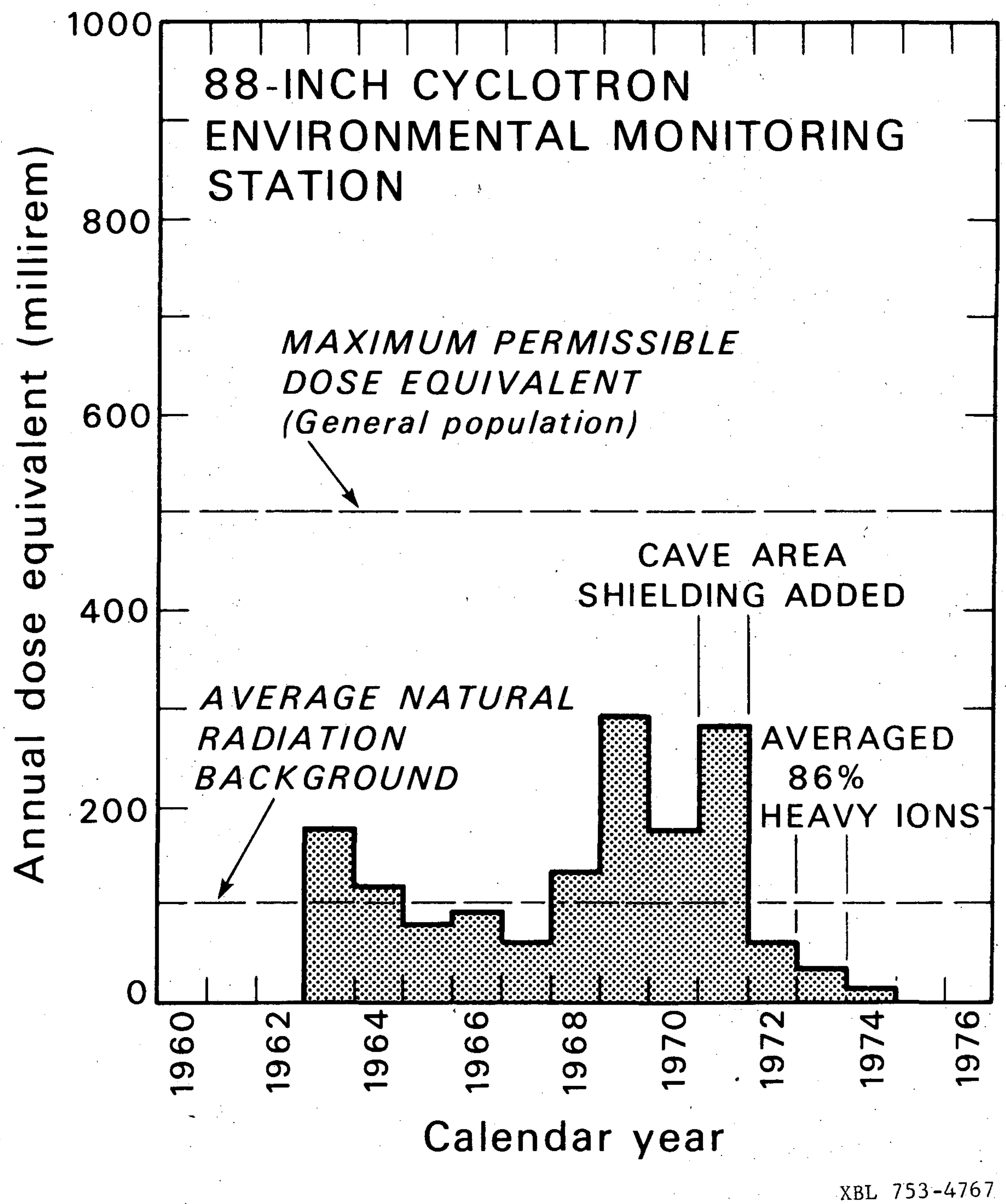
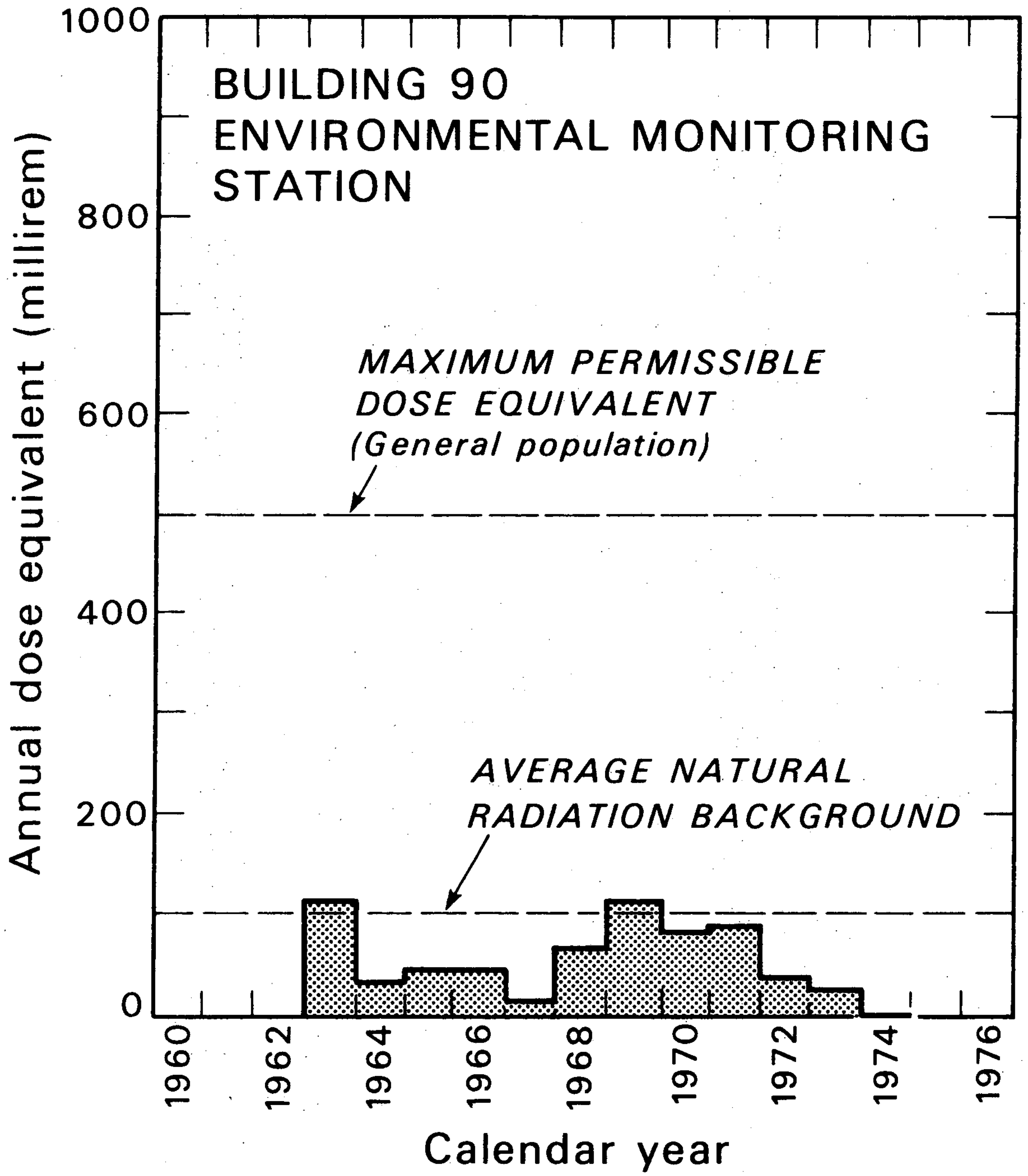
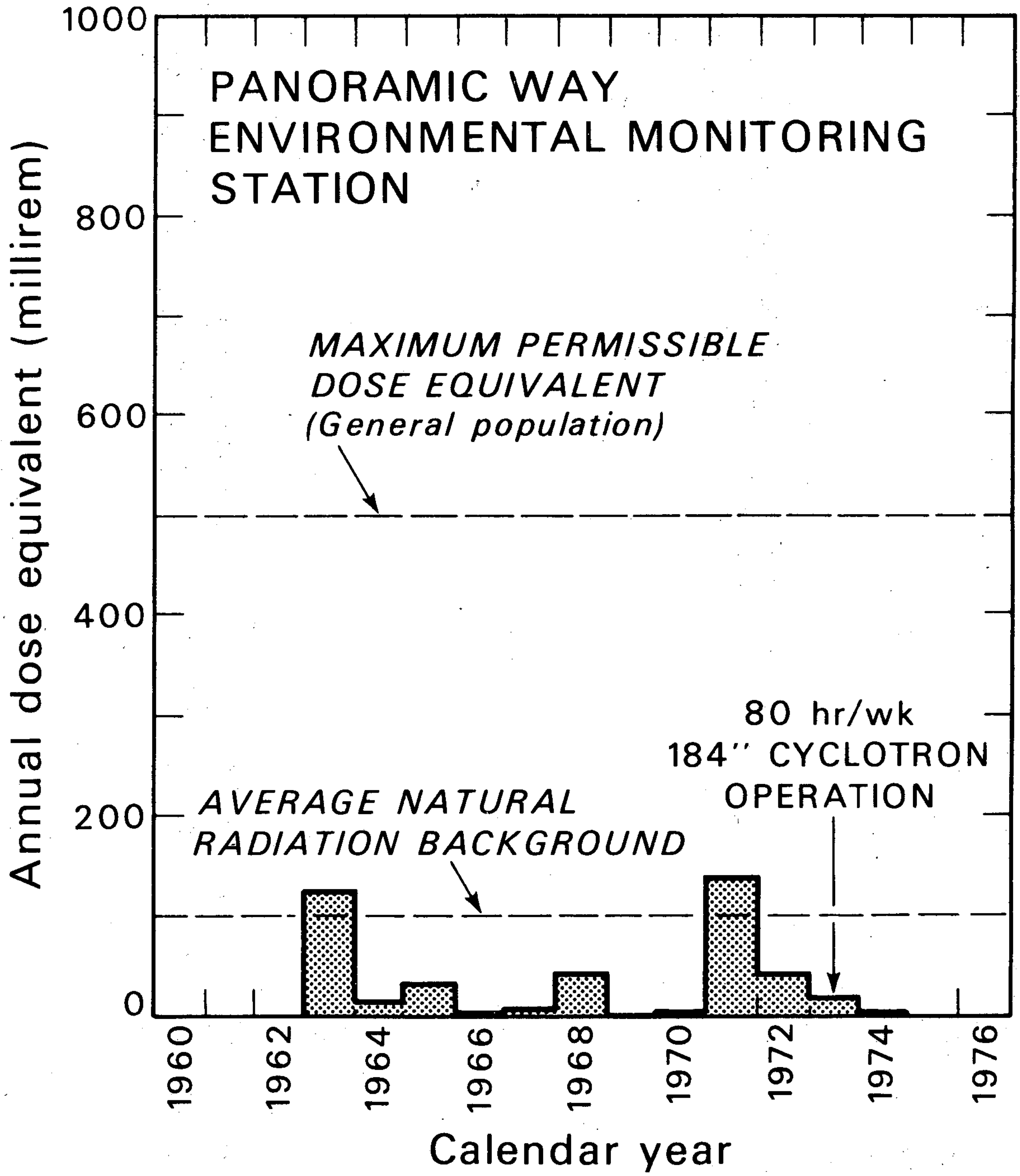


Fig. 6. 88-Inch Environmental Monitoring Station annual dose equivalents.



XBL 753-4768

Fig. 7. Building 90 Environmental Monitoring Station annual dose equivalents.



XBL 753-4769

Fig. 8. Panoramic Way Environmental Monitoring Station annual dose equivalents.

Present Radiation Levels at the Laboratory Boundary

The maximum permissible annual dose equivalent to which members of the general population, at the boundary of a laboratory such as Lawrence Berkeley Laboratory, may be exposed is 500 millirem/year. It has been Laboratory policy to place considerable effort in maintaining radiation levels well below this limit. Thus, for 1974, the highest radiation level near the LBL site boundary was reported as $28.3\,^{+0}_{-10}$ millirem or 5.6% of the radiation protection standard.

This uncertainty does not reflect the accuracy of the physical data obtained from the monitoring program -- but rather the uncertainty in converting this data to units of dose equivalent for the purposes of radiation protection. The ICRU has recognized this diffculty, and suggested that when the maximum dose equivalent is considerably less than the radiation protection standard, an uncertainty of as much as a factor of three in estimation of the dose equivalent is acceptable.[11] In the past this uncertainty in the reporting of LBL site boundary levels has been of little consequence, because we have been able to demonstrate that, even with a conservative estimate of site boundary annual dose equivalent, we were below the radiation protection standard.

The accelerator-produced component of the radiation field at the Laboratory perimeter consists of photons and neutrons. Natural background at LBL amounts to between 70 - 110 millirem/year, made up as follows:

Natural radioactivity of surrounding earth	approx. 40-80 millirem/yr [12]
Cosmic rays - μ mesons	approx. 30 millirem/yr [13]
Neutrons	approx. 4 millirem/yr [13]
Total	approx. 70-110 millirem/yr

The component due to natural radioactivity shows wide fluctuations from place to place, due both to geological and human causes, e.g., outcrop of granitic rocks, presence of large buildings, or paved roads. Furthermore, the natural γ-ray background at a particular place may show secular variation of as much as 20%, primarily due to fluctuations in the water content in the surrounding soils. An accuracy of better than 20 millirem/yr will be quite difficult to obtain.

The determination of neutron dose equivalent presents some problems. Neutrons up to an energy of 20 MeV may be readily measured with a moderated BF_3 counter, and the neutron fluences at the site boundary in this energy region may be determined with good accuracy. Conversion of this fluence to dose equivalent is, however, a more difficult matter.

The evaluation of dose equivalent consists of two steps: a physical measurement capable of good accuracy, and the conversion of this physical measurement to units appropriate to radiation protection. This is limited by a general lack of knowledge in radiobiology. The assignment of the appropriate conversion factor is, to some extent, an arbitrary matter. It is, in essence, an administrative judgment. The problem is compounded by the fact that the accelerator-produced neutrons are distributed over a wide range of energy, and neutrons greater than 20 MeV in energy may make a significant contribution to the dose equivalent.

Although the ICRP have published fluence to dose equivalent conversion factors for monoenergetic neutrons,[14] there is no official guidance as to how such factors should be used for neutrons distributed in a continuous energy spectrum. The relative numbers of high energy (greater than 20 MeV) to low energy neutrons in a spectrum can greatly influence the biological potency of the overall neutron fluence. For example, the biological potency of neutrons in a cosmic ray spectrum is lower than that of neutrons emerging from the shielding of the Bevatron, by a factor of 1.5.[15]

For neutron spectra, the dose equivalent at the maximum of the dose equivalent-depth distribution in the body should be used to calculate fluence-dose equivalent conversion factors.[16,17] Shaw et al[16] have reported calculations of the conversion factors for a variety of spectra, both for unilateral and multilateral irradiation. Table X summarizes these values and compares them with conversion factors routinely used at LBL at the present time. It shows that there are substantial differences between the conversion factors for multilateral irradiation (which is the most reasonable assumption as to radiation conditions beyond the Laboratory boundaries) and those in routine use at LBL.

Beginning in 1973, it seemed to be a better policy to report site boundary levels, based on our best estimate of the actual conversion factors. This had the effect of reducing the reported neutron contribution of dose equivalent by a factor of 1.7 to 2.5.

TABLE X. Dose equivalent per unit fluence for cosmic ray and Bevatron neutron spectra.

Neutron Spectrum	Shaw et al [Unilateral Irradiation] (rem n^{-1} cm^2)	Shaw et al [Multilateral Irradiation] (rem n^{-1} cm^2)	LBL (rem n^{-1} cm^2)
Cosmic ray (Hess et al)[31]	2.0×10^{-8}	1.3×10^{-8}	2.3×10^{-8}
Bevatron	2.3×10^{-8}	1.9×10^{-8}	3.2×10^{-8}

PART III. MAN-REM EXPOSURE TO THE SURROUNDING COMMUNITY

The radiation exposure to the surrounding community, due to the radiation released by the Lawrence Berkeley Laboratory, is in two categories: first, the occasional release of tritium, and second, the neutrons and gamma rays. Because these two types of radiation are so different, the population dose estimates are calculated separately.

Distribution of Population Around the Lawrence Berkeley Laboratory

Thomas[22] has studied the distribution of population around the Lawrence Berkeley Laboratory, using the U.S.Department of Commerce 1970 census data[23] and Campus statistics for the University of California Berkeley Campus for 1972/73.[24] Figure 1 shows the regions investigated. Concentric circles at 1000 ft intervals were drawn around the Laboratory, between 1000 ft to 16,000 ft from the Bevatron. The residential population within each ring was obtained by summing the census data of the blocks located inside each circle. Table XI summarizes the data so obtained.

The Campus of the University of California at Berkeley is a special case, since its occupancy is not continuous. An estimate of the total time spent on campus by students is difficult in that non-instructional hours can vary randomly with each student. Stephens and Thomas[25] estimated the average student to spend 780 hrs/yr on the Berkeley campus (based on the assumption that students are on campus 4 hrs/day, 5 days/week for 39 weeks/year). Campus statistics for the University of California at Berkeley[24] show that a full-time-equivalent (FTE) student spends 450 hrs/yr in classroom instruction, but this will give a lower limit to the time spent on campus. An upper limit on campus attendance may be obtained from the University Catalogue which gives an FTE student as one that takes 36 units/year, each requiring 30 hours of instruction and preparation (3 hrs/wk, 10 wk/quarter), giving a total of 1080 hrs/yr. Estimates of campus attendance for the average student may therefore range between 450 and 1080 hrs/yr, with an average of 765 hrs/yr, which is close to the estimate of 780 hrs/yr given by Stephens and Thomas.[25] The value of 765 hrs/yr has been used in the data of Table XI in calculating the number of full time equivalent residents (FTER) on the University campus. In a 1973 report[26] on "Administration, Academic and Staff Personnel Headcount", the total FTE Berkeley staff numbered 9,809. Assuming a full time employee works 40 hrs/wk for 46 weeks, staff and faculty contribute 2,059 FTER. From the residential population data and the estimates of University

TABLE XI. Distribution of population around the Lawrence Berkeley Laboratory.

Distance (ft) from - to	Residential Population (census data)	Average UC Berkeley FTER*	Total Population
1,200 - 2,000	1,449		1,449
2,000 - 3,000	2,715	1,610	4,325
3,000 - 4,000	4,627	1,894	6,521
4,000 - 5,000	6,570	1,231	7,801
5,000 - 6,000	9,568		9,568
6,000 - 7,000	8,275		8,275
7,000 - 8,000	12,857		12,857
8,000 - 9,000	13,200		13,200
9,000 - 10,000	11,859		11,859
10,000 - 11,000	13,671		13,671
11,000 - 12,000	14,654		14,654
12,000 - 13,000	16,423		16,423
13,000 - 14,000	17,751		17,751
14,000 - 15,000	15,559		15,559
15,000 - 16,000	14,150		14,150
		Grand Total	167,973

*Full Time Equivalent Resident

campus full time equivalent residents, the average population density in each ring shown on Fig. 1 may be calculated.

The use of these estimates of total population or population density in calculating population dose equivalent will give conservative (high) values for the following reasons:

a. Many students and staff members of the University of California, Berkeley, live close to the campus. They will therefore be counted twice in this estimate.

b. The daily migration of population to work places, stores, schools, etc. tends to be away from the Laboratory. Thus, for a significant fraction of the day the total residential population close to the Laboratory will be lower than that given in Table XI.

Estimates of Man-Rem, Due to the Release of Tritium

Three separate estimates have been made for the population dose equivalent due to the ^{3}H release. The first calculation uses conventional atmospheric dispersion formulae assuming typical weather conditions. This calculation tends to minimize the total man-rem estimate but is probably the best estimate. The second estimate assumes a special weather type which occurs 3% of the time. This value is intermediate in terms of man-rem but is certainly less likely to occur since it requires that the release occurs during the 3% of the time assumed for this weather type.

The third is a direct calculation, using observed results from a sampler operated at the nearest occupied area, the Lawrence Hall of Science (LHS).

1. The conventional expression for integrated crosswind concentration[18] has been used. The average atmospheric condition "Type C" (slightly unstable) has been assumed and an average wind speed of 3 knots used, as suggested by our Wind Data Summary.[1] The population distribution[19] is shown in Table XI and was extrapolated to a distance of 80 kilometers. To simplify the calculation, it was assumed that the angular distribution of both population and wind direction is uniform. This is not strictly true, but because the general wind flow is over an unpopulated region, no serious error will result. This calculation indicates an integrated population dose-equivalent out to 80 kilometers of 10^{-2} man-rem.

2. Occasionally the Bay Area has episodes of stagnant air, when there is little ventilation, and pollutants are trapped by surrounding hills. From data in ref. 1, it appears that about 12 days a year the base of the inversion is below the tops of the surrounding hills, but above the Laboratory, and the wind speed is less than or equal to 3 knots. Assuming that during these times the tritium released is trapped in a total volume of 4.3×10^{12} m^3, the total dose to the approximately 4×10^6 people in the area would be 3×10^{-2} man-rem.

3. The nearest occasionally inhabited downwind area is the Lawrence Hall of Science. A sampler was operated there during the year and no tritium was detected. The limit of sensitivity is 0.05% of the standard (0.5 rem per year). The average occupancy of the building is 104 people. Thus, the total dose contributed in this location was less than 3×10^{-2} man-rem, and therefore, the population dose equivalent resulting from the release of radionuclides is estimated to be between 10^{-2} and 3×10^{-2} man-rem. The population dose from ^{14}C is estimated to be at least one order at magnitude less than that from the ^3H released.

Estimate of Man-Rem Due to Accelerator Operation

The population dose equivalent, M, is defined by the equation:[20]

$$M = \int H\, N(H)\, dH \qquad (1)$$

where $N(H)dH$ is the number of people receiving a dose equivalent between H and $H + dH$.

In a homogeneous urban area it is plausible that the population density at a given location may be considered constant when averaged over long periods of time.[21] This should not result in serious error in the estimate of population exposure, provided the intensity of accelerator operation is uncorrelated with fluctuations in population (e.g., high intensity operation is not restricted to times of known low population). If this assumption is made, equation (1) may be simplified to

$$M = \int_{r_0}^{R} H(r)\, N(r)\, dr \qquad (2)$$

where $H(r)$ is the annual dose equivalent to a person at a distance from r to $r + dr$ from the accelerator. The closest and farthest distances of approach to the accelerator are r_0 and R respectively. r_0 will correspond to the distance of the Laboratory boundary from the source of radiation. It is conventional to estimate population dose equivalent out to a distance of 80 kilometers from the facility.

Evaluation of the integral of equation (2) requires estimates of the distribution of population, N(r), and the variation of dose equivalent, H(r), with distance from the Laboratory.

Variation of Dose Equivalent with Distance from the Lawrence Berkeley Laboratory

Rindi and Thomas[27] have reviewed measurements of the variation of dose equivalent with distance made at many particle accelerators. Experimental data is limited to distances less than 1500 meters from an accelerator, but at all accelerators the dose equivalent beyond 300 meters falls faster than inversely, as the square of the distance from the accelerator. These authors conclude from the data that, in direct line of sight of shielded accelerators, the dose equivalent beyond 300 meters is probably best expressed in the empirical form:

$$H(r) = a \frac{e^{-r/\lambda}}{r^2} \qquad r \geqslant 300 \text{ meters} \qquad (3)$$

The parameter $e^{-r/\lambda}$ is attributed to air attenuation and λ may take the values between 225 meters and 850 meters. For accelerators capable of producing neutrons of energy greater than about 100 MeV, such as the 184-inch cyclotron and Bevatron, the higher value of λ should be used. Accelerators such as the SuperHILAC and 88-inch cyclotron do not produce neutrons greater than about 50 MeV in energy and, in this case, λ has a value of $\sim$ 250 meters.

Calculation of Population Dose Equivalent

Substitution of equation (3) into the expression for population dose equivalent gives

$$M = a \int_{r_0}^{R} N(r) \frac{e^{-r/\lambda}}{r^2} \, dr \qquad (4)$$

where a has to be determined.

If the dose equivalent at distance r_0 from the Bevatron is H_0, substitution into equation (3) gives

$$a = r_0^2 \; H_0 \; e^{r_0/\lambda} \qquad (5)$$

and equation (4) becomes

$$M = r_0^2 \; H_0 \; e^{r_0/\lambda} \int_{r_0}^{R} \frac{N(r) \; e^{-r/\lambda}}{r^2} \cdot dr \qquad (6)$$

Stephens and Dakin[28] have described the environmental monitoring program of the Laboratory. Since 1964, radiation levels have been continuously measured at locations which were strategically selected to monitor the radiation output of the Laboratory's accelerators, both close to each accelerator and at the Laboratory perimeter. From these measurements the dose equivalent at the Laboratory's perimeter (the "fence post" dose) may be determined.

Equation (6) does not take into account the shielding from the Laboratory of a large fraction of the populated area by the hills surrounding the Laboratory or by the buildings which they occupy, equation (6) can be written

$$M = \frac{r_0^2 \; H_0 \; e^{r_0/\lambda}}{S_1 \; S_2} \int_{r_0}^{R} \frac{N(r) \; e^{-r/\lambda}}{r^2} \cdot dr \qquad (7)$$

where S_1 and S_2 are shielding factors which take into account the shielding provided by hills and buildings, respectively. Only approximate estimates may be made for S_1 and S_2. Figure 9 shows three topographical profiles drawn in different directions from the Laboratory. The Bevatron sits in a basin shielded from almost the entire urban area surrounding the Laboratory. Experimental data obtained by McCaslin[29] suggest that radiation levels are depressed by a factor of almost two when hills intervene (see Appendix). From this preliminary data $S_1 \approx 1.8$.

Thomas[30] has estimated the shielding factor for buildings to be ~ 1.2 for the residential population and students and staff of the University campus. This estimate is based on an assumed occupancy factor of 0.8 and the known types of buildings adjacent to the Laboratory. Thus, the product S_1S_2 has the value 2.2.

In our earlier paper[21] a uniform population density was assumed in estimating the population dose equivalent which limited the accuracy of the estimate. A more accurate value may be obtained by writing:

$$M = \frac{2\pi \; r_0^2 \; H_0 \; e^{r_0/\lambda}}{S_1 \; S_2} \int_{r_0}^{R} \frac{\sigma(r) \; e^{-r/\lambda}}{r} \; dr \qquad (8)$$

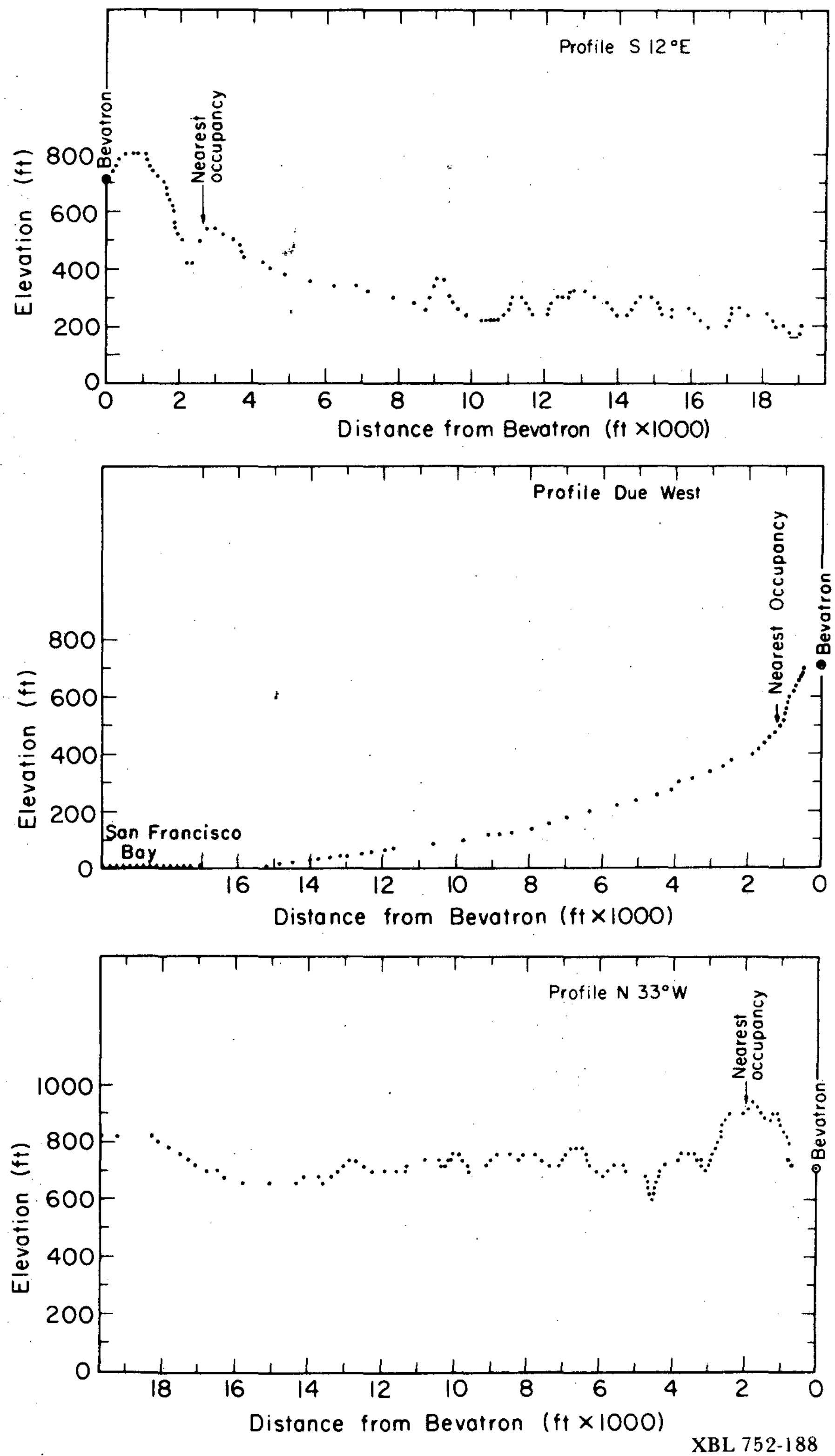


Fig. 9. Terrain profiles from the Bevatron out to a distance of 19,000 feet (see Fig. 1).

The integral of equation (8) may numerically be evaluated by assuming a uniform distribution of population within each ring drawn around the Laboratory (Fig. 1). M may then be approximated by:

$$M \quad \frac{2\pi \; r_0^2 \; H_0 \; e^{r_0/\lambda}}{S_1 \; S_2} \sum_{i=1}^{i=n} \sigma_i \int_{r_{i-1}}^{r_i} \frac{e^{-r/\lambda}}{r} \, dr \quad . \tag{9}$$

where σ_i is defined by:

$$\sigma_i = \frac{N_i}{\pi(r_i^2 - r_{i-1}^2)} \tag{10}$$

Values of σ_i are given in Table XI.

The number of annuli, n, is determined by the convergence of the integral in equation (9). Population dose equivalent resulting from the operation of a nuclear installation is a scalar quantity, independent of distance from the installation, and should therefore be calculated out to infinity.

If we write

$$M(r') = \frac{2\pi \, H_0 \, e^{r_0/\lambda}}{S_1 \; S_2} \int_{r_0}^{r'} \frac{\sigma(r) \; e^{-r/\lambda}}{r} \, dr \tag{9a}$$

in general:

$$M(r') \rightarrow M \quad \text{as} \quad r' \rightarrow R$$

It is conventional to assume that $M(r')$ has reached its convergent value, M, at a distance of 80 kilometers from the installation.

In the case of high energy accelerator operation at LBL, however, the integral of equation (7) rapidly converges[21] and it is necessary to extend integration out to a distance of about 5 km from the Laboratory (see Fig. 10). In the evaluation of the integral, the following values were used:

$$n = .15$$

$$r_0 = 366 \text{ meters (1200 ft)}$$

$$r_1 - r_0 = 244 \text{ meters (800 ft)}$$

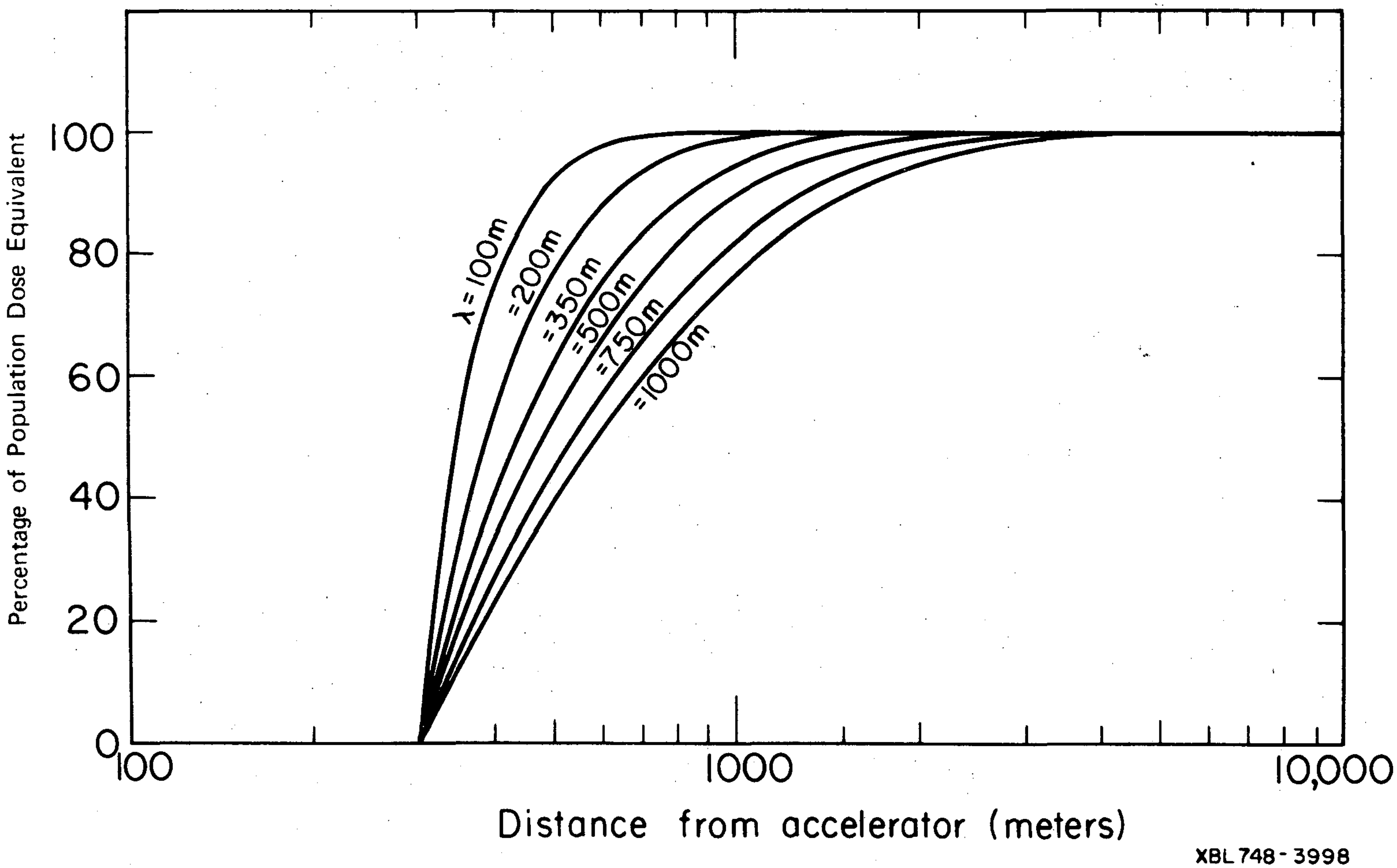


Fig. 10. Graphical representation of the convergence of accelerator produced radiation. λ values of 100 to 1000 meters are shown.

$$r_i - r_{i-1} = 304.8 \text{ meters (1000 ft) for } r \geqslant 2$$

$$r_{15} = 4{,}877 \text{ meters (16,000 ft)}$$

$$\lambda = 850 \text{ meters}$$

$$S_1 \; S_2 = 2.2 \quad .$$

Substituting into equation (11) we obtain:

$$M/H_0 = 5.875 \times 10^5 \sum_{i=1}^{15} \sigma_i \int_{r_{i-1}}^{r_i} \frac{e^{-r/850}}{r} \, dr \quad . \tag{11}$$

with r in meters, and σ_i in persons/m^2.

Values of the integrands of equation (13) were obtained by numerical integration and are summarized in Table XII. The population dose equivalent due to LBL accelerator operation calculated using this model is then:

$$M/H_0 \approx 1023 \text{ man rem/fence post rem} \quad .$$

In practice, this value will give an upper limit to the population dose equivalent because:

a. The population density estimates used in the calculation are conservative (Section III).

b. The value of population dose equivalent depends strongly upon the value of λ assumed. In the calculations presented here, a value of $\lambda = 850$ meters has been used. This value is appropriate for that component of the fence post dose equivalent contributed by the Bevatron and 184-inch cyclotron. The contribution of the SuperHILAC and 88-inch cyclotrons to the population dose will overestimate in the ratio $\approx (850/250)^{2/3}$, [21] or a little more than a factor of two. If these two accelerators contribute a proportion, f, of the minimum fence post dose equivalent, the population dose equivalent is then more accurately written:

$$M = 1000 \; H_0 \left[(1 - f) + \left(\frac{250}{850}\right)^{2/3} f \right]$$

$$= 1000 \; H_0 \; [1 - 0.56 \; f]$$

TABLE XII.

Distance (meters) From	To	σ_i (persons/m^2)	I_i*	M_i/H_0 Man rem/ fence post rem
366 (1,200 ft)	610 (2,000 ft)	$\sigma_1 = 1.94\times10^{-3}$	2.938×10^{-1}	341.1
610 (2,000 ft)	914 (3,000 ft)	$\sigma_2 = 2.96\times10^{-3}$	1.690×10^{-1}	299.2
914 (3,000 ft)	1219 (4,000 ft)	$\sigma_3 = 3.19\times10^{-3}$	8.343×10^{-2}	159.2
1219 (4,000 ft)	1524 (5,000 ft)	$\sigma_4 = 2.97\times10^{-3}$	4.511×10^{-2}	80.2
1524 (5,000 ft)	1829 (6,000 ft)	$\sigma_5 = 2.98\times10^{-3}$	2.571×10^{-2}	45.8
1829 (6,000 ft)	2134 (7,000 ft)	$\sigma_6 = 2.18\times10^{-3}$	1.5174×10^{-2}	19.8
2134 (7,000 ft)	2438 (8,000 ft)	$\sigma_7 = 2.94\times10^{-3}$	9.177×10^{-3}	16.1
2438 (8,000 ft)	2743 (9,000 ft)	$\sigma_8 = 2.66\times10^{-3}$	5.652×10^{-3}	9.0
2743 (9,000 ft)	3048 (10,000ft)	$\sigma_9 = 2.14\times10^{-3}$	3.531×10^{-3}	4.5
3048 (10,000ft)	3353 (11,000ft)	$\sigma_{10} = 2.23\times10^{-3}$	2.2309×10^{-3}	3.0
3353 (11,000ft)	3656 (12,000ft)	$\sigma_{11} = 2.17\times10^{-3}$	1.422×10^{-3}	1.8
3656 (12,000ft)	3962 (13,000ft)	$\sigma_{12} = 2.25\times10^{-3}$	9.141×10^{-4}	1.2
3962 (13,000ft)	4267 (14,000ft)	$\sigma_{13} = 2.25\times10^{-3}$	5.911×10^{-4}	0.8
4267 (14,000ft)	4572 (15,000ft)	$\sigma_{14} = 1.84\times10^{-3}$	3.844×10^{-4}	0.4
4572 (15,000ft)	4877 (16,000ft)	$\sigma_{15} = 1.56\times10^{-3}$	2.512×10^{-4}	0.2

$$^{*}I_i = \int_{r_{i-1}}^{r_i} \frac{e^{-r/850}}{r}\, dr \; .$$

c. In calculating M the maximum value of H_0 is used. At the present time there are considerable uncertainties in the evaluation of the γ-component of the fence post dose equivalent -- principally caused by uncertainties in the intensity of natural background to better than 20 millirem/year.[30] This uncertainty is comparable to the annual fence post dose equivalent itself.

For these reasons we feel justified in expressing the population dose equivalent due to high energy accelerator operation at LBL as:

$$M/H_0 < 1000 \text{ man-rem/fence post rem} \quad .$$

Total Population Dose Equivalent Due to All Laboratory Operations

We can combine the accelerator-produced component of the environmental radiation with the radionuclide produced dose equivalent to get a total population dose equivalent.

Using an average of the site boundary dose equivalents from the four environmental monitoring stations, Table IX, 11.6 mrem, the population dose equivalent would be < 11.6 man-rem. To this we add the average radionuclide dose equivalent of 0.027 man-rem for the total population dose equivalent of 11.627 man-rem.

The upper and lower limits of this estimate would be 28.34 man-rem and 2.21 man-rem, respectively.

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APPENDIX I

Influence of Hills on the Radiation Level Around LBL

Three environmental monitoring stations at the Laboratory are approximately 400 meters from the Bevatron. Only the first of these stations is in direct view of the Bevatron. Table A1 summarizes average flux densities measured at these three stations during a period in which only the Bevatron was operating (McCaslin[29]).

TABLE A1

Environmental station	Distance from Bevatron (meters)	Observed average neutron flux density* ($n\ cm^{-2}\ sec^{-1}$)	Flux density normalized to 435 meters ($n\ cm^{-2}\ sec^{-1}$)
1	435	0.106	0.106
2	421	0.063	0.058
3	385	0.080	0.059

*Normalized to an external proton beam intensity of 10^{12} ppp.

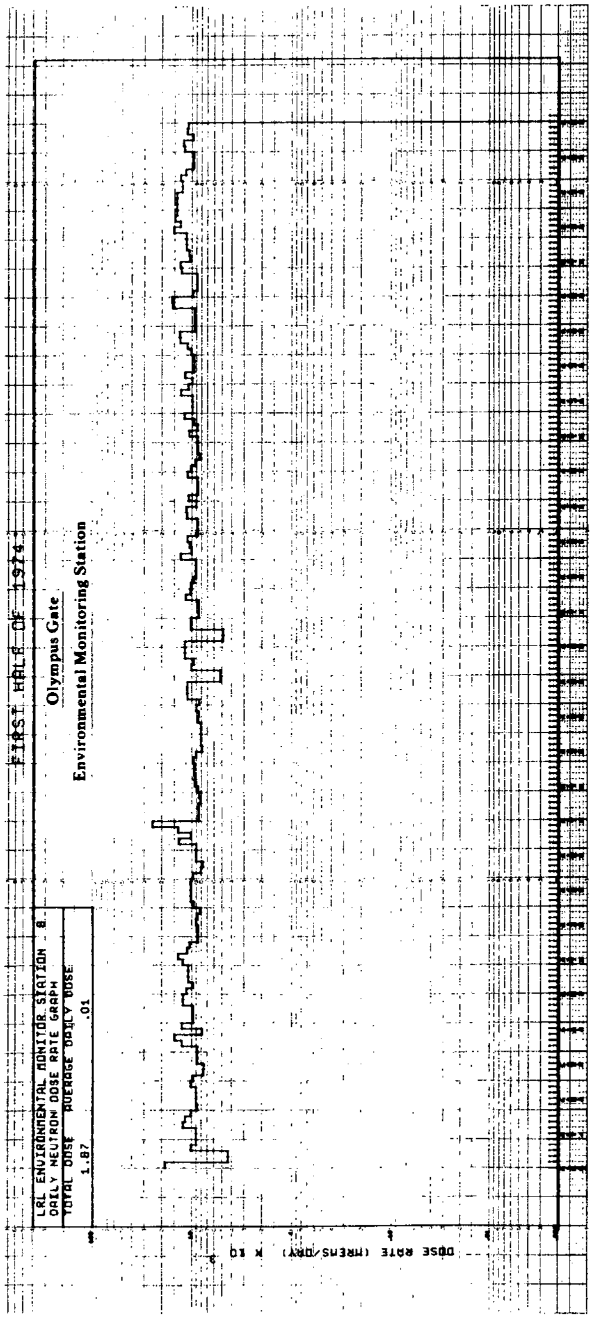
Column 4 shows the flux densities that would have been observed if all stations had been 435 meters from the Bevatron, assuming the flux density to vary with distance as:

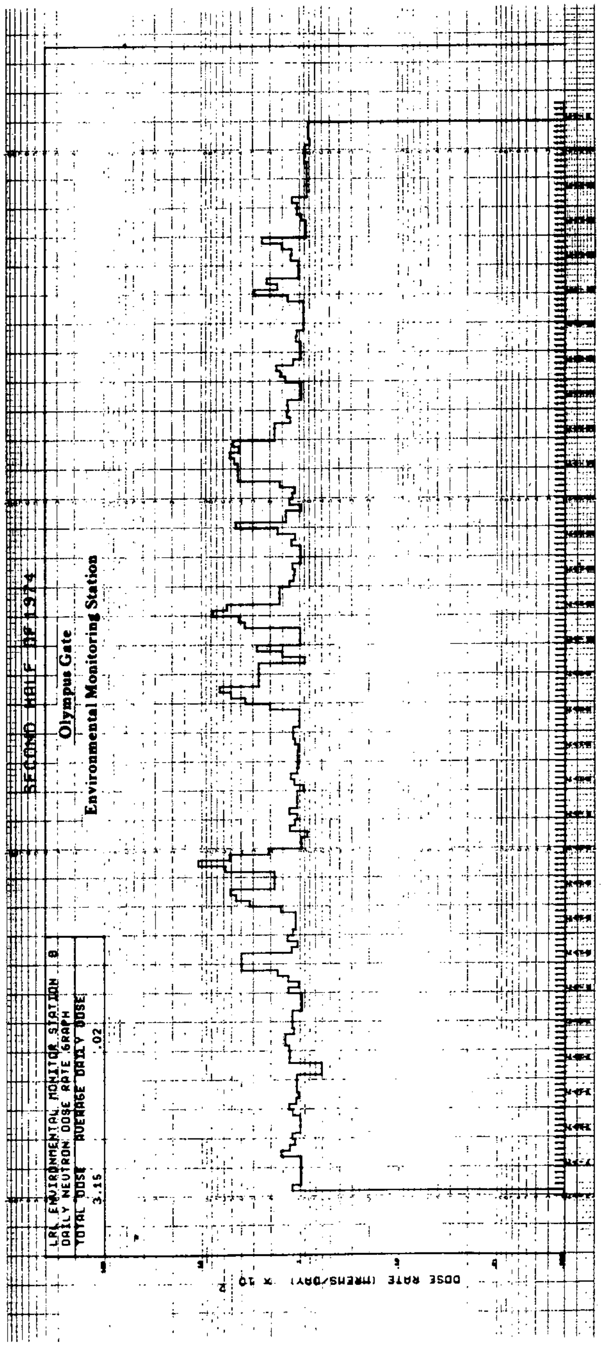
$$\phi(r) \approx e^{-r/\lambda} / r^2$$

with λ taken to be 850 meters. The flux density is depressed by a factor of $\sim$ 1.8 by the presence of hills.

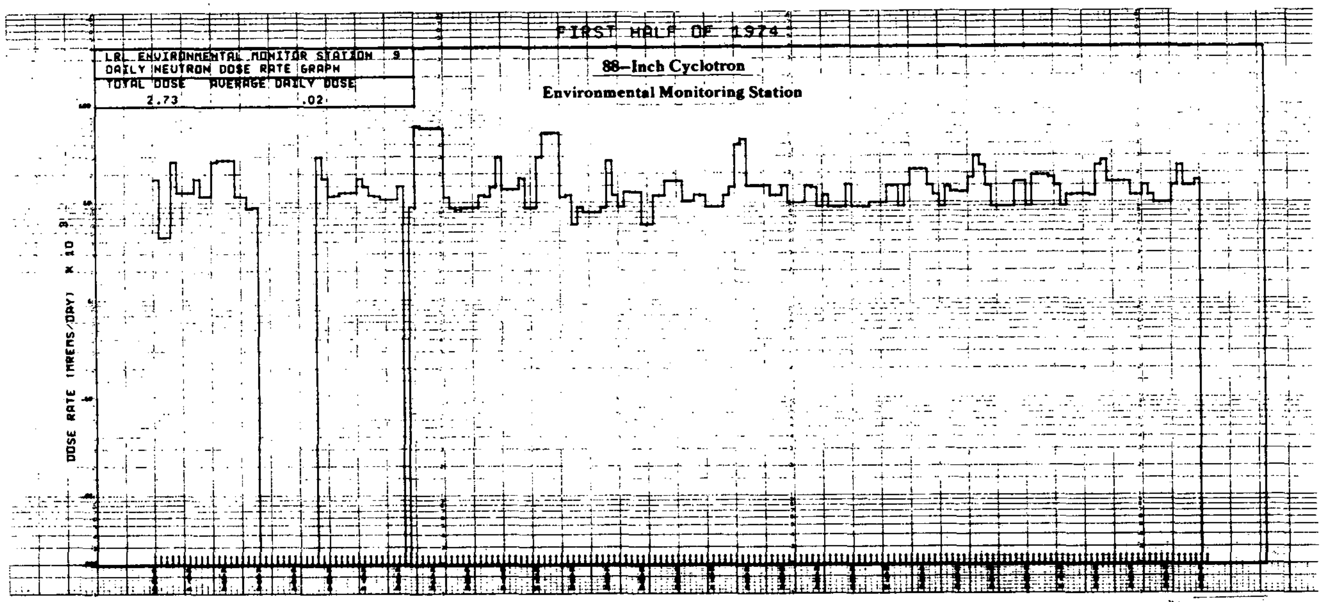
APPENDIX II

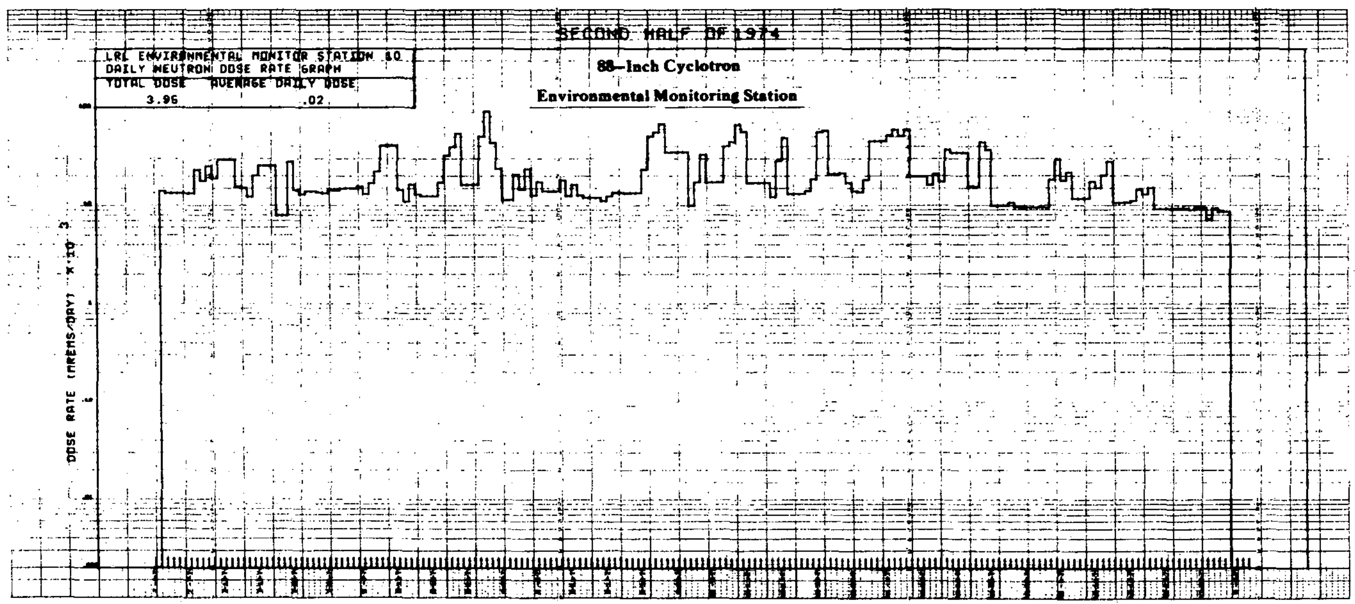
Figures 1a through 4a are representations of the daily neutron dose equivalents recorded from each of the Environmental Monitoring Stations. The data presented here include background radiation.





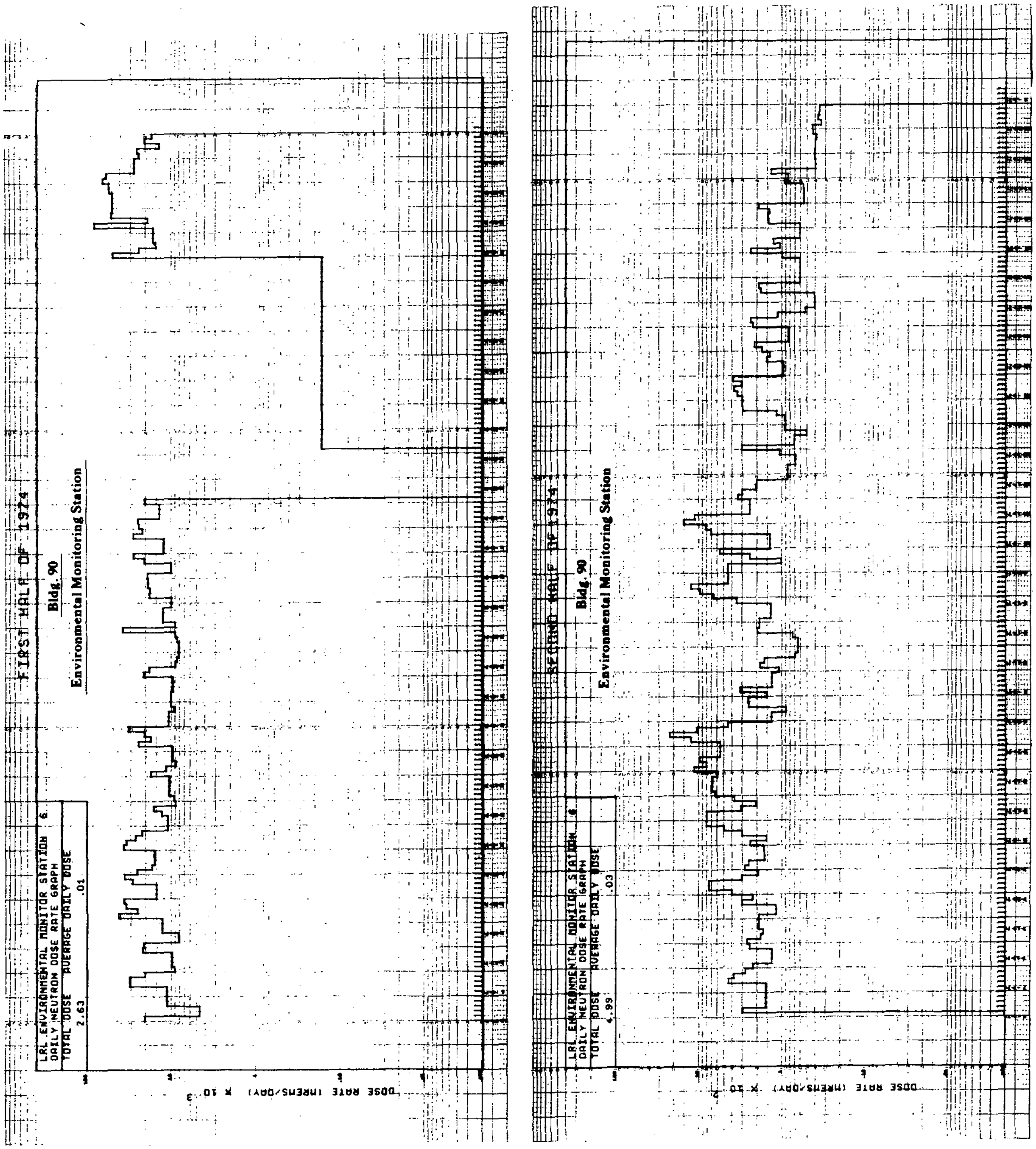
XBL 753-2456A



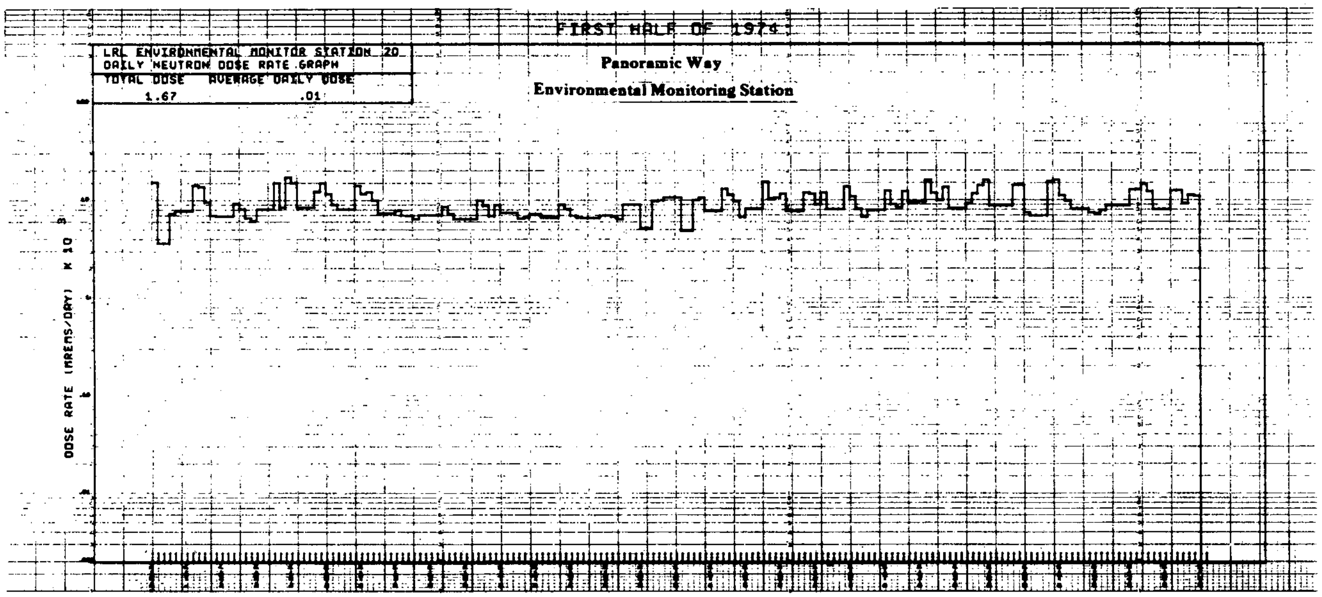


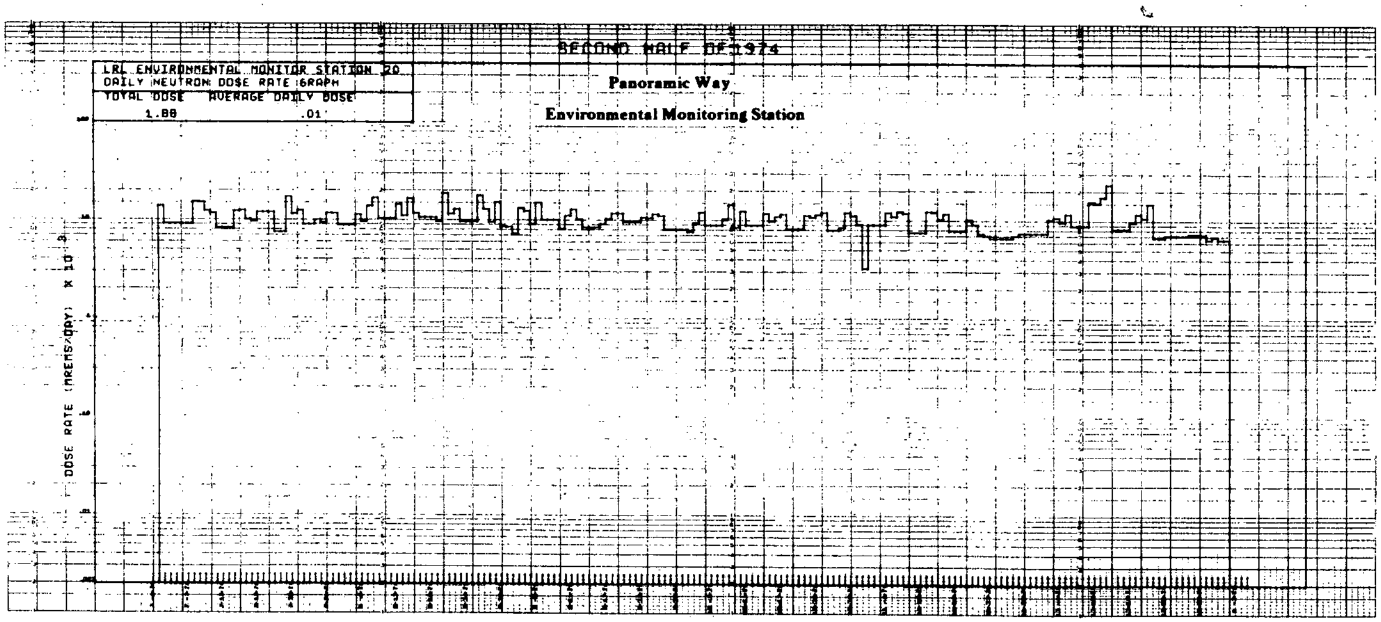
XBL 753-2454A

0 0 0 0 4 3 0 3 7 2 2



XBL 753-2451A





XBL 753-2458A

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