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MIGRATION OF FALLOUT AND FALLOUT SIMULANTS INTO SOILS

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U. S. NAVAL CIVIL ENGINEERING LABORATORY
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MIGRATION OF FALLOUT AND FALLOUT SIMULANTS INTO SOILS

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by

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ABSTRACT

A series of tests was performed to determine whether radioactive fallout would migrate vertically downward through soils. A thin layer of fused or leachable fallout simulant (Monterey sand coated with barium^{140}-lanthanum^{140}) or of natural fallout (fission products in soil) was spread on trays containing frozen soil mixtures. The trays were alternately thawed and allowed to refreeze, with radiation-level measurements made periodically. After a number of thaw-freeze cycles the frozen soils were vacuumed to remove surface activity. Core samples of the soils were taken and layers of the cores were counted to determine actual migration.

It was concluded that migration did occur by leaching and particle movement, and that particle migration occurred only in soils having a wide range of particle sizes. A single vacuuming removed most of the detectable activity.

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The Laboratory invites comment on this report, particularly on the
results obtained by those who have applied the information.

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INTRODUCTION

The Naval Civil Engineering Laboratory has been conducting studies on radiological decontamination methods for cold-weather areas. It was deemed that a study of the migration of fallout in alternately frozen and thawed soils was in order since no previous work of such nature had been reported.

An examination of weather maps of the United States will reveal that at least half of the country experiences freezing conditions during the year. In this study, it is assumed that a radioactive fallout-producing incident has occurred while such freezing conditions prevail. Residents of an area go into shelters, and the fallout settles on various land surfaces. Sunlight and the ambient temperature vary and produce alternate thawing and refreezing of the soil surfaces. This alternation includes the fallout in the uppermost soil layer, at least by freezing it to the surface through contact with existing moisture. The questions that arise are: Will the fallout migrate vertically down into the soil under this alternate thawing and freezing? and if so, how far will it migrate? This study was undertaken in an attempt to answer these questions.

TEST SERIES

One series of tests was conducted in NCEL's cold chamber, using a fused fallout simulant. Results of that series were only partially conclusive, so a second series was planned. During this second series additional radioactive materials including natural fallout were to be employed, and at least two different counting systems were to be used.

TEST FACILITIES

Facilities at NCEL

For the initial experiment, conducted in the NCEL cold chamber, four sheet-metal trays (Figure 1), each containing a different type of moist soil, were arranged in a rectangular pattern (Figure 2) and were separated by block walls (Figure 3). A heating unit (Figure 3) provided thermal radiation for thawing the frozen soils, and a stepwise scanning spectrometer (Figure 4) measured gamma radiation emitted during the test. Graded (150- to 300-micron) Monterey sand treated with barium^{140} and then covered with a fused layer of sodium silicate was used to simulate actual fallout material. Plastic sheeting was placed under the trays to decrease the probability of contaminating the chamber through accidental spillage of the radioactive simulant.

Trays. The metal trays were made of 1/16-inch-thick mild-steel sheet, and were 4 feet square by 6 inches deep. A 4-inch-wide lip was formed around the top and bent outward at a 45-degree angle.

Soils. Four different soils were used to represent types that might be common in areas affected by cold weather. Those used were beach sand, loam, loam mixed with small gravel, and crushed sandstone mixed with small gravel. All were obtained locally. The mixtures were prepared on a 50-50 volume basis in a conventional half-yard-capacity concrete mixer.

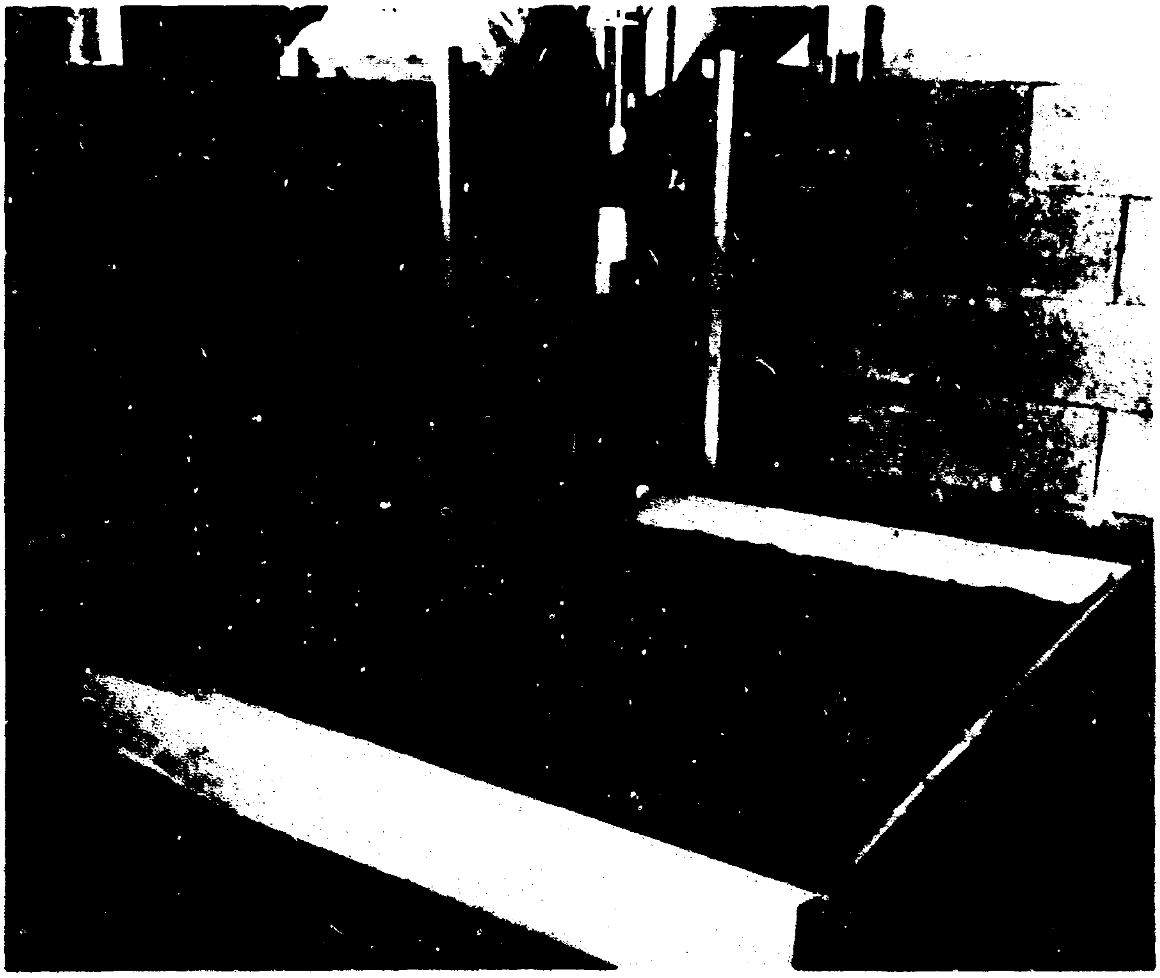

Figure 1. Sheet-metal tray and shielded scintillation probe.

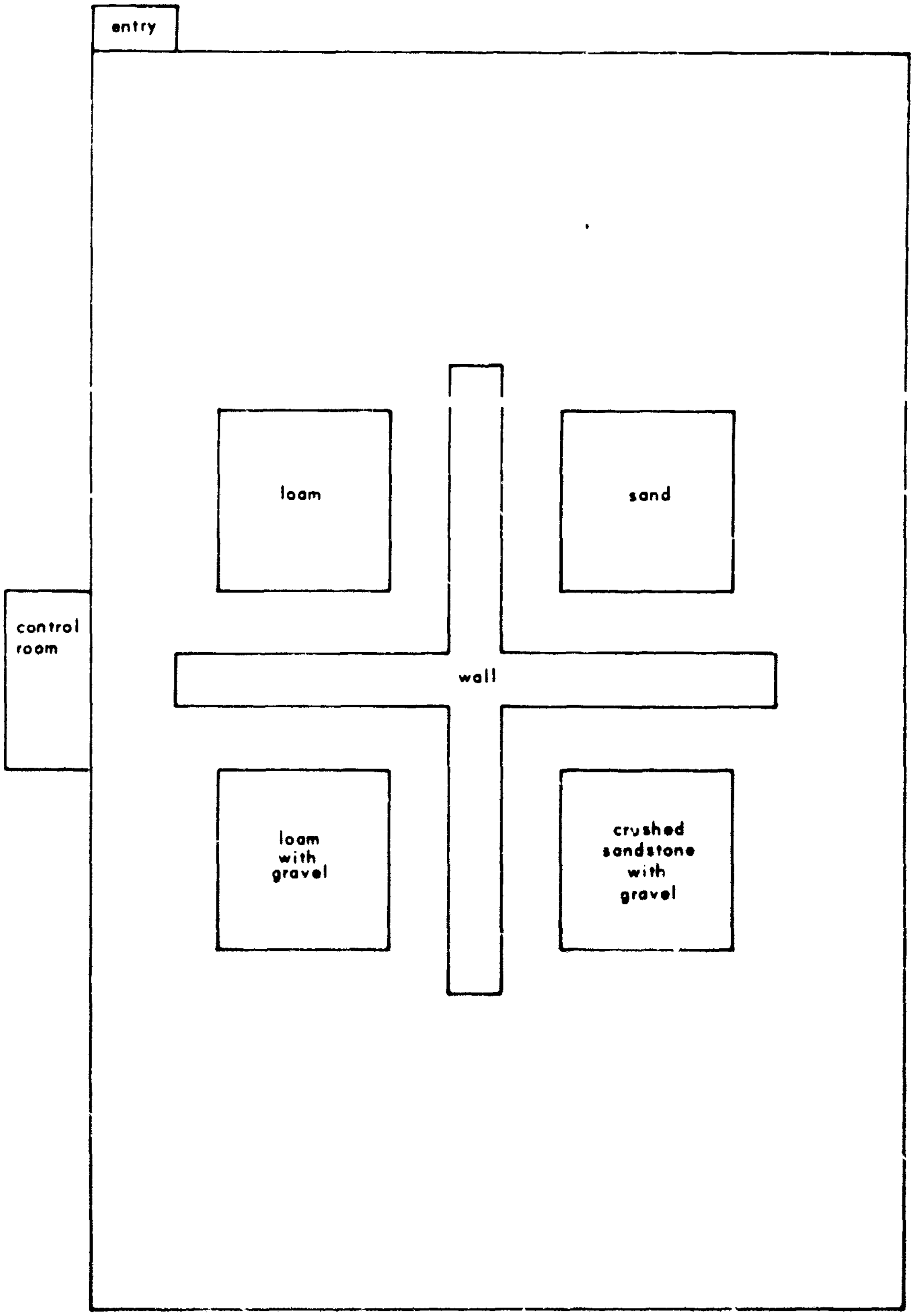

Figure 2. NCEL cold chamber arrangement.

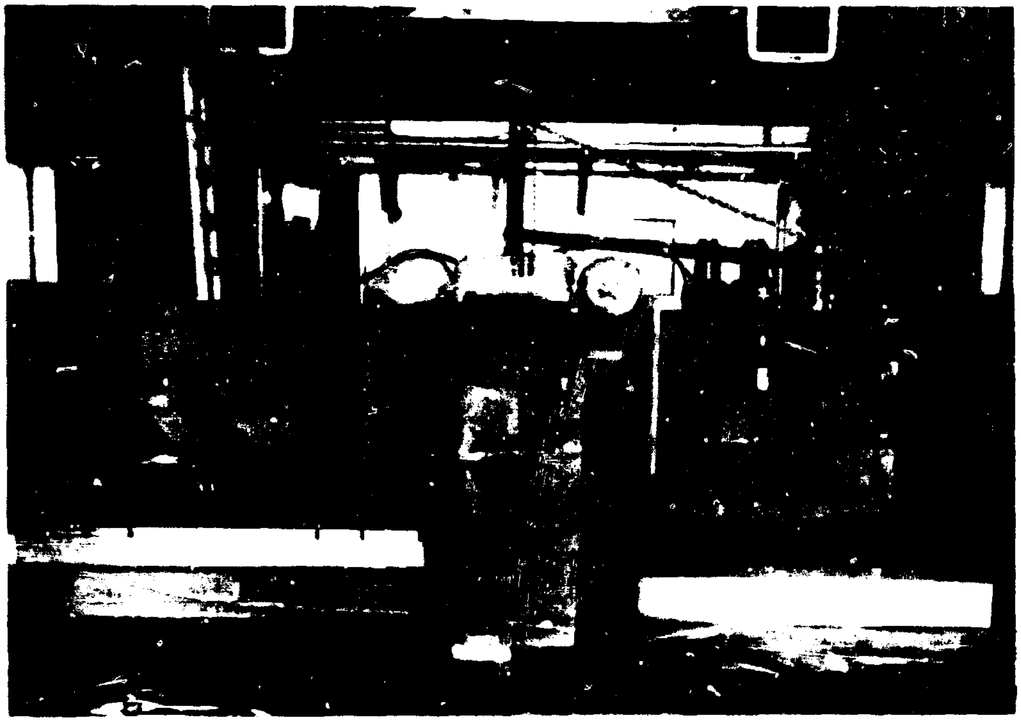

Figure 3. Setup for initial fallout migration study at NCEL. From left: heating unit on tray of soil, block walls, detector over tray of soil.

Figure 4. Spectrometer.

Walls. Hollow 8 x 8 x 16-inch concrete blocks were used to form the separating walls. The walls were in the form of a cross, with each equidimensional arm composed of two thicknesses of blocks. By using half- and quarter-sized blocks it was possible to build the wall so that radiation from one tray could not travel in a straight line and affect radiation readings over any of the other trays. The voids in the blocks were filled with moist sand to further minimize side-radiation effects.

Heating Unit. A radiant heating unit (Figure 5) was constructed from ten 5-foot-long heating elements, aluminum sheet, and fiberglass insulation. The heating elements were wired alternately in separate groups of five each and were insulated from the metal cover by pieces of asbestos board. A sheet of polished aluminum was placed behind the heating elements to reflect heat downward onto the soils. Power was supplied to the unit through controls outside the chamber; the controls were always turned off when personnel were working inside the chamber. Control sections consisted of a safety switch, a rheostat, a voltmeter, and an ammeter, with a separate section wired to each group of heating elements.

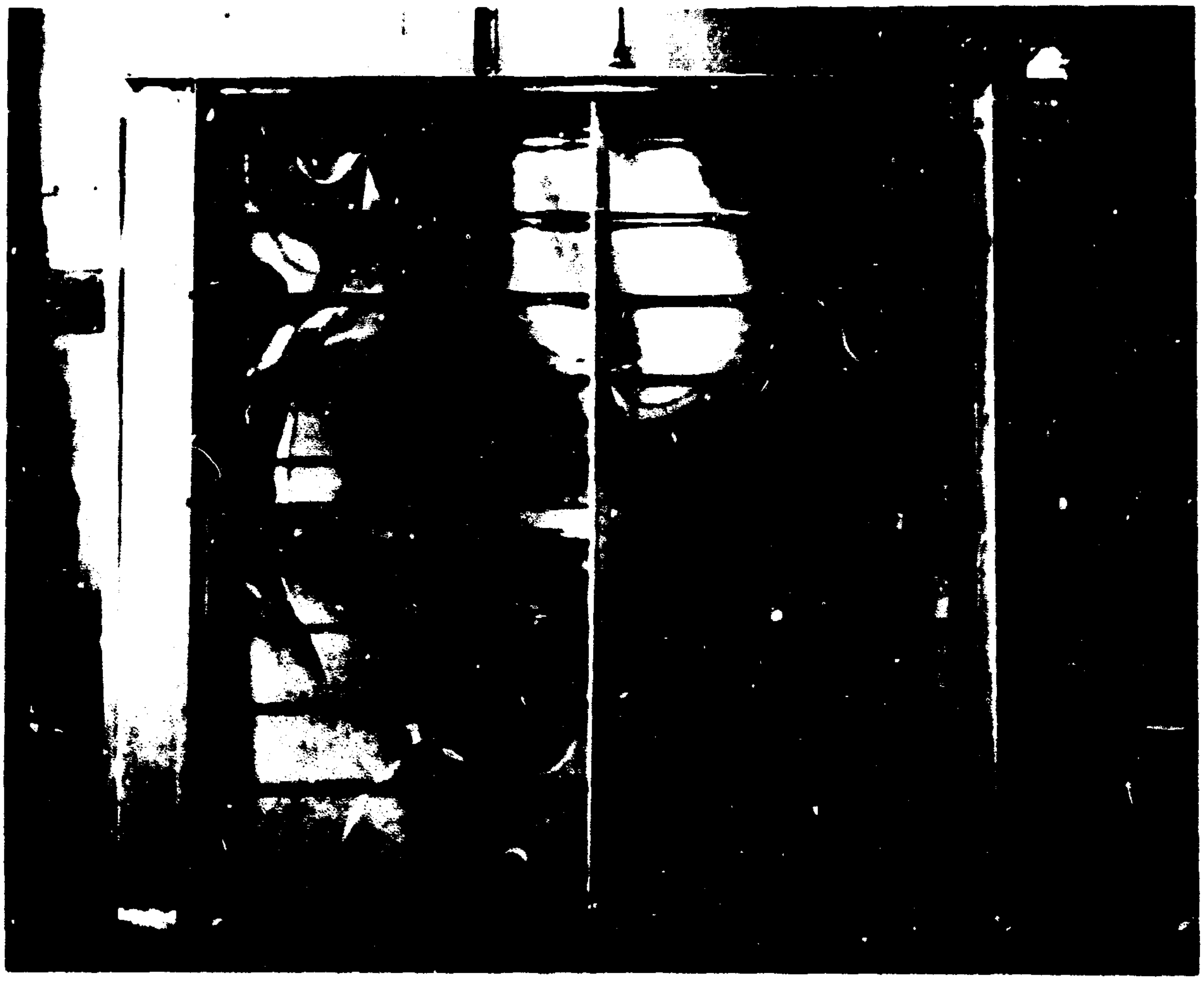

Figure 5. Heating unit, showing heating elements and polished aluminum sheet.

Spectrometer. A description of the spectrometer is given in Appendix A.

Facilities at NMC, Point Mugu

The second series of tests was conducted in a small environmental chamber at the Naval Missile Center, Point Mugu, California (Figure 6). Four sheet-metal trays similar to the ones used in the first test series but only a fourth as large, each containing a different type of moist soil, were arranged in a line (Figure 7) and were separated from each other by block walls (Figure 8). A smaller heating unit than the one used at NCEL was employed for thawing the frozen soils. A scaler (Figure 9) and a multichannel analyzer (Figure 10) were used to measure radiation emitted during the test. A mixture of fission products in soil (also called fallout or natural fallout) and two types of fallout simulant, one fused and the other leachable, were used in this test. Plastic sheeting was placed under the trays as in the initial experiment to protect the chamber from contamination by accidental spillage of radioactive materials.

Figure 6. Environmental chamber at NMC, Point Mugu.

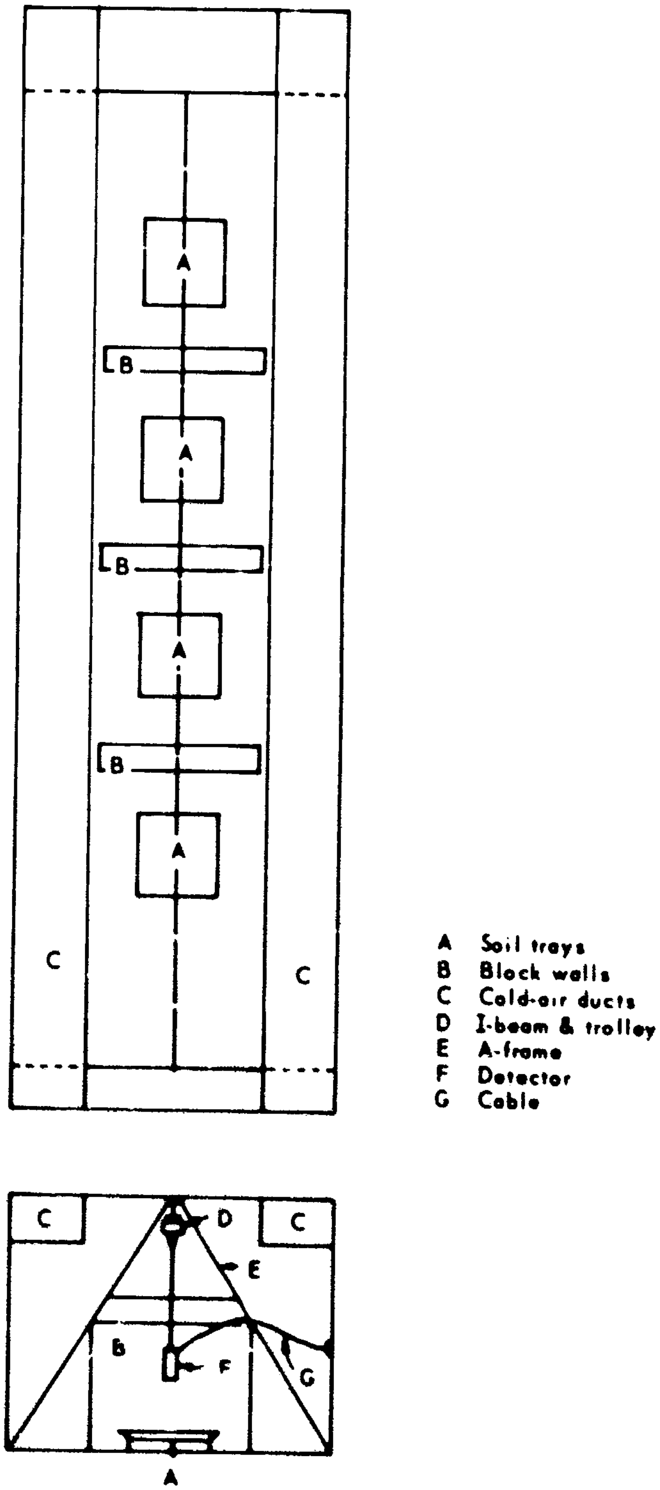

Figure 7. Mugu environmental chamber arrangement.

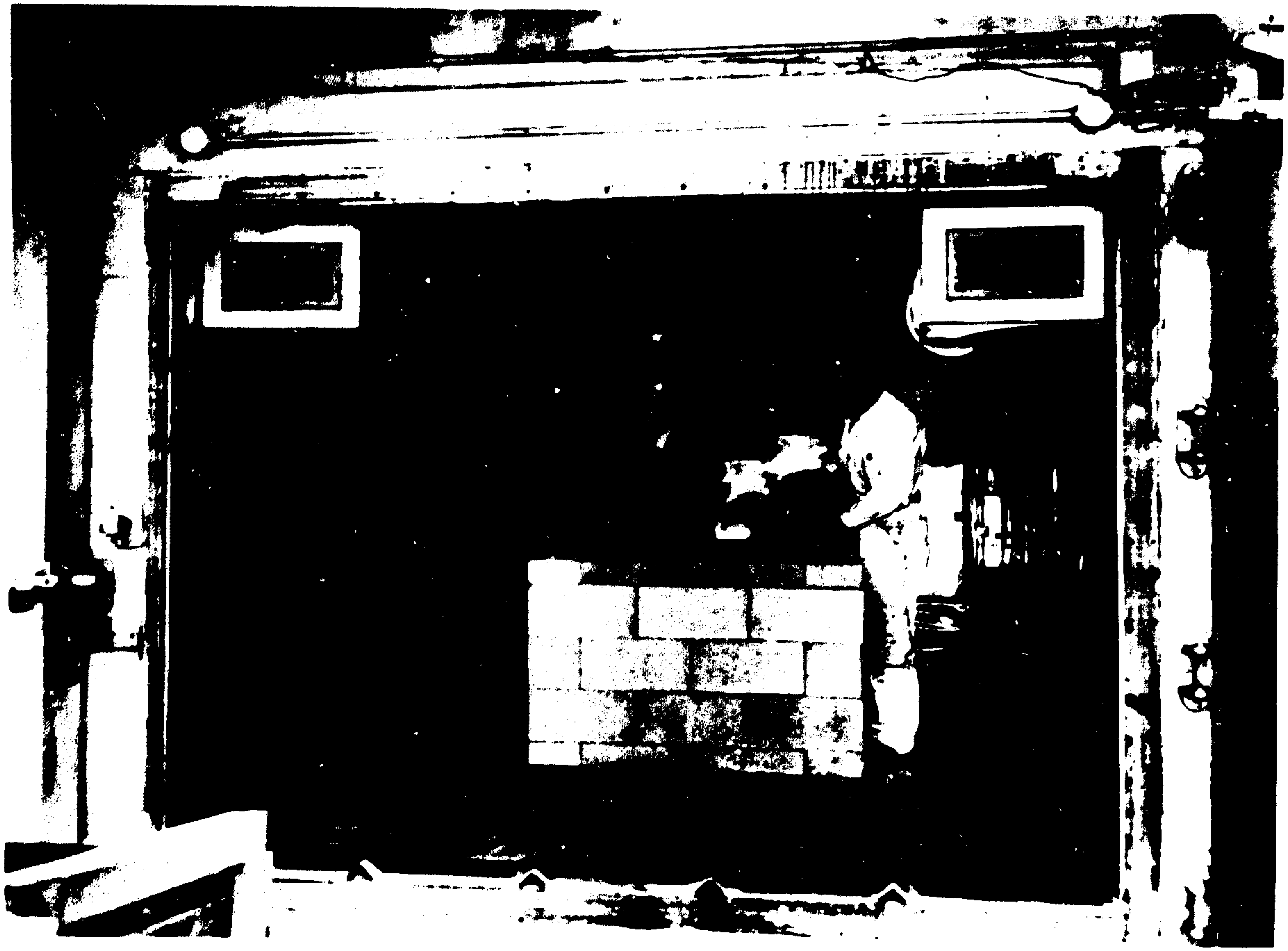

Figure 8. Filling voids in block wall at Mugu with moist sand.

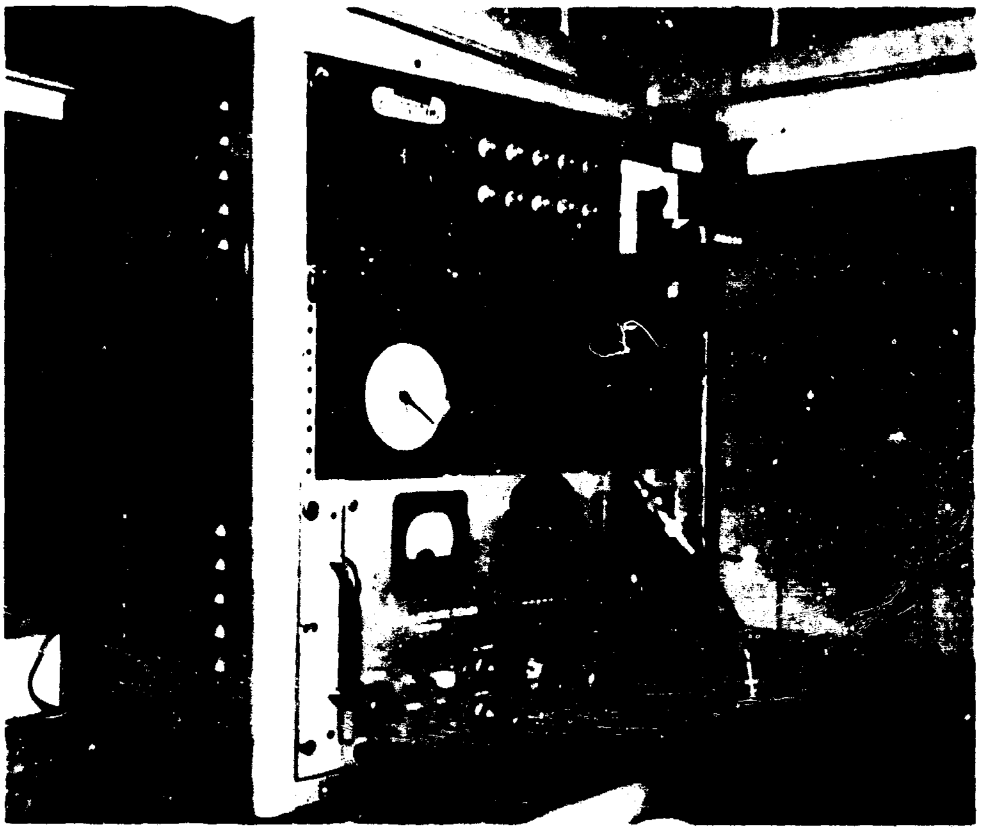

Figure 9. Scaler assembly for Geiger-Mueller counter system.

Figure 10. Multichannel analyzer.

Trays. The metal trays were made of 1/16-inch-thick mild-steel sheet, but were only 2 feet square by 3 inches deep. The reduction in size was made to reduce the waste-disposal problem. A 3-inch-wide lip was formed around the top and bent outward at a 45-degree angle, similar to the trays used previously.

Soils. The same four soil mixtures were used in the tests at Mugu as were used in the NCEL tests. Preparation was essentially the same, except for a lower capacity cement mixer.

Walls. Hollow concrete blocks used to make the walls in the NCEL tests were re-employed at Mugu. Due to the dimensions of the Mugu chamber it was necessary to lay the trays in a straight line, with short block walls built across the chamber to separate the trays. These walls were 4 feet long and 3 feet high, with the blocks staggered to minimize straight-line radiation effects. Voids in the blocks were filled with moist sand to provide additional radiation shielding.

Heating Unit. The radiant heating unit used at Mugu was a modification of the one used at NCEL. The materials of construction were the same, except that only five heating elements were used. The unit was reduced in width to correspond with the reduction in heating elements. Power was supplied by a 220-volt outlet on the outside of the building. A twist-lock plug was used, and a safety switch had to be thrown to complete the circuit.

Measuring Equipment. A description of the equipment used to detect and measure radiation is included as part of Appendix A.

PROCEDURES

The basic radiological safety procedures followed in these experiments are given in Appendix B.

After either test facility was assembled, the chamber temperature was lowered to 25° F. When the soils were frozen, the heating unit was placed on one tray and the power turned on. After a predetermined period the power was turned off, the heating unit was removed from the tray, and the depth of thaw in the soil was measured. The heating unit was replaced, and thawing continued until approximately 2 inches of soil was thawed. During the NCEL tests it was found that this took about an hour for the first soil, so each of the others was thawed for 1 hour. The depth of thaw was checked, and in each case it was found to be approximately 2 inches. The 1-hour thaw period was used during the NCEL tests; during the tests at Mugu the period was decreased to 45 minutes in order to allow for more thaw-refreeze cycles.

When the soils were refrozen, quantities of fallout simulant or natural fallout were spread over the surfaces (Figure 11). A counting procedure was established, as given in Appendix A, after which the initial radiation level was measured over each tray (Figure 12). Each soil was thawed and allowed to refreeze; this procedure was repeated over a period of time, with radiation-level measurements made at varying intervals. After a number of thaw-freeze cycles the trays of soils were vacuumed twice to remove surface radioactivity. The radiation level over each tray was measured immediately before and immediately after each vacuuming. Cores of the several contaminated soils were obtained during the Mugu tests in hopes that successive layers of each core would show whether or not migration did in fact occur.

All used soils were placed in covered galvanized iron cans, along with contaminated plastic and equipment that was not wanted. This waste was turned over to a firm licensed to dispose of radioactive wastes.

Figure 11. Spreading radioactive material on tray of frozen soil.

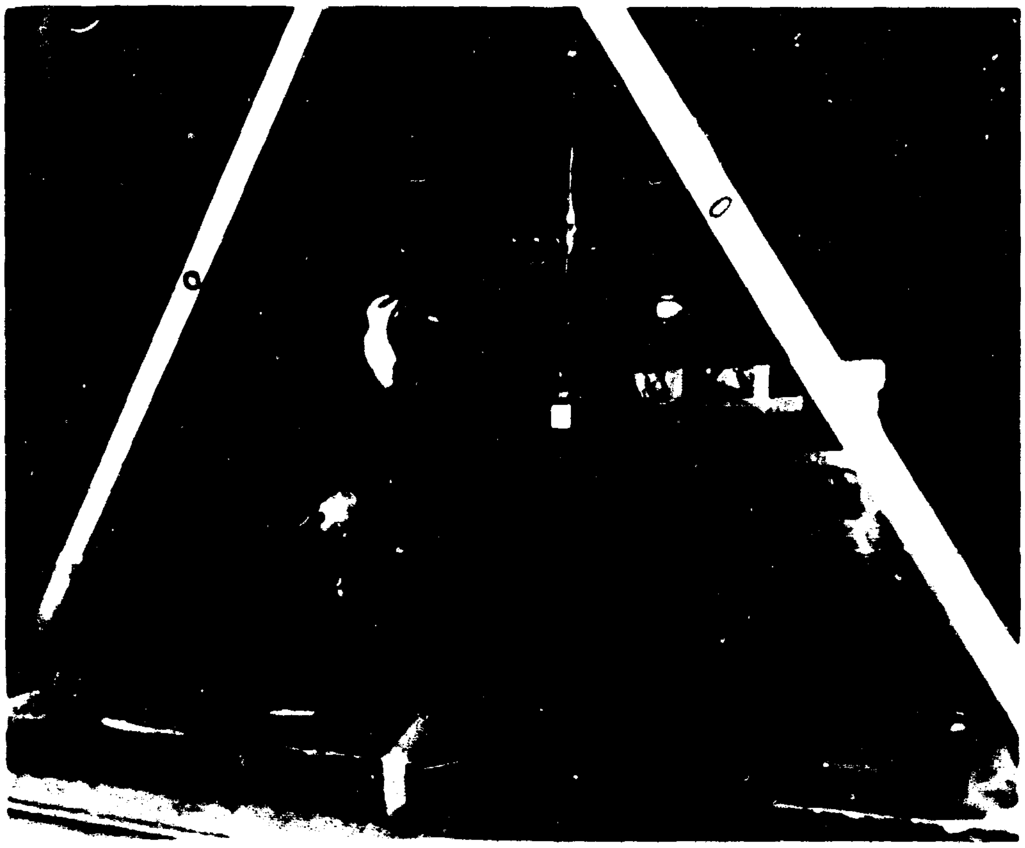

Figure 12. Positioning detectors (Geiger-Mueller tube and scintillation crystal with photomultiplier tube) over tray of soil. Assistant wearing voice-powered intercom.

RESULTS

Routine health physics measurements were made by Laboratory personnel during the NCEL test series. The Radiological Safety Officer, Pacific Missile Range, Point Mugu, maintained a continuing check on the health physics aspects of the tests conducted at Mugu. On completion of the test series and following final cleanup his report was submitted to the Laboratory by official letter, and is included in this report as Appendix C.

Table I shows the results obtained by vacuuming the several soils, together with the total depth of each soil removed by the two vacuumings. All percentages are based on unconverted data shown as the "before" and "after" counts.

The table shows that a single vacuuming removed at least 88 percent of the detectable radioactivity at NCEL. A second vacuuming increased the removal to 96 percent. Instrument error plus overnight decay can account for the variation in three of the four NCEL sets. The fourth variation is outside any expected limit, and no reasonable explanation for this can be found.

Table I. Effect of Vacuuming on Radiation Level

Tray No.	First Vacuuming			Second Vacuuming			Total Percent Decrease	Soil Depth Removed (in.)
	Counts/Minute		Percent Removed	Counts/Minute		Percent Removed		
	Before	After		Before	After			
NCEL: Fused Simulant[1]								
1	37,211	2,002	94.6	3,109	2,157	30.6	96.3	3/32
2	29,884	3,103	89.6	3,110	970	68.8	96.8	1/16
3	34,994	3,951	88.7	3,814	1,041	72.7	96.9	1/8
4	34,259	3,050	91.1	2,862	1,292	54.9	96.0	1/16
Mugu: Fused Simulant								
1	7,324	635	91.33					<1/16
2	6,218	123	98.02					1/8
3	7,835	146	98.14					1/8
4	8,090	244	96.99					1/16
Mugu: Leachable Simulant								
1	2,950	82	97.22					>1/16
2	3,943	124	96.86					1/8
3	5,125	154	97.00					1/8
4	4,518	728	83.90		270		94.03	<1/16
Mugu: Fission Products								
1	2,808	79.8	97.2					1/8
2	1,959	69.8	96.44					3/16
3	2,106	73.4	96.51					1/8
4	1,992	88.5	95.55					3/32

[1] Data under first vacuuming at NCEL are in counts per 1/2 minute.

During the tests at Point Mugu the first vacuuming removed from 83 to 98 percent of the detectable activity. In only one instance, as shown, did the second vacuuming produce a significant change in the percent activity removed. All others were within the range of instrument error.

Figure D-1 in Appendix D shows the radiation levels after successive thaw-freeze cycles as measured during the initial tests at NCEL. The actual measurements are corrected for decay. (If neither decay nor migration had taken place, all values would have remained at the initial radiation level.) The curves show an increase in radioactivity, rather than the uniform intensity that would be expected. Variations in the power supply or the performance of internal components of the counting equipment may account for the increase.

Figure D-2 shows the radiation levels after a varying number of cycles during the Mugu tests. These data also have been converted to indicate the original activities required. The line shown with each set of data points is an average of the points; its location was determined by the least-squares method. The majority of these lines indicate at least a slight increase in activity whether the maximum value of a peak or the total count under a peak is used. However, the data obtained by using a Geiger-Mueller tube as the detector indicates a decrease in activity in two-thirds of the cases.

Core samples were taken from the various trays of soils used at Mugu; layers of the soil mixtures were removed from each core and the radiation level measured. This was successful only with the fission products, and then to a limited degree. The results from this one group of cores are shown as Figure D-3. The highest count from a layer of each core was arbitrarily equated to 100 counts, and the counts in the other layers of the core reduced proportionately. In getting the layers from the loam-gravel and crushed sandstone-gravel mixtures, particles obviously different from the soil mixture were observed around the pieces of gravel. The particles closely resembled the fission product mixture in size and color, so such was assumed to be their identity.

It was noted incidentally that the loam and the loam-gravel mixture both suffered extensive cracking under the thaw-freeze cycling.

DISCUSSION

The initial tests, at NCEL, showed that a single vacuuming could remove 88 percent of the detectable activity, along with about a 1/16-inch layer of the soil surface. It was assumed that essentially none of the fallout simulant had migrated vertically in any of the soil systems. The simulant employed was a non-leachable type; that is, contact with water would not dissolve the radioisotope, nor would chemical action remove the activity.

Since natural fallout is at least partially leachable, it was felt that additional tests should be run, using both fused and leachable simulants, and true fallout material as well. Also, in view of the apparent increase in initial activity required to produce the radiation levels measured, it was decided to use two or more different detection systems. The spectrometer system used previously was partly inoperable, so it could not be employed for comparison purposes.

In comparing the results of the NCEL tests and the first tests at Point Mugu it is seen that the results of the latter tests are more accurate; that is, the variation in data at Mugu was between ±10 percent, while at NCEL the variation was more than 10 percent. Most of the variation in the NCEL tests was in the latter part of the work, and can be attributed to irregularities in the counting equipment. As noted above, the spectrometer did break down subsequent to its use in these tests.

Radiation measurements over the individual trays do not provide conclusive evidence that migration occurred. Although counting with the Geiger tube system is fairly consistent in indicating migration, the values of the two photo peaks obtained from successive spectra are even more consistent in denying migration.

The core sample data (Figure D-3), however, provide a firm indication that migration did occur. The radioactive material generally was in a layer approximately 1/32 inch thick initially; any radiation detected below that depth could come only from migrated activity, natural background, or contaminated instruments. The detection of strong activity below 1/16 inch of depth is firm proof that migration took place. The activity detected in the loam core may have been the result of leaching; no fission product particles were observed. Actual particles were observed along the surfaces between gravel fragments and the loam, presumably getting there as a result of the loam freezing and separating from the gravel, thus permitting fallout inclusion.

It is unfortunate that the cores from the fallout simulants were unsatisfactory; as a result, the comparison between fission products and simulated fallout cannot be made on the basis of the best confirmative method. The surface radiation measurements indicate corresponding results between simulated fallout and fission products, but these cannot be compared to nonexistent core data.

It must be emphasized that these tests were conducted under laboratory conditions. The thaw-freeze cycle was decreased to one-fourth a normal cycle; thawing the soil and allowing it to refreeze took more than 2 hours, but generally takes a day under natural conditions. The intensity of heat from the radiant unit is about eight times that of solar radiation at sea level. The constant air circulation between the working area and the refrigeration coils probably extracted moisture from the soil; this extraction might be less under natural conditions.

Migration of fallout by leaching or particle movement has been shown to be of relatively minor importance in these tests. Because of the variation between laboratory and natural conditions, there may be some virtue in conducting field tests. Such tests, however, would present a new series of problems. The vagaries of weather in any locale would be a major problem, with precipitation or ice formation contributory factors. The prevalence of some form of vegetation would require consideration.

If such tests were considered necessary, they would be conducted at an appropriate cold-weather site. Such a site should have a variety of soil types, or different soils could be imported. If the latter were necessary, the soil density should be determined in its original location, and should be equalled by recompaction at the test site. Natural and simulated fallouts could then be spread on the soils and radiation level measurements be made over an extended period. Core samples could be taken and thin layers counted to determine actual migration.

CONCLUSIONS

1. Migration of fallout did occur by leaching and by particle movement.

2. Migration of fallout particles probably took place only in soils with a wide range of particle sizes.

3. A simple decontamination method removed most of the detectable activity.

ACKNOWLEDGMENTS

Many of NCEL's personnel participated in this investigation and many staff members of the Pacific Missile Range and the Naval Missile Center, Point Mugu, provided direct and indirect assistance. Special appreciation is extended to Mr. Walter L. Milne, Radiological Safety Officer, PMR, who provided continuing health physics support during the experiments at Mugu and supplied Appendix C of this report; to Mr. James Chapman of NCEL, who provided valuable technical assistance; and to Mr. Delmar W. Wilson, NCEL Trades Department, who was directly involved in all the work at Point Mugu, from initial setup to final decontamination.

Appendix A

DETECTION EQUIPMENT AND COUNTING PROCEDURE

SPECTROMETER (at NCEL)

The stepwise scanning spectrometer consists of a shielded scintillation probe (Figure 1), a spectrometer section, a scaler section, and a printing section (Figure 4). The probe includes a thallium-activated sodium iodide crystal and a photomultiplier tube. Radiations from a given source are registered on the crystal as light flashes. Each flash is proportional in intensity to the energy deposited in the crystal by a particular gamma ray. The flash is detected by the photomultiplier tube, which converts the energy to an amplified voltage impulse and transmits the impulse to the spectrometer section. The impulse is again amplified and its magnitude compared to upper and lower limits which are determined by the channel being counted. If the impulse is between the two limits a signal is sent to the scaler, which registers the signal as a single count.

After a preset time the scaler quits accepting signals or impulses from the spectrometer. The scaler then tells the printing section to record the channel which was counted, the total counts, and the time of counting. The printer does this and, if the assembly is set for automatic operation, switches the spectrometer to the next channel. At the same time the printer tells the scaler to accept signals from the spectrometer again, and the counting begins for another channel.

ANALYZER (at Mugu)

The multichannel analyzer is essentially many spectrometers, each preset to register only impulses between different specific limits. Instead of automatically switching the limits after a preset time, the analyzer simultaneously counts on all channels for the desired time interval. When counting is complete, switches may be adjusted to have the data thus obtained reproduced by typing the counts in each channel, or by reproducing the data in some other form.

G-M COUNTER (at Mugu)

The Geiger-Mueller counting system consists of a G-M tube and a scaler. A high voltage is impressed on the tube, [illegible] radiation causes a fluctuation in this voltage. The fluctuation is detected in the scaler, which tells a counting segment to register the fluctuation as a count. No differentiation is made between fluctuations caused by radiation of different energies. After a predetermined time the scaler is turned off, and the total counts are recorded.

COUNTING PROCEDURE

During the NCEL tests the soils were frozen and covered with the fused radioactive fallout simulant. The probe was positioned over the center of one of the trays and a spectrum obtained (Figure A-1a). The peaks corresponding to 0.815 Mev and 1.6 Mev are quite prominent, so they were monitored during the experiment. The gain shown in Figure A-1a was doubled for the 1.6-Mev peak and quadrupled for the 0.815-Mev peak so that either peak could be measured around channel 40 of the spectrometer. A seven-channel spread was used for finding the total number of counts in each peak. The spread is indicated in Figure A-1b for the 0.815-Mev peak. The difference in peak height between Figures A-1a and A-1b is attributable to the change in gain. Correction for minor changes in gain were made by moving the seven-channel spread a short distance along the spectrum until the maximum count rate was found.

During the Mugu tests, while using the fallout simulants, a sealed source was used to set the analyzer so that the 0.815-Mev peak fell in about channel 40, and the 1.6-Mev peak fell in channel 80. While using the fission products it was necessary to first determine the spectrum of the material and then select appropriate peaks. The same sealed source was used to insure that the peaks of this material were in the same channels during successive readings. It was also necessary to take several spectra over a period of time to determine the half-lives associated with the peaks selected. These half-lives were used to calculate original activities. The fission products are a classified material, so the peaks monitored cannot be identified.

The scintillation probe was suspended from a trolley attached to the bottom of a steel T-beam assembly running lengthwise of the working chamber (Figure 12). The G-M tube was taped to the outside of the probe's shielding, and all connecting cables were taped together. While measurements were being made with the multichannel analyzer, the G-M counting system could be used on the same soil and obtain concurrent data.

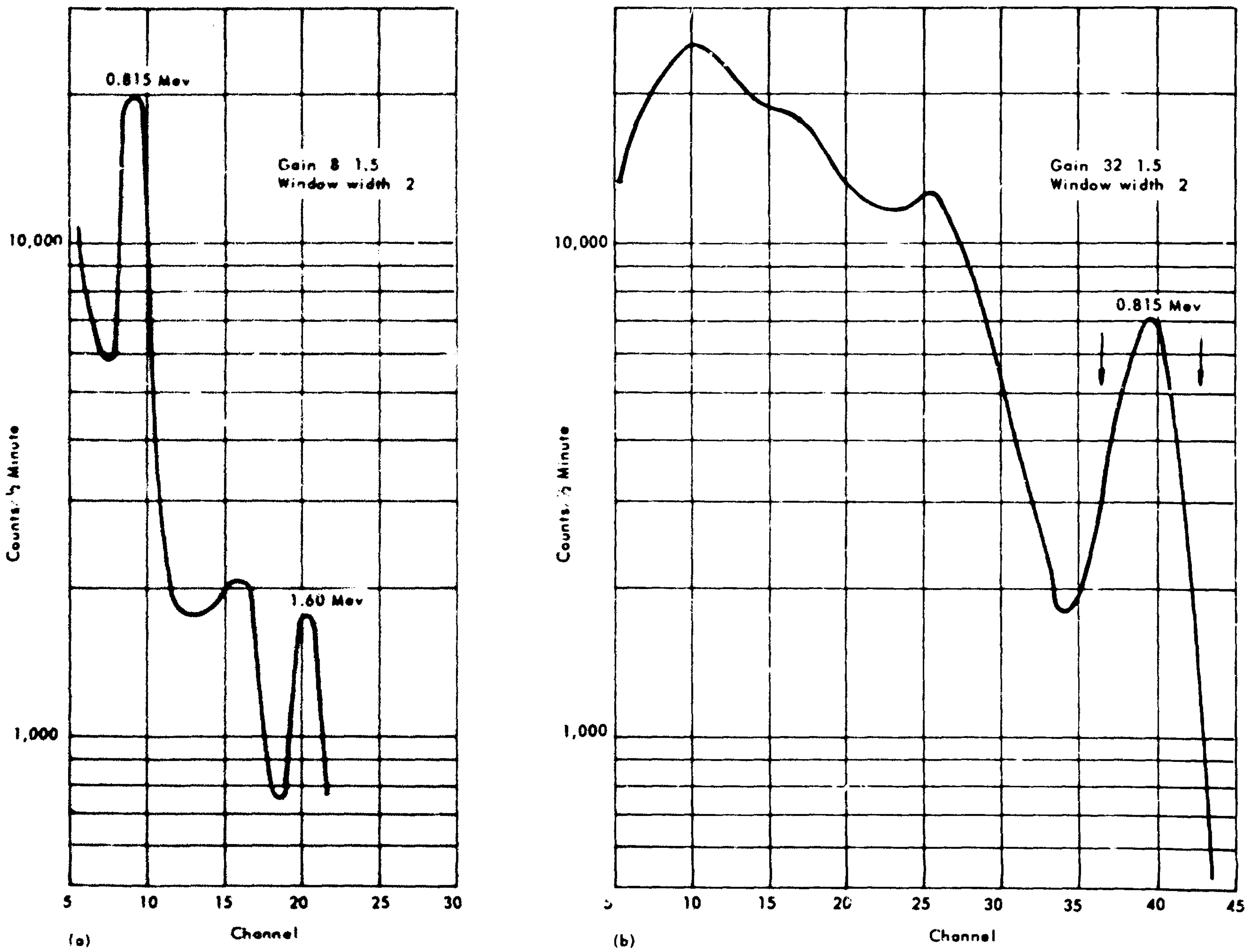

Figure A-1. Barium^{140}-lanthanum^{140} spectra.

Appendix B

RADIOLOGICAL SAFETY PROCEDURES FOR USE OF RADIOACTIVE SIMULANT (Ba^{140}-La^{140}) IN NMC

POINT MUGU, CALIFORNIA, ENVIRONMENTAL LABORATORY

1. Rules and regulations set forth in Title 10, Code of Federal Regulations, Chapter 1, Parts 20 and 30, will be complied with. Also the licensee will adhere to NCEL Instruction 5100.10C of 11 October 1963, and will adhere to current Naval Missile Center instructions.

2. The total amount of activity to be in use at any one time will not exceed 1 millicurie of $Barium^{140}$-$Lanthanum^{140}$, or an equal amount of true fallout material if available. This will give a dose of about 1.72 milliroentgens per hour at one yard. Since this is to be divided into four equal parts, the dose rate from any of the four trays used will not exceed approximately 15 mr/hr at 6 inches from the surface of the tray. At the working distance of 2 feet for the scintillation counter the dose rate should not be over 1 mr/hr.

3. In addition, the following procedures and safety regulations are to be followed:

a. The materials, as received from their separate sources, should be shipped in a container which complies with the AEC and U. S. Department of Commerce shipping regulations.

b. The loading of sand into the trays can be done in the cold chamber. A 10-mil plastic sheet can be spread under each tray extending 3 feet beyond the edge of the tray to collect any sand which may spill when the fallout simulant is being spread over the trays. Protective clothing, masks, and gloves should be used during the spreading operation. People engaged in this operation will carry pocket ionization chambers as well as self-reading electroscopes (0-200 mr) and film badges. The operation will be monitored with a Cutie Pie Radiation Detector. A Colman 20-liter/min air sampler or an acceptable alternate will be used to detect any airborne radioactivity.

c. At least one licensed user will be present at all times that any work is being done in the cold chambers.

d. The cold chamber will be locked at all times except when a licensed user is present, and the keys will be retained only by licensed users.

e. Records of all readings will be kept in a logbook.

f. During the entire period of the experiment in the cold chamber, all personnel entering the cold chamber (whether for experimental work or for maintenance) will have the radiation detecting devices mentioned above. While decontamination procedures are being tested, all personnel will wear the protective clothing mentioned in paragraph 3b, and the air sampler will be used.

4. Any radioactive waste material will be stored in an appropriately marked can with a lid. After a thorough vacuum cleaning of the cold chamber to remove all loose contamination, all material removed in final decontamination procedures will be stored in this waste can.

5. Upon completion of the experiment, all the sand from the trays and other contaminated material (determined by survey with a thin-window Geiger tube survey instrument) will be placed in suitable containers for disposal.

6. A final survey of the chamber and trays and all equipment used in this operation will be made with a thin-window Geiger tube survey instrument.

7. All contaminated material in cans will be picked up and disposed of by a commercial disposal company such as U. S. Nuclear Corporation, License No. 4-5241-3, Burbank, California.

Appendix C

HEALTH PHYSICS MEASUREMENTS

by

Walter L. Milne*

During the period of 31 May 1964 to 29 July 1964, the U. S. Naval Civil Engineering Laboratory (NCEL) conducted a series of radioactive fallout experiments at Point Mugu, California. These experiments were carried out in Building 722-A (Figure 6) in accordance with Atomic Energy Commission License No. 4-7316-1 as amended.

The Pacific Missile Range (PMR) provided continuing health physics support during the experimental period. During the experiment numerous samples were taken to determine the level of surface contamination (Figure C-1). A continuous air-monitoring program was undertaken to determine the level of airborne particulates (Figure C-2), and routine beta-gamma environmental surveys were conducted to control external radiation levels.

Swipes were taken at seven different positions inside the environmental chamber. Listed below are the highest readings found on each sample day for any of the samples taken.

	Concentration ($\mu c/m^2$)	
Date	Beta	Gamma
5-26-64	1.5×10^{-2}	4×10^{-2}
6-10-64	1.5×10^{-2}	4×10^{-2}
6-23-64	1.5×10^{-2}	5.7×10^{-2}
6-29-64	1.5×10^{-2}	4×10^{-2}
7-21-64	1.5×10^{-2}	4×10^{-2}

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*Radiological Safety Officer, Headquarters, Pacific Missile Range, Point Mugu, California.

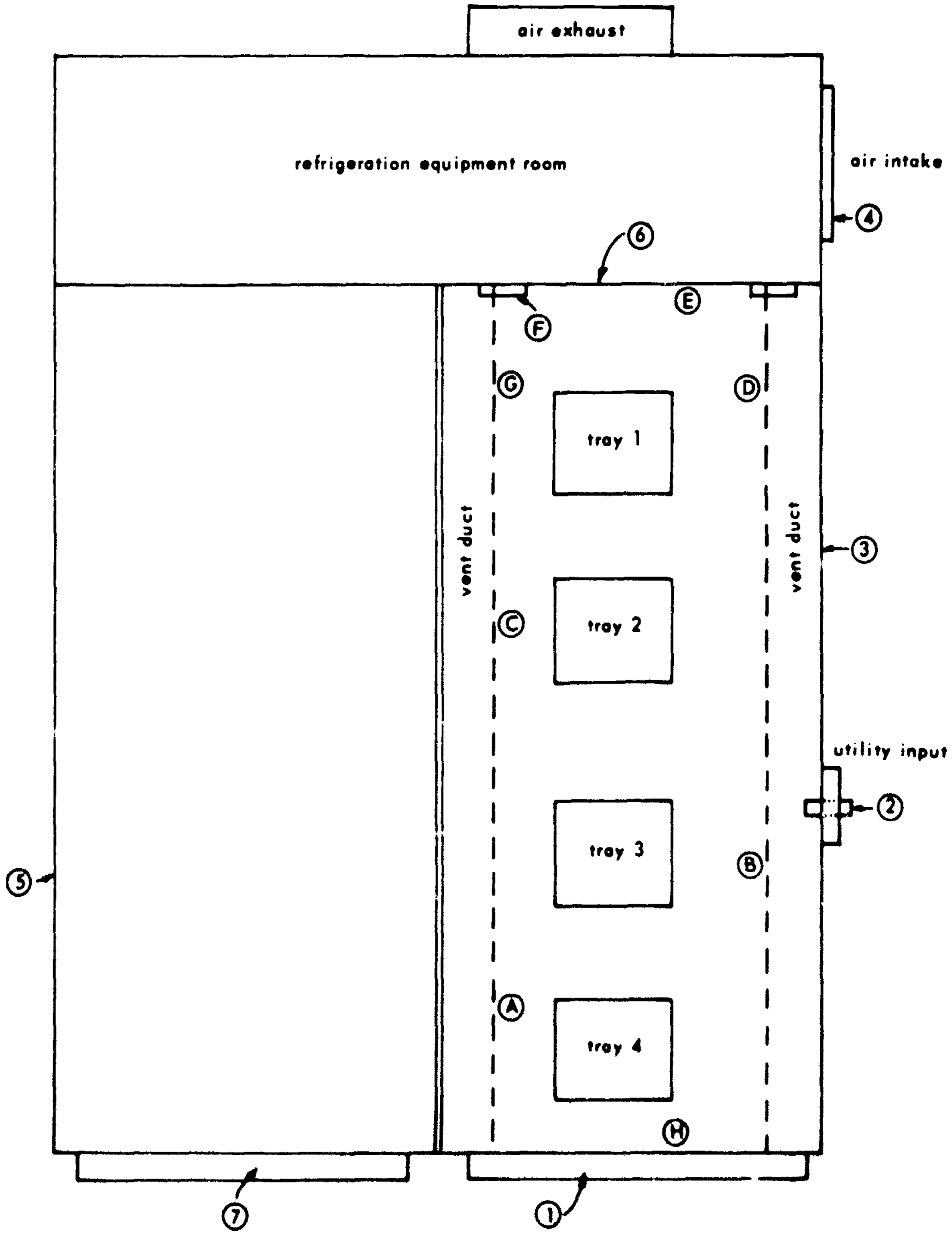

Figure C-1. Beta and gamma monitoring stations (numbered) and swipe sample stations (lettered).

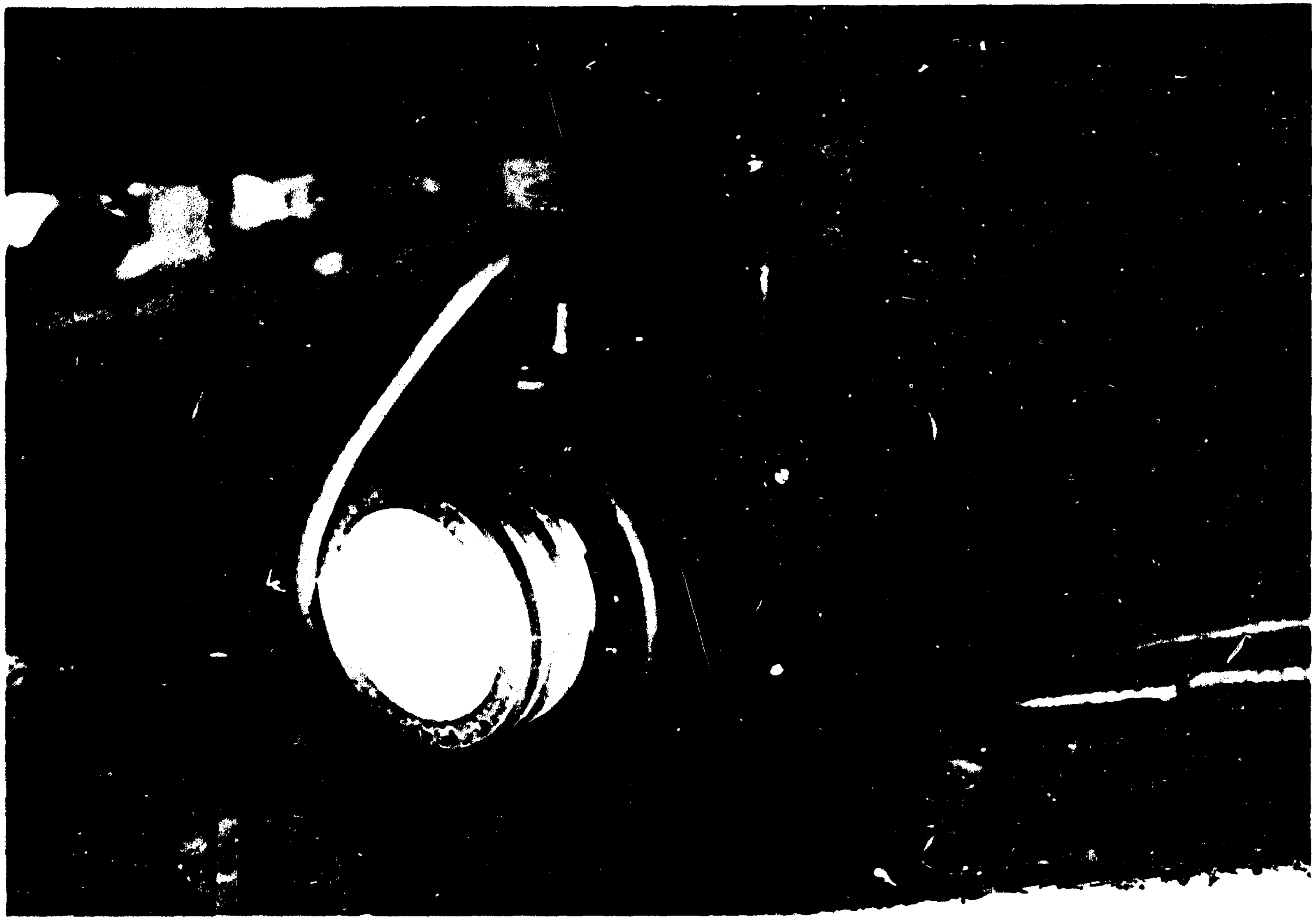

Figure C-2. Air sampler used during fallout migration study.

Air samples were taken continuously between 13 May 1964 and 1 June 1964, and between 22 June 1964 and 14 July 1964. Samples were counted for both beta and gamma activity and results expressed as microcuries (μc) per cubic meter (m^3) of air.

The isotopes of concern in the first two experiments are Ba^{140} and La^{140}, which exist in secular equilibrium. Ba^{140} levels were used as the governing factor since it has the lowest maximum permissible concentration (MPC) in air, 1×10^{-1} $\mu c/m^3$ of air for a 40-hour week. Since the total average time spent in the chamber by experimental personnel was less than 4 hours per week, the allowable MPC was increased by another factor of ten, to 1 $\mu c/m^3$.

In the third experiment, dealing with an unknown combination of radioisotopes, the MPC was established as 3×10^{-3} $\mu c/m^3$ of air (allowing for a maximum exposure of 4 hours per week). Gamma spectrum analysis revealed an age and decay rate that indicated the possible presence of the strontium series; therefore the MPC for Sr^{90} was used as the governing factor. With the exception of the five air samples listed below, all airborne radioactivity concentrations were less than 10^{-13} $\mu c/m^3$ (beta) and 10^{-7} $\mu c/m^3$ (gamma).

	Concentration ($\mu c/m^3$)	
Dates	Beta	Gamma
5-15-64 to 5-18-64	2.54×10^{-13}	3.97×10^{-9}
5-26-64 to 5-27-64	6.73×10^{-12}	1.72×10^{-7}
6-24-64 to 6-25-64	1.91×10^{-11}	1.03×10^{-6}
6-29-64 to 6-30-64	3.47×10^{-11}	6.93×10^{-11}
7- 8-64 to 7-14-64	8.18×10^{-12}	1.24×10^{-7}

Following assay of the 6-24 to 6-25 sample, NCEL personnel were issued and instructed to use respirators when working in the environmental chamber. The MSA Type H particulate filter was specified because of its high efficiency in filtering particles down to submicron diameter. Subsequent assay of the filter surfaces using a G-M detector showed no significant activity.

Accepted levels for whole body maximum permissible dose (MPD) are 100 milliroentgens (mr) per week in controlled areas and 10 mr per week in non-controlled areas. Periodic surveys were taken on all sides of the environmental chamber. At no time did the integrated dose outside the chamber exceed 0.8 mr per week, which is well within the allowable limits. The highest level inside the chamber was found 3 inches over the top of the fallout trays, during the first experiment. This level was 1.5 mr per hr or 60 mr per 40-hour week, again within allowable limits.

At the completion of the experiment the chamber was decontaminated by NCEL personnel. Following decontamination, swipe samples were taken and assayed. No removable radioactivity was found.

In summary, it may be stated that

1. At no time did the level of surface contamination exceed the maximum permissible levels.
2. Environmental radiation levels in the vicinity of Building 722-A were maintained within prescribed limits.
3. On several occasions the level of airborne particulates approached the maximum permissible concentration as defined by Title 10, Code of Federal Regulations, Part 20. PMR action was to require personnel to use respirators when working inside the experimental chamber of Building 722-A.
4. On completion of the experiment the chamber was decontaminated by NCEL personnel. No removable radioactivity was found, and the decontamination was certified as complete.

Appendix D

DATA CURVES

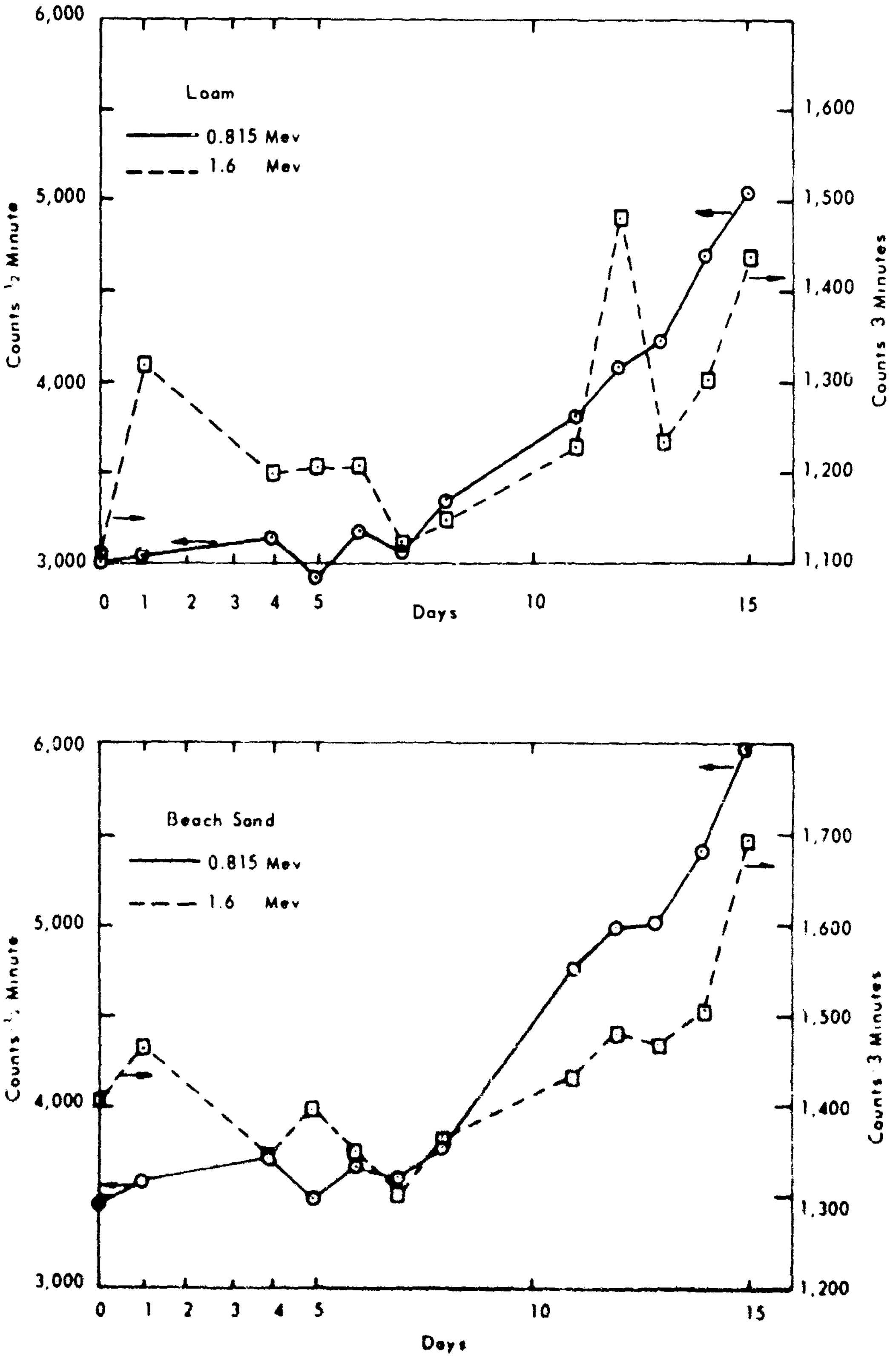

Figure D-1a. NCEL radiation levels after successive thaw-freeze cycles. (Corrected for decay.)

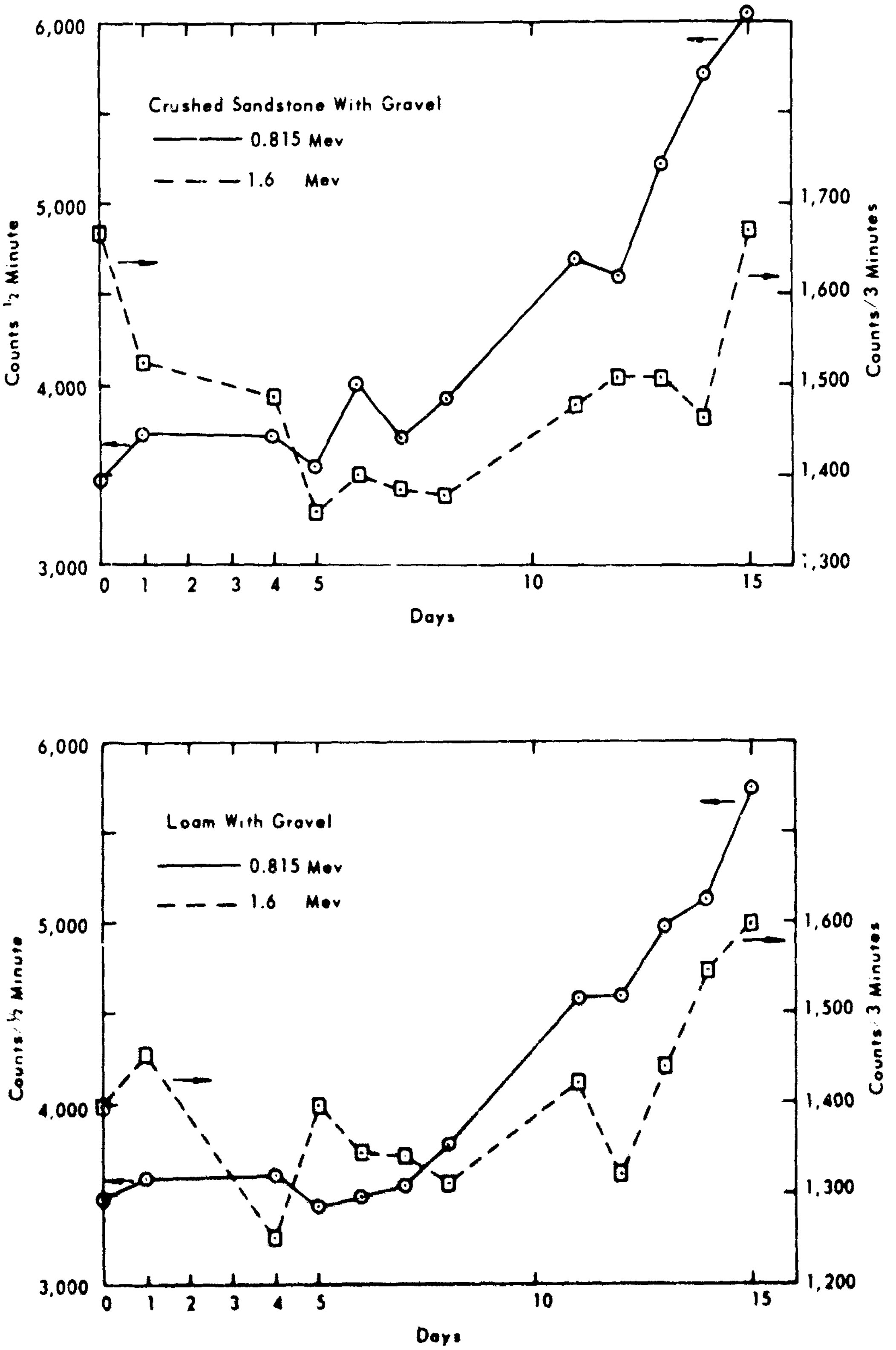

Figure D-1b. NCEL radiation levels after successive thaw-freeze cycles. (Corrected for decay.)

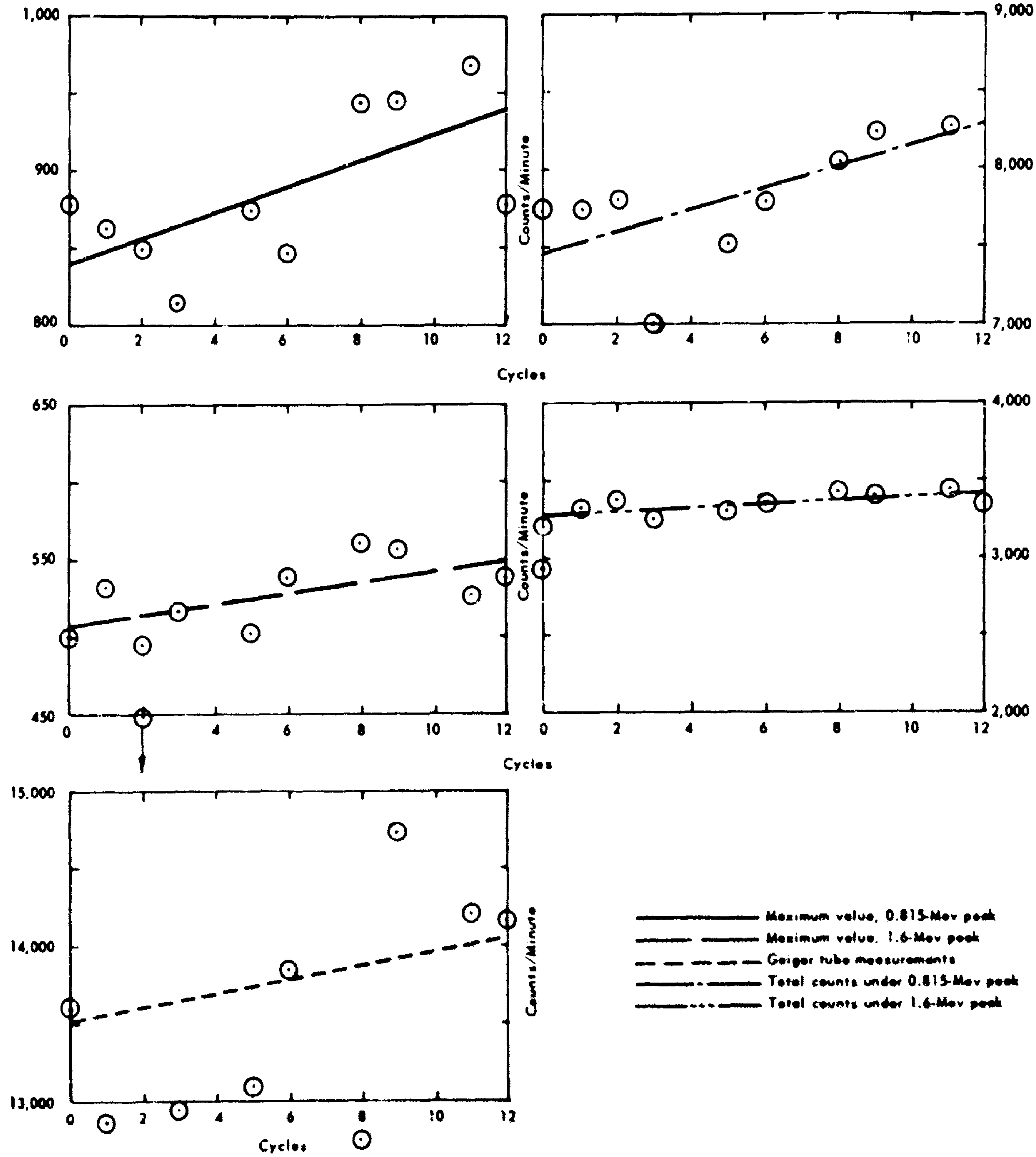

Figure D-2a. Mugu radiation levels, after successive thaw-freeze cycles, for fused simulant on sand. (Corrected for decay.)

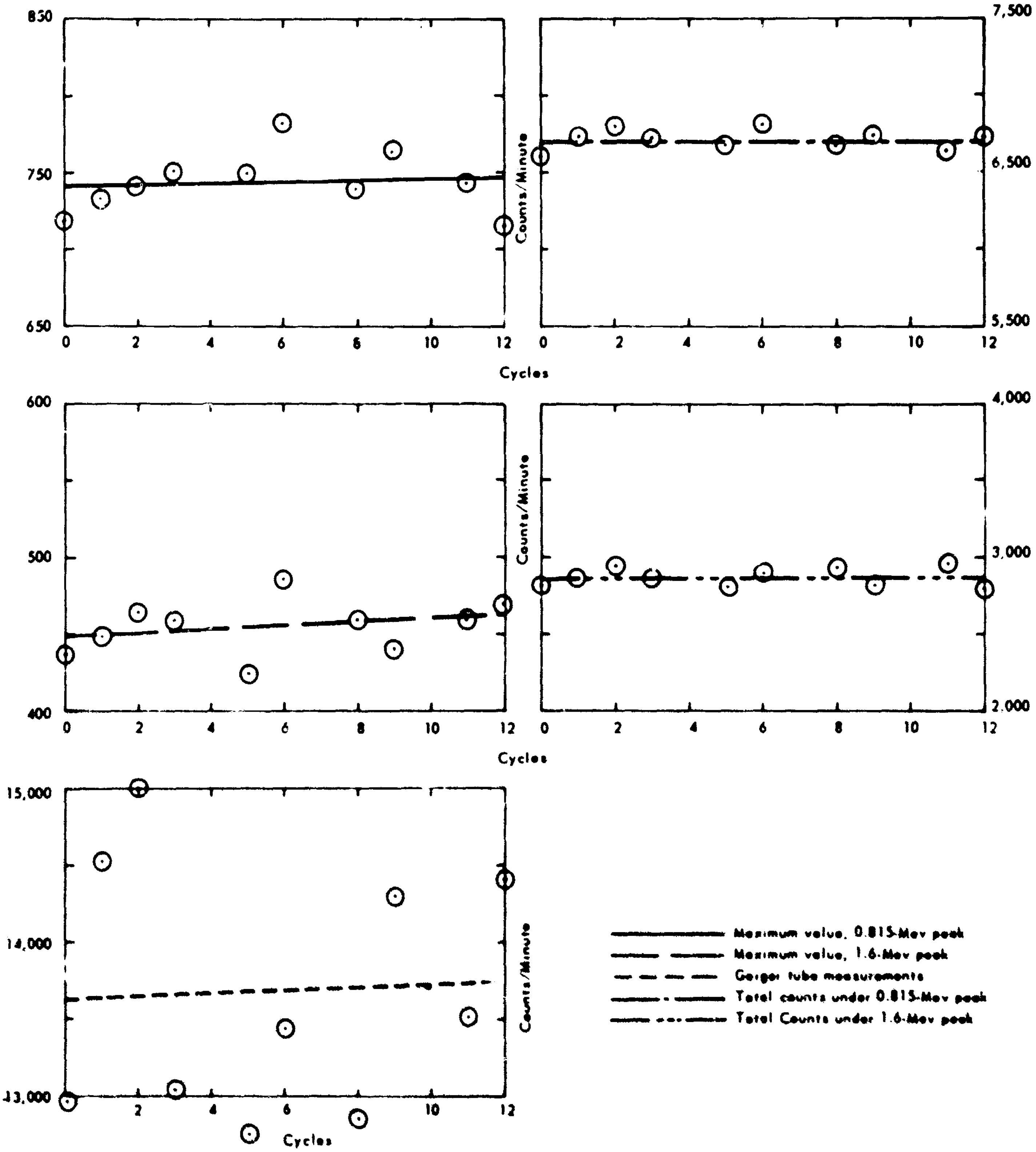

Figure D-2b. Mugu radiation levels, after successive thaw-freeze cycles, for fused simulant on loam. (Corrected for decay.)

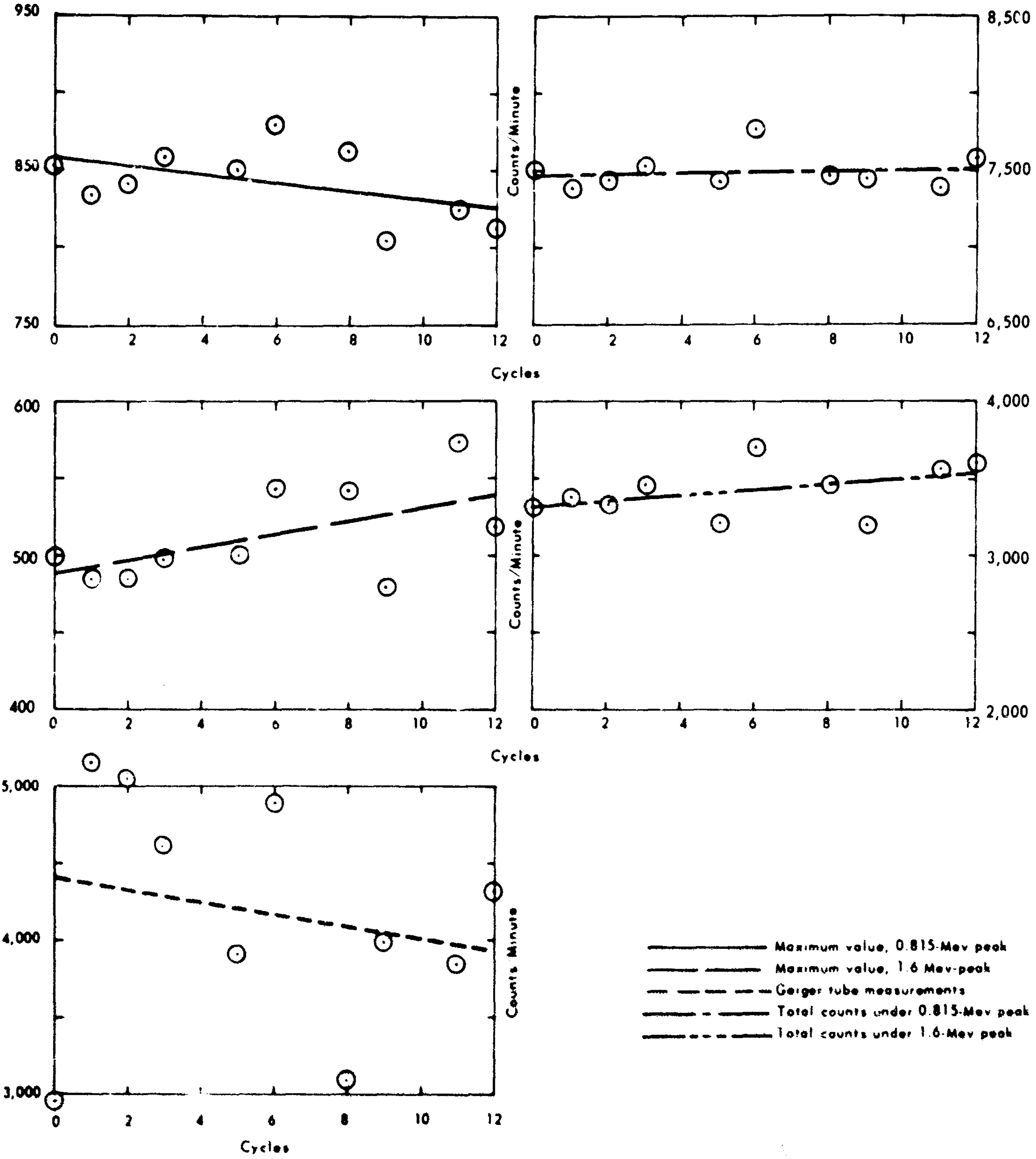

Figure D-2c. Mugu radiation levels, after successive thaw-freeze cycles, for fused simulant on loam and gravel. (Corrected for decay.)

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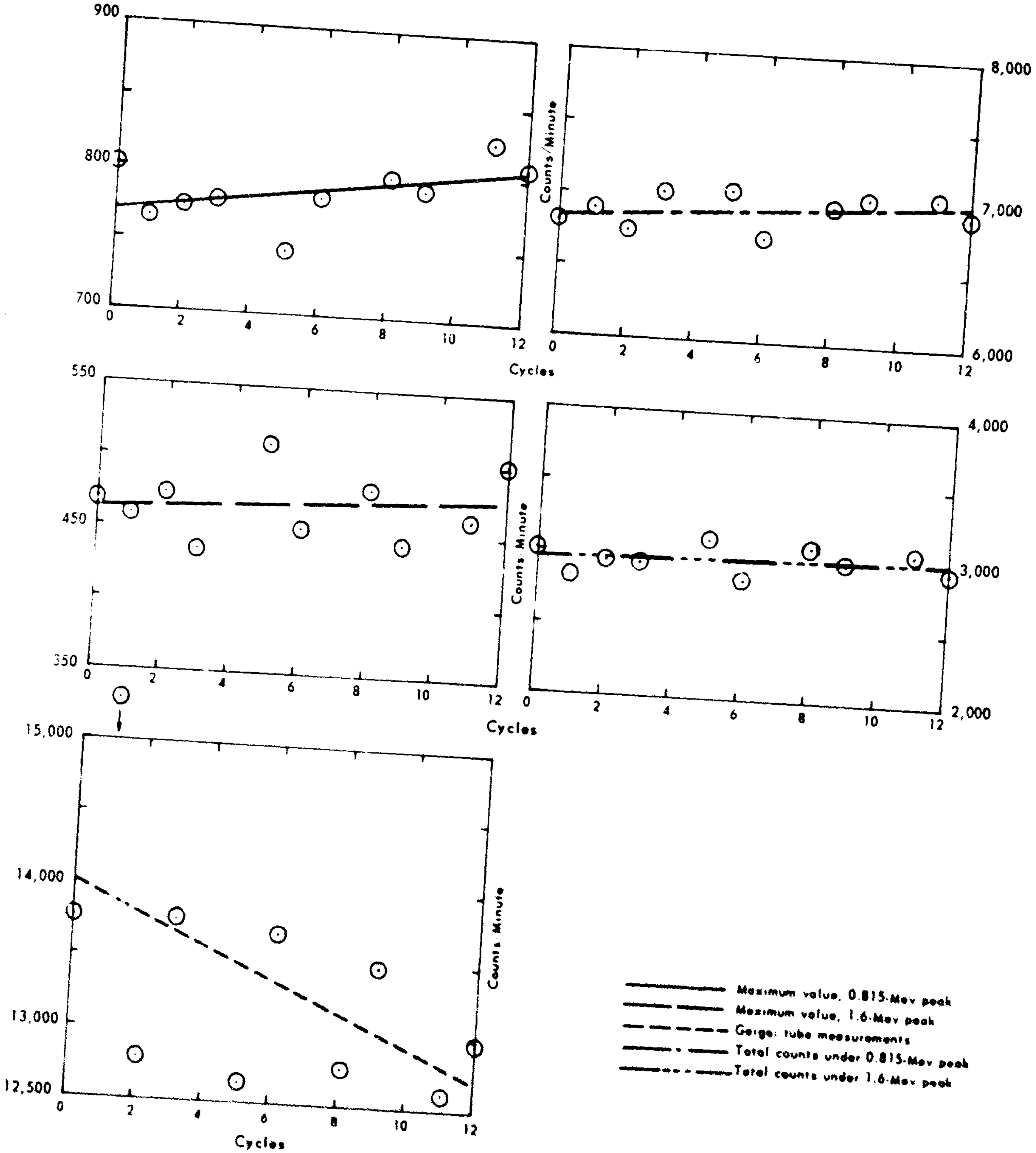


Figure D-2d. Mugu radiation levels, after successive thaw-freeze cycles, for fused simulant on crushed sandstone and gravel. (Corrected for decay.)

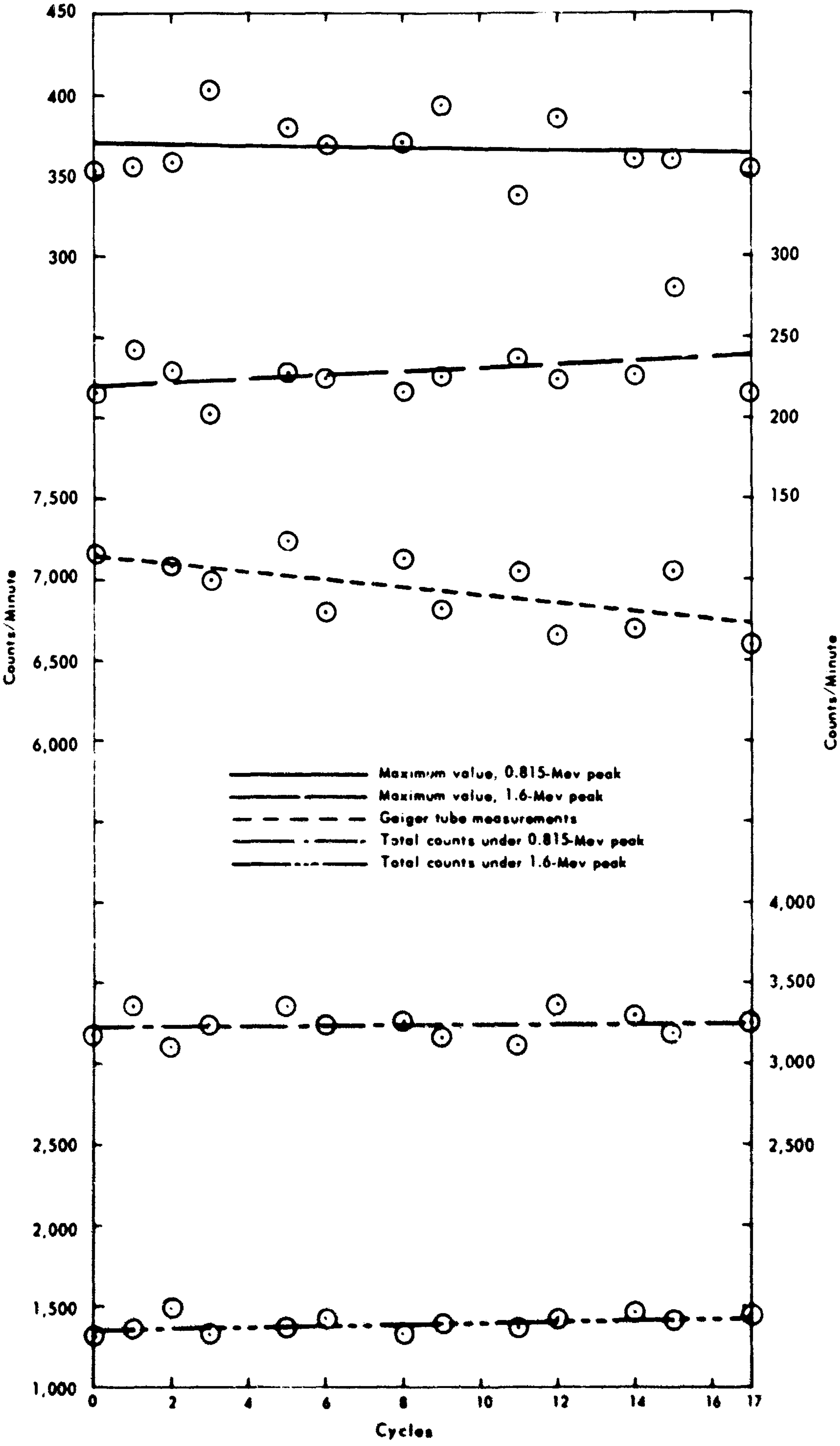


Figure D-2e. Mugu radiation levels, after successive thaw-freeze cycles, for leachable simulant on sand. (Corrected for decay.)

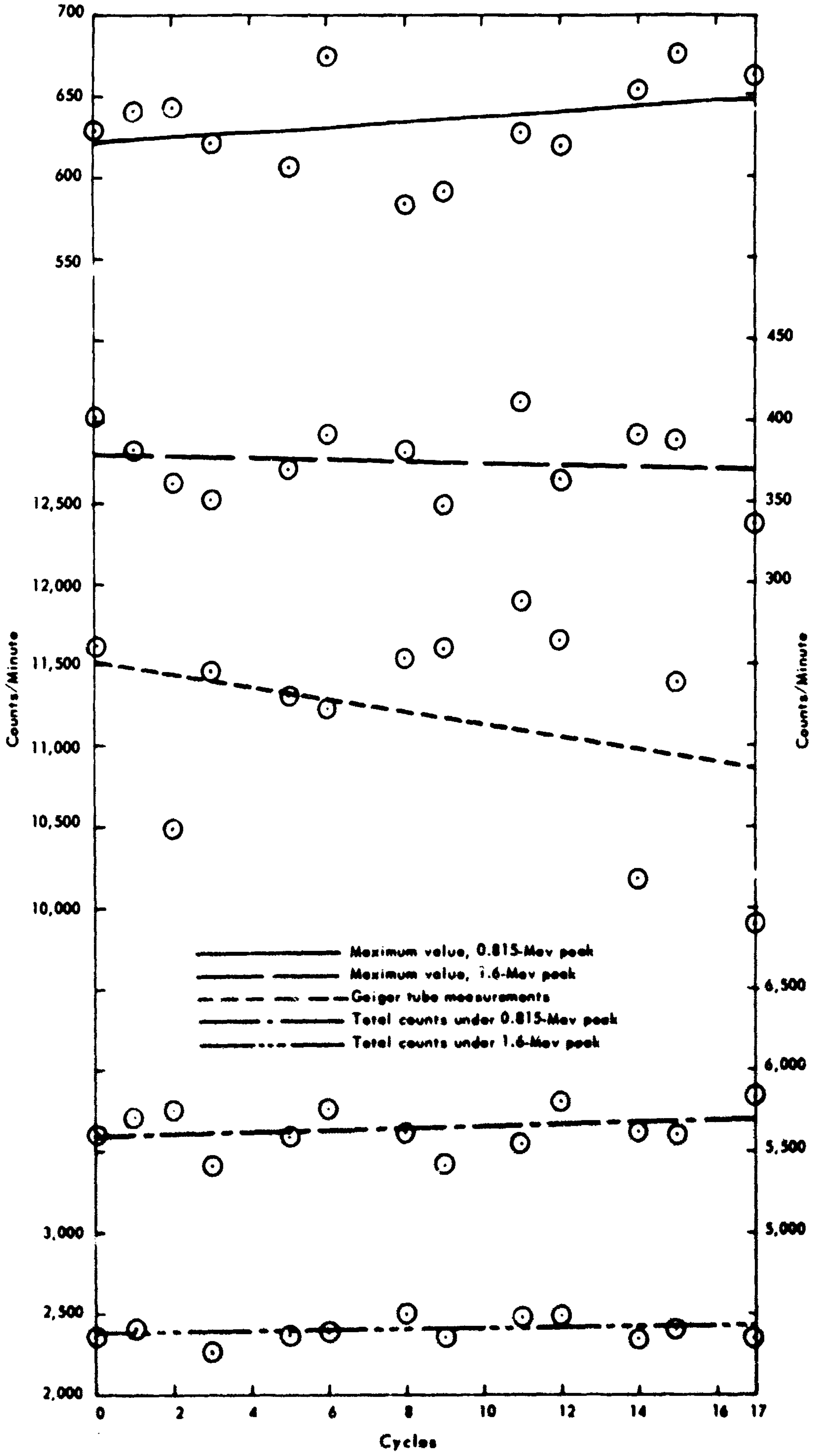


Figure D-2f. Mugu radiation levels, after successive thaw-freeze cycles, for leachable simulant on loam. (Corrected for decay.)

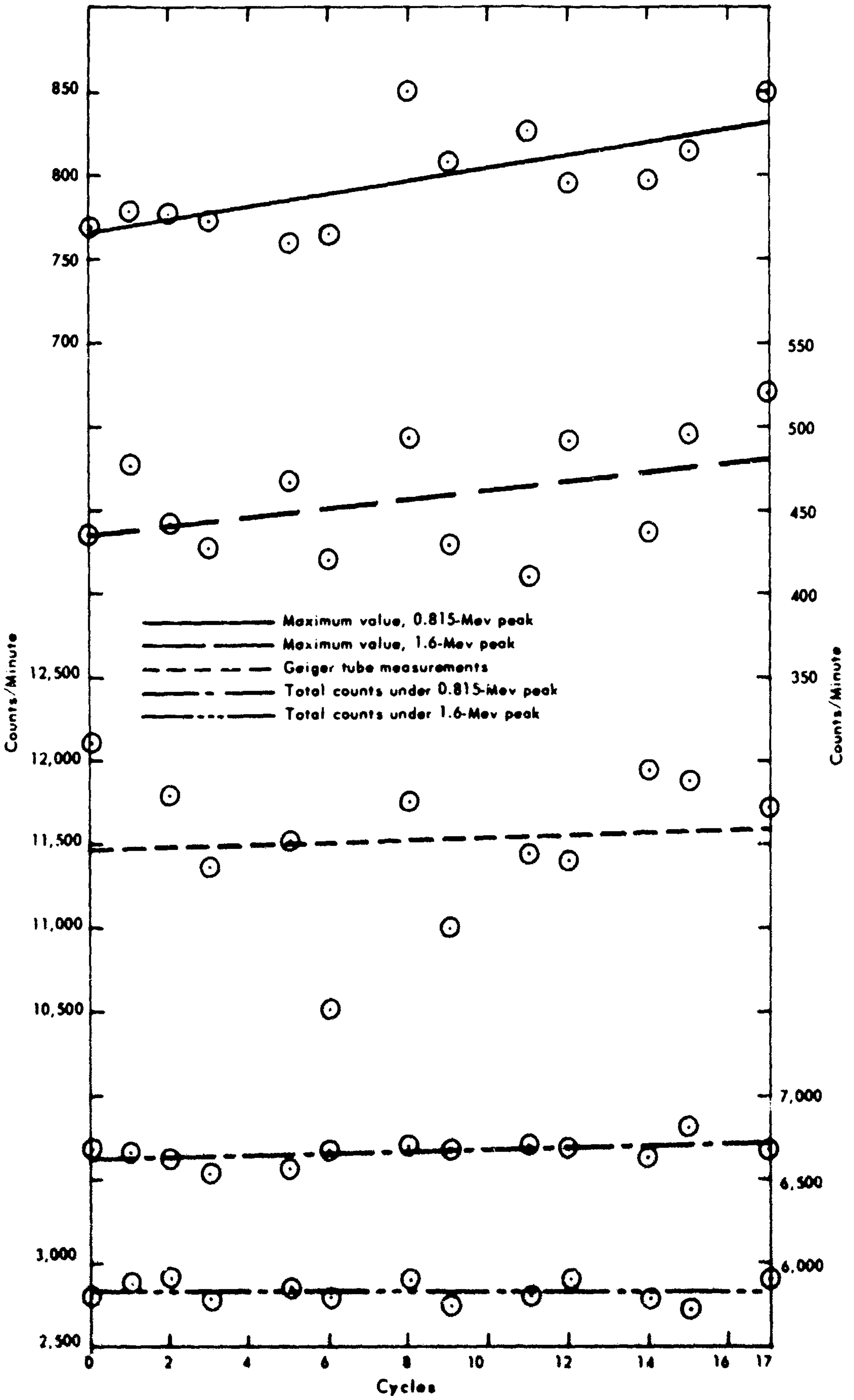


Figure D-2g. Mugu radiation levels, after successive thaw-freeze cycles, for leachable simulant on loam and gravel. (Corrected for decay.)

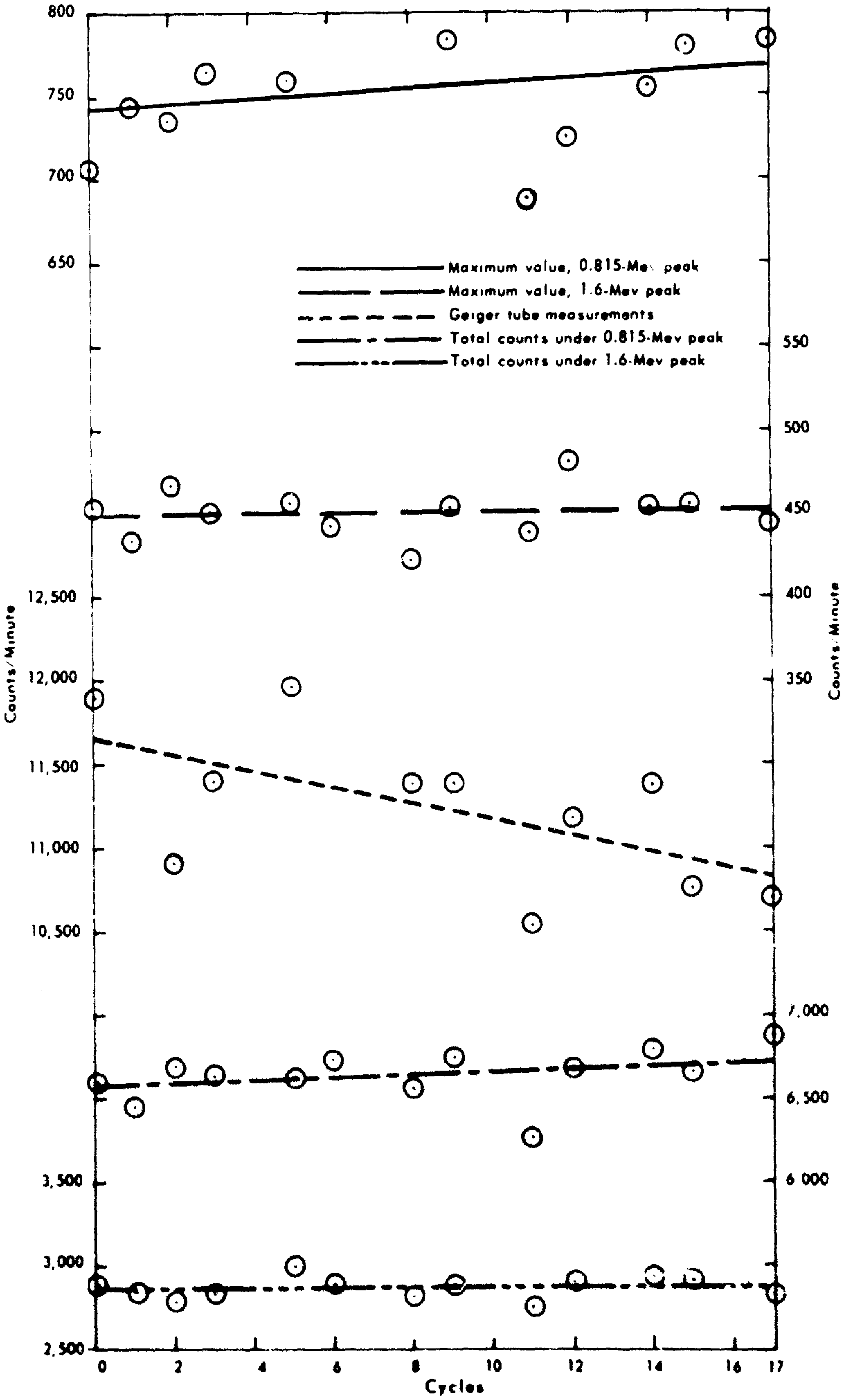
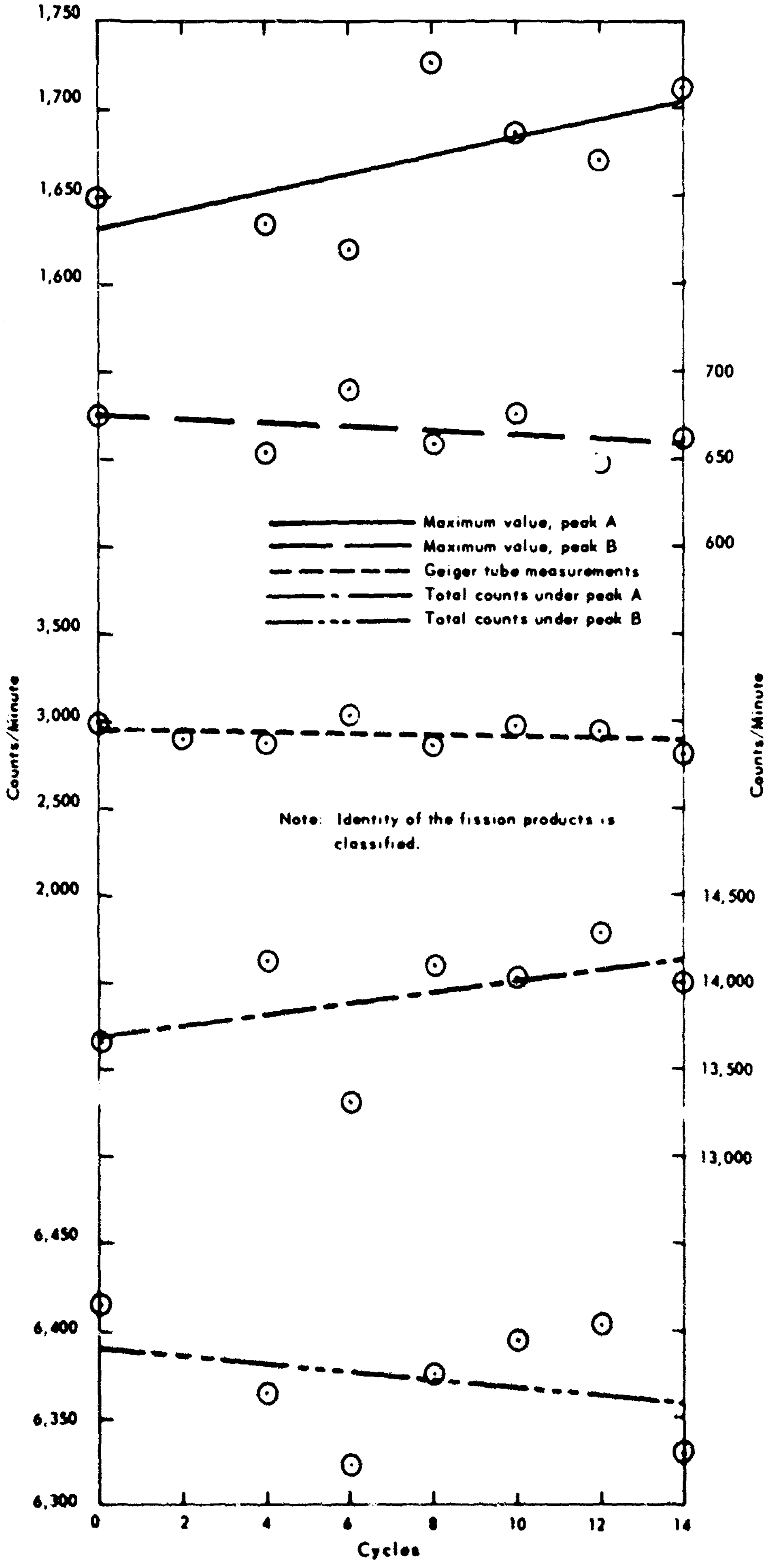


Figure D-2h. Mugu radiation levels, after successive thaw-freeze cycles, for leachable simulant on crushed sandstone and gravel. (Corrected for decay.)



Note: Identity of the fission products is classified.

Figure D-2i. Mugu radiation levels, after successive thaw-freeze cycles, for natural fallout on sand. (Corrected for decay.)

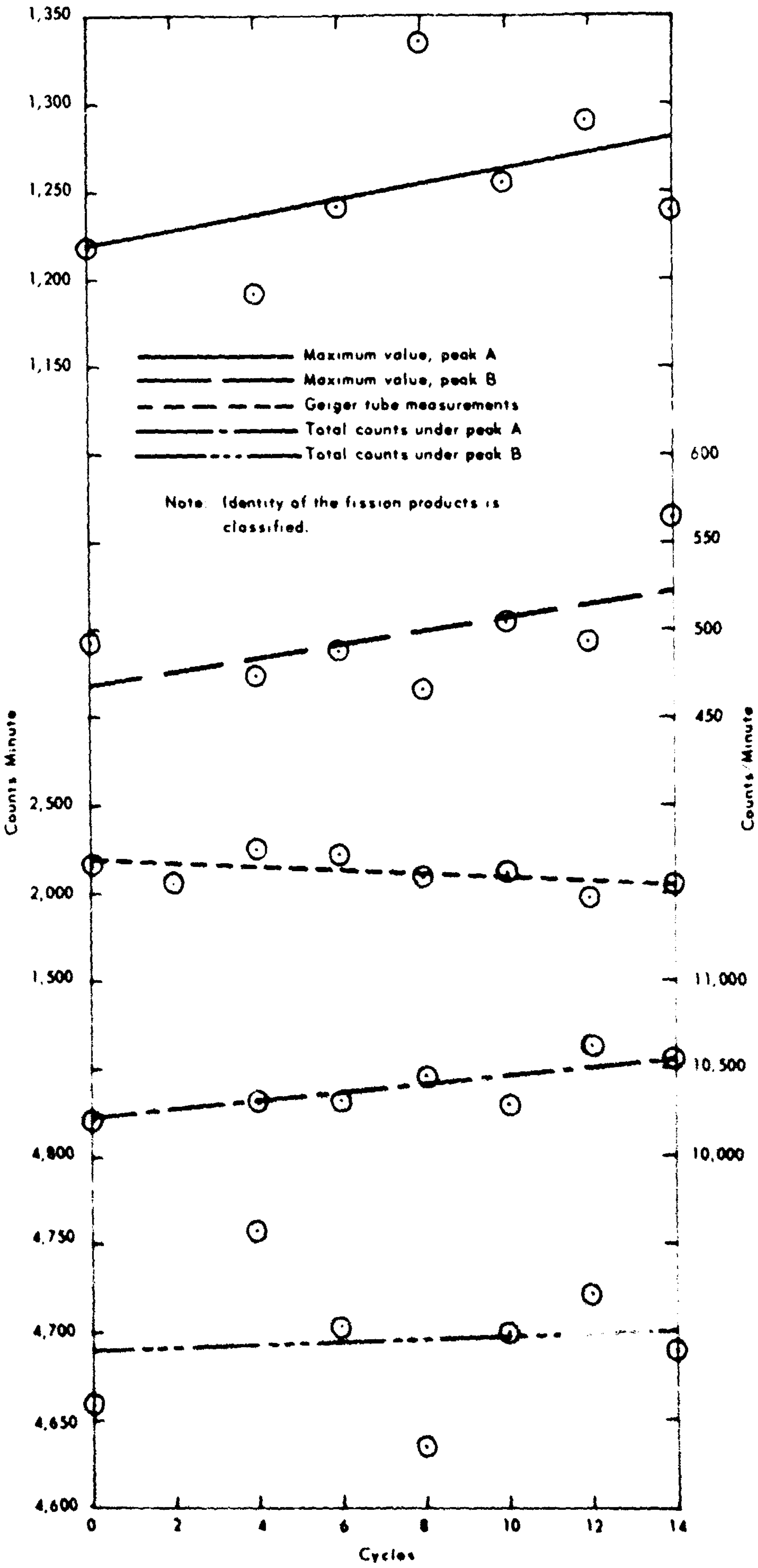


Figure D-2j. Mugu radiation levels, after successive thaw-freeze cycles, for natural fallout on loam. (Corrected for decay.)

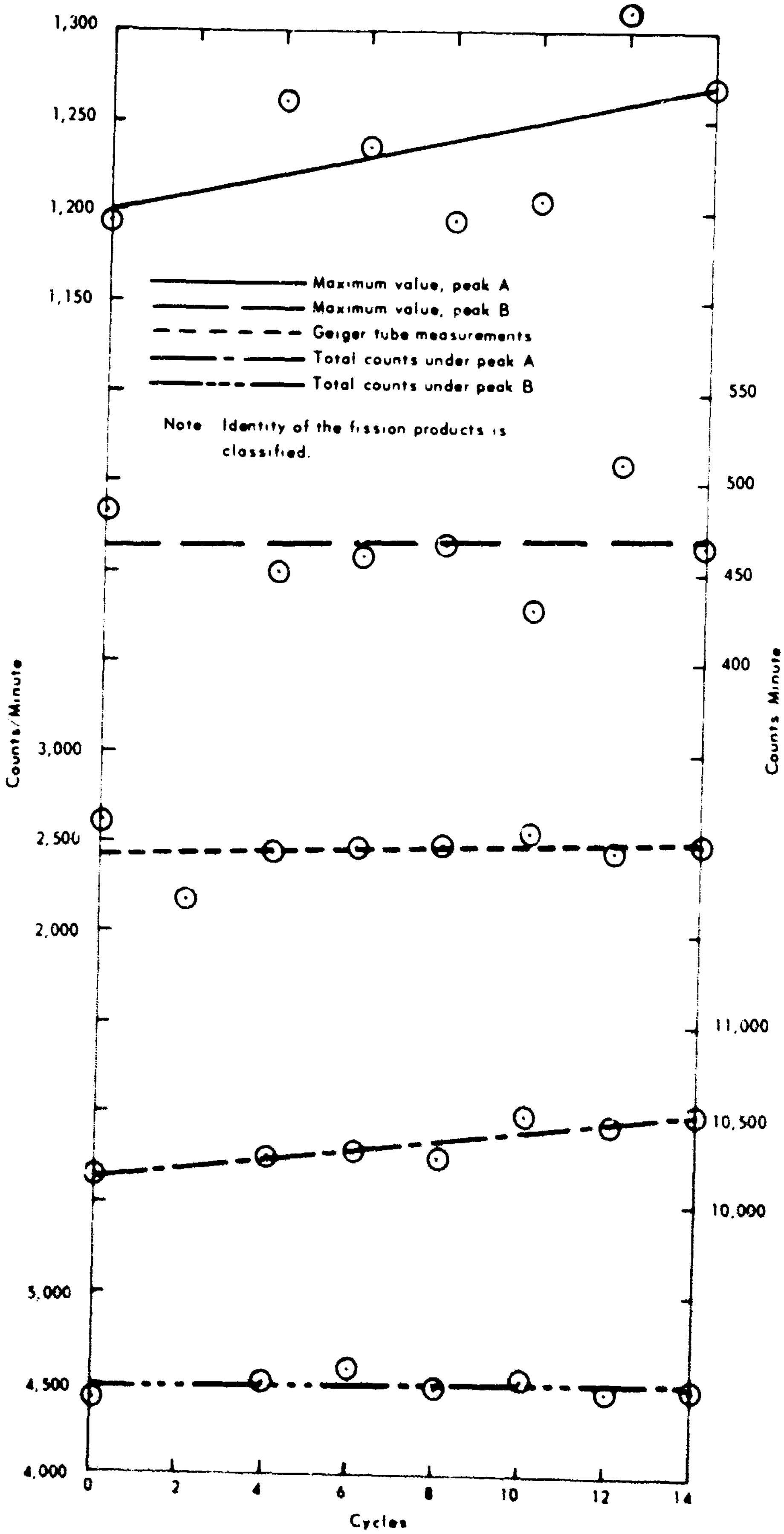


Figure D-2k. Mugu radiation levels, after successive thaw-freeze cycles, for natural fallout on loam and gravel. (Corrected for decay.)

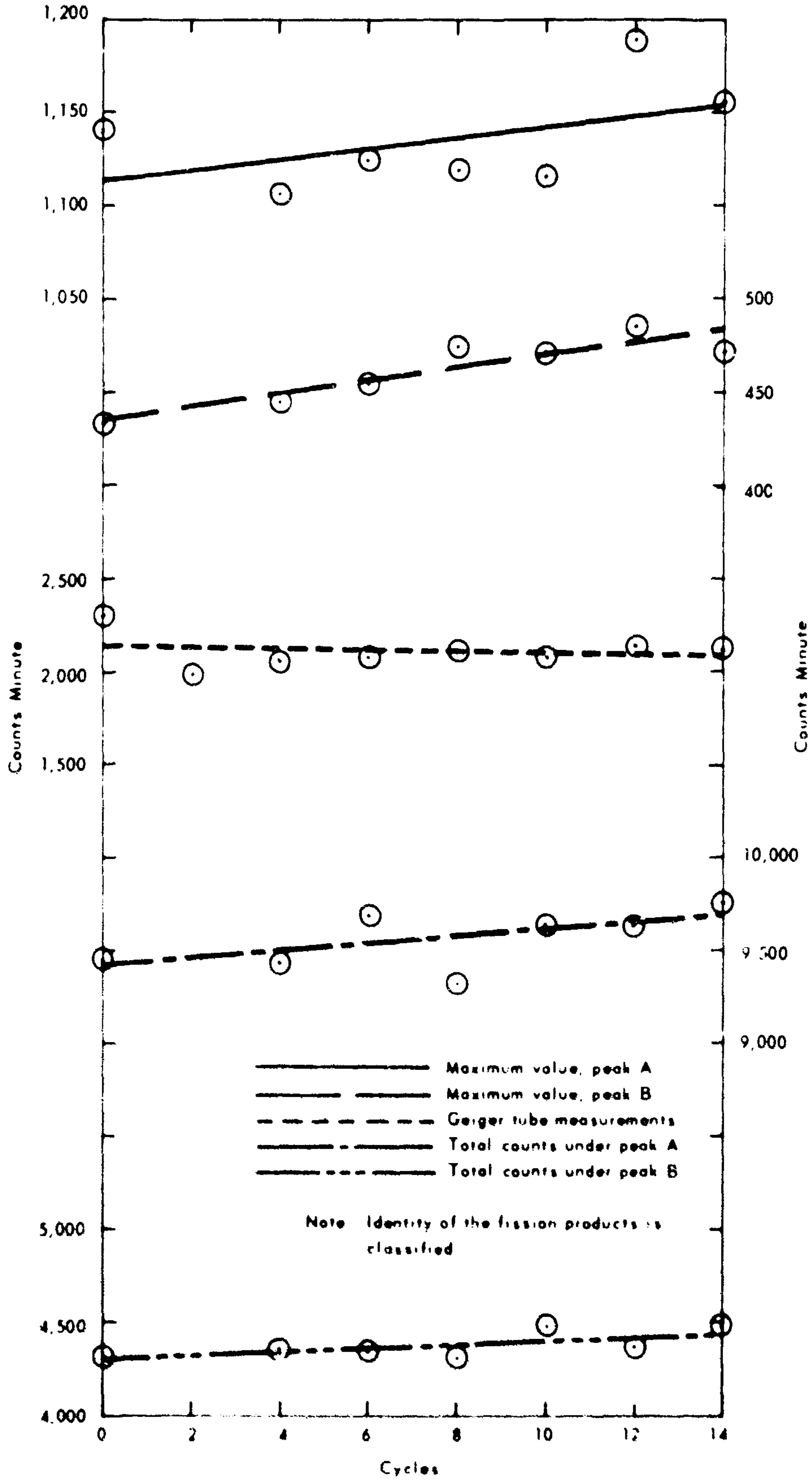


Figure D-21. Mugu radiation levels, after successive thaw-freeze cycles, for natural fallout on crushed sandstone and gravel. (Corrected for decay.)

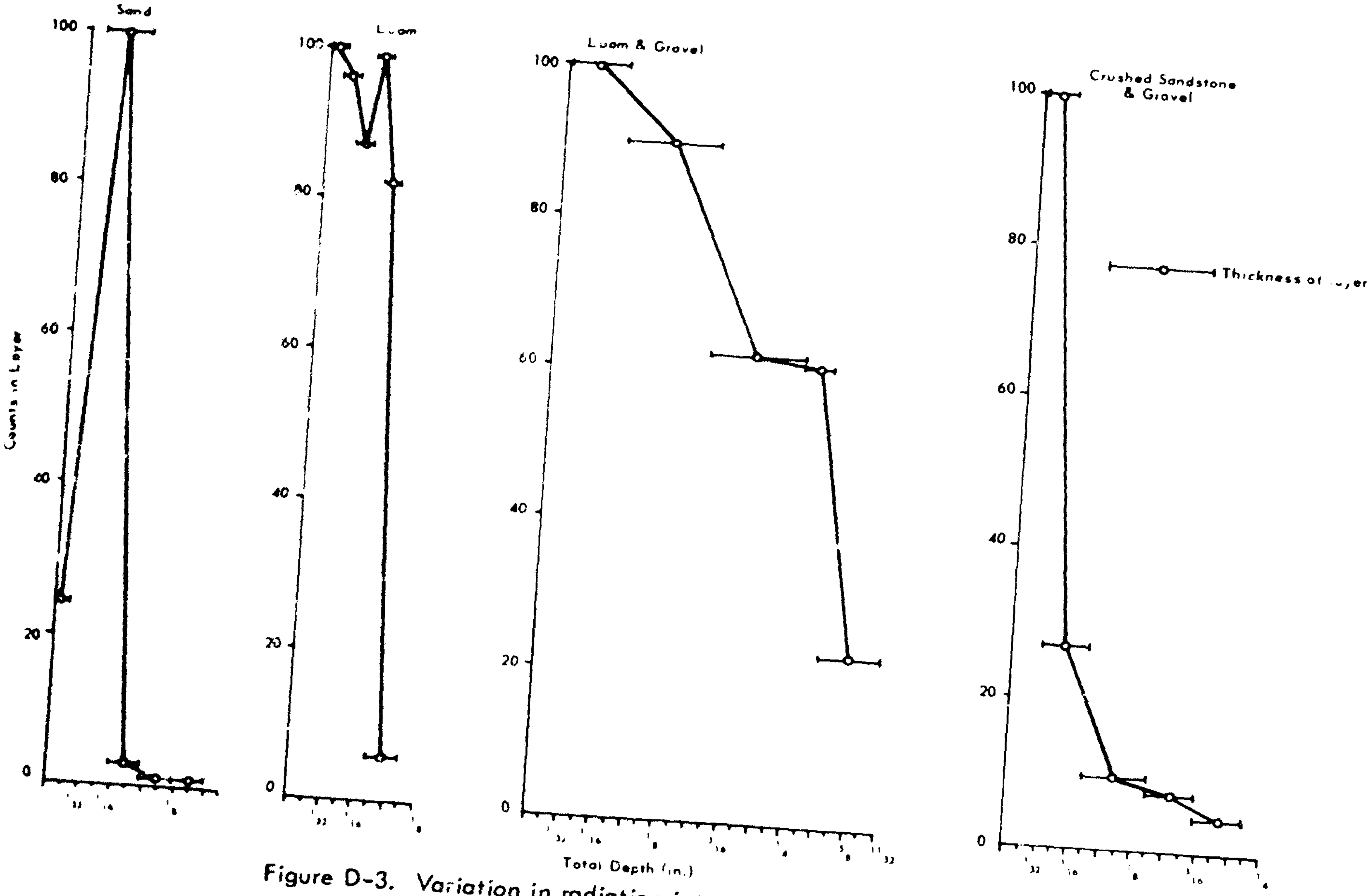


Figure D-3. Variation in radiation intensity with depth in core for fission products.

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