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HIGH-LEVEL SPILL AT THE HILAC

Nelson B. Garden and Carroll Dailey

September 24, 1959

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ABSTRACT

On July 3, 1959, an incident occurred in the Hilac Building when the turning of the wrong valve resulted in pressurizing a helium cooling box, with a resultant "blowout" of a thin foil. The burst of He gas disintegrated experimental foils made up with 10^{11} dpm of Cm^{244}. The resultant activity was quickly dispersed as airborne particulates throughout the building. The 27 people in the building were evacuated within 10 minutes under surveillance of the Health Chemistry personnel; wherever clothing proved to be contaminated it was removed, and in cases where nose swipes were pertinent they were taken.

Although an assumption of a combination of the worst conditions could conceivably have resulted in 1 man's inhaling between 2 and 4 times the calculated allowable inhalation for short bursts, evaluation from air analysis and medical tests indicate that it is unlikely that anyone actually did receive this amount.

The building was closed during decontamination procedures, which required about 30 people for 3 weeks in direct decontamination work and 30 people for 3 weeks in indirect work.

The cost of labor, material and other charges related to the spill amounted to about $30,500 without overhead; equipment loss was held to less than $2000. The lost time of operation of the hilac has been evaluated at $26,000, so that the total loss from the incident amounts to roughly $58,500.

The primary cause of the accident has been determined to be an error by the experimenter. Steps have been taken to help insure against any recurrence of an uncontained radiation spill at the hilac, and to decrease the danger of exposure to personnel in the event that a spill should occur in the future.

CONCLUSIONS

It is clear that the primary cause of the hilac curium spill was an error by an experimenter at the hilac. Failure to operate certain valves properly caused an overpressure on a 0.1-mil nickel foil "window" of a helium cooling chamber, so that it ruptured; the resultant outrush of helium shattered and dispersed the curium target that was just outside the chamber.

It should be pointed out, however, that the chamber that blew out contained two foil windows of identical type—one separating the atmosphere from the helium and the other separating the helium from the accelerator tank vacuum. In all previous ruptures, the foil on the vacuum side was involved, since it is always under one atmosphere higher pressure than the other foil. The result in such a case is a small explosion into the tank, so that the target is not affected. That the foil at the much lower pressure differential failed in this spill indicates a very unusual situation.

The cost, for which an upper limit of $ 58,500 has been given, is regrettable and serves to indicate the financial justification for carefully implemented operating procedures and, where possible, design of experimental equipment in such a way that mistakes cannot result in spills. The time lost to research—three weeks—is also an important consideration.

Although the field of research is one for which it is admittedly very difficult to set down routine-type safety procedures, the foregoing information makes it clear that it is incumbent on the Atomic Energy Commission, the Lawrence Radiation Laboratory, and the researcher himself to insure that everything possible is done to prevent an occurrence of this nature. This means that the research programs should be reviewed carefully for possible improvements in health and safety measures, and that all possible efforts should be made to carry out suggestions made by the appropriate groups.

The investigating committee commends the personnel of the hilac for prompt and effective action following the spill, and the members of the Health Chemistry department for the efficiency and thoroughness with which the radiation problems were handled. In particular, the Decontamination Team is to be commended for substantially reducing both the loss in research time and the cost of unusable equipment by painstaking efforts and by application of advanced decontamination techniques.

RECOMMENDATIONS

1. A more clearly defined and forceful attitude regarding health and safety measures should be evidenced. The magnitude of contamination from this spill can probably be attributed, at least in part, to lack of firm policy.
2. Arrangements for obtaining the services of a physician quickly in case of a radiation incident should be made more workable. Although procedures have been set up for such an emergency, about an hour and a half elapsed before an M. D. could be reached for advice.
3. There should be more storage space for apparatus not being currently used. The presence of large amounts of extraneous equipment in the experimental areas greatly complicated the task of decontamination. Good housekeeping practices should be conscientiously enforced.
4. A shower with catch basin, should be provided near an exterior door of the building for removing surface radioactive contamination from personnel involved in spills. The existing shower is designed for removal of chemicals and was in the area of greatest contamination. Hilac personnel found it necessary in this case to travel more than a quarter of a mile to shower.
5. An automatic alarm system actuated by an alpha air monitor should be installed.
6. Primary enclosures, i. e., enclosures around individual pieces of experimental equipment containing radioactive materials, should be provided.
7. Secondary enclosures should be provided to isolate reasonable work areas. These areas should be individually ventilated.

I. PHYSICIST'S REPORT

(Statement supplied by Dr. Albert Ghiorso, who was conducting the experiment involved in the radiation spill.)

The experimental setup was arranged so that two curium targets were mounted in an atmospheric pressure of helium to be bombarded by a heavy-ion beam which had been degraded in energy. Each of these particular targets of curium had been electroplated onto a 0.1-mil nickel foil spot-welded across a 1/4-in.-diameter hole in a stainless steel plate, and contained approximately 150μg of curium (95% was Cm^{244}; the rest was heavier isotopes). The target chamber was separated from the hilac vacuum by the degrading-foil assembly. This consisted of variable aluminum absorbers mounted in a circulating helium cooling atmosphere. Windows of 0.1-mil nickel foil across 3/8-in.-diameter holes were used to allow passage of the beam through this unit.

Over a period of more than a year this apparatus was used with great success. It was found that when the beam occasionally melted one of the foils in the degrader assembly this fact was almost immediately apparent and prompt measures could be taken. Since the pressure on the window separating the hilac vacuum was always 15 lb/in.^{2} higher than the window on the target side it was felt that an explosive breakage of a window would always occur into vacuum. Thus a gate was installed to protect the hilac tank from contamination. This breakage had always been into vacuum until the accident, and had occurred many times when the beam was focused into spots that were too intense. Breakage of the window on the target side was never explosive, since the pressure across the foil during operation could never be more than about 2 lb/in.^{2}

The system seemed relatively foolproof except for difficult problems in handling of the intensely radioactive curium targets. Most of our safety efforts were thus directed toward improving our techniques in the manipulation and storage of the targets, since previous minor spills could be traced in their causation to these parts of the experiments. For this and other reasons the detection apparatus had been recently moved to a separate cave to further this isolation. For "end of the fiscal year" budget reasons the complete isolation of the air for this cave had been postponed for a few months.

On the afternoon of July 3, preparations were made as usual to begin an experiment. Although the curium targets were not to be bombarded on this day they had not yet been removed from the target chamber, since it had been decided that they should be handled as little as possible—the safest storage spot for them was deemed to be in their running position during the preceding experiment. It was necessary to flush the degrading-foil chamber prior to startup of the circulating system to remove any air that had entered the system. For this purpose the supply of helium was allowed to travel through the system and then was bled out to the cave. After this purge operation had been completed—a matter of 10 to 15 minutes—the bleed valve was closed. Unfortunately I forgot to open the return valve on the system to complete the gas circuit for the circulation pump. As a result when I turned on the pump (located outside the cave) the pressure built up to about 9 lb/in.^{2} Normally even this mistake should not have been catastrophic, since the pressure on the first foil was 9 + 15 = 24 lb/in.^{2} and hence the first foil was much more likely to break. Previously when this same mistake in operation had been made this is what had happened—consequently a false sense of security had been built up by this "foolproof" pressure fuse.

This time the target window broke with an explosive force. The helium which then must have come in with a high velocity broke through a 0.1-mil nickel shielding foil and then through both curium targets. Nothing was left inside the 1/4-in.-diameter holes. Apparently most of the curium was blown out into the cave—approximately 10^{11} α dpm! The curium was literally exploded into a dust, as demonstrated by the fact that much of the "fallout" was in the submicron range of size. The natural draft out of the cave (aptly named Hades) apparently carried much of the activity over the shielding wall into the back cave and up above the cave timber ceiling into the main accelerator room. From here it traveled everywhere, but mainly toward the east end of the building (which was open at the time). Blowers picked it up and distributed it in some very unlikely places.

At the time of the explosion I was fortunately just outside the cave and heard a sound as of a high-voltage arc. I entered the cave within less than one minute after the rupture occurred to look for trouble. I noticed that the helium pressure was wrong and guessed that a window had been blown. I quickly turned off the proper valves and the pump and proceeded to check to verify what had happened. Pulling the absorber changer out for inspection revealed that the

window on the target side was broken for the first time! A check with an alpha meter showed greater than 10^5 α cpm on the target side of the absorber changer. A quick survey of the vicinity showed upwards of 10^4 α cpm on the floor, table, apparatus, and myself.

I called Sue Hargis over the intercom and told her that there had been a release of activity into the cave. She came quickly and checked the air-monitoring filter paper and discovered that there was a lot of air-borne contamination in the cave area adjoining the Hades cave where the "spill" had occurred. With an admirable alacrity she went to the control room and told Bill Stahl to clear the building. This he quickly did over the public address system by calmly instructing everyone in the building to leave via the west entrances, where they would be checked for contamination. I estimate that everyone without a respirator was out of the building within five minutes of the explosion.

Meanwhile a respirator and suit of coveralls had been given to me at the entrance of the cave. These I had donned, and after shutting down equipment that I thought might make things worse, I went to take a shower in Bldg. 70. I estimate that I was in the Hades cave (unaware of the magnitude of the accident) for not more than ten minutes. Fortunately for me the helium released by the explosion must have created an updraft to carry the fine particles upward out of the cave. Most of the time that I was in the cave I was crouching at the entrance.

The building was sealed off for the day and the next morning I joined members of Health Chemistry assembled at the hilac to assess the damage and decide what had to be done next. With proper equipment we went into the cave to check on the targets. Examination showed that they had both been completely blown away. I still felt that some of the material might have lodged in the apparatus, but later this proved not to be the case. It was soon found by spot checking that there was alpha activity everywhere and so the laborious job of decontamination was begun.

That this job was essentially finished in three weeks so that the accelerator could operate again was a tribute to the efforts of Joe Rainey and his crew of decontaminators recruited from all of Health Chemistry. During this period the hilac accelerator operators were put under Rainey's direction to help in special ways with the cleanup. The decontamination of Bldg. 71 was thorough and painstaking and yet quick, and is all the more remarkable when one considers the complexity of an accelerator and its equipment.

Since the spill a great amount of thought has been given to the problem of how to prevent the recurrence of such an incident. With Pat Howe and other members of Health Chemistry we have evolved a new completely isolated system which will be as nearly foolproof as possible. Although we certainly cannot reduce the hazards to zero, I think that what we are now installing in the way of equipment will minimize the dangers and confine them to well-controlled areas. The lesson learned from this incident I think has been well-learned, and since no one ingested more than 10% of a body burden we are fortunate that the cost of the lesson was only financial.

II. MONITOR'S REPORT

(Account given by the building monitor, Sue Hargis, of her activities subsequent to the spill.)

The following events occurred immediately after the explosion of two Cm^{244} targets in the target chamber of Albert Ghiorso's "cart" located in the center cave or center target area. Ghiorso's cave is equipped with an alpha meter (Goldie type) and also a P. A. system. Al asked the control room to send the monitor to his area. I went to the doorway of the cave. Al said he had spilled some curium and he was monitoring the floor. I went back to my room for clean gloves, booties, and a meter. After giving booties and gloves to Al, I went to the rear cave area, where the Filter Queen (a clamshell type) samples air from the center cave. The meter was pinned off scale on the 1000 scaler, or more than 20,000 cpm. I returned to my office,telephoned Bob McCracken,and told him we had a Cm spill and to send anyone he could find. I got three respirators, a pair of coveralls, and the Filter Queen in my room. I had a Robbie type meter. Returning to the front cave entrance, I asked Frank Grabelch, who was standing by the cave door, to get the roll of tar paper from my room and lay a piece down by the door. I gave him a respirator and one to Al, told him to remove his clothing, put the coveralls on, and get out, as the Cm was air-borne. I plugged in the Filter Queen and placed it in front of the cave entrance. I planned to take a 5-minute air sample to see if the Cm was airborne outside the cave. Removing the paper to check the background, I found the paper over 2,000 cpm. I went to the front cave; the filter paper read about 5,000 cpm. Bill Stahl, control room operator, was in the hallway. I asked him to make an announcement over the P. A. requesting everyone to leave the building immediately, via the control room door. I asked Bobby Garrett to pick up nose swipe equipment on her way out.

Outside the building we began monitoring each person and taking nose swipes of each. After checking out two hilac operators, I asked them to go to the south end of the building and close the big bay door.

Twenty-seven persons were in the building at the time of the spill. At least half of these were plumbers working on the back end of the poststripper tank and the front end of the prestripper tank. Al left immediately for Bldg. 70 to shower. I also showered. Vic Viola washed his hair in the sink located in Room 134. Persons whose clothes were contaminated were asked to tag them. These were placed in cement sacks and removed to Bldg. 70.

After great difficulty and a long lapse of time, we located a doctor. He suggested a 24-hour urine specimen be taken. The time was then 1640, and all persons involved had departed to various locations. Five persons turned in 24-hour specimens on Monday, July 6. The period elapsing between the time of the spill and the evacuation of the building was about 10 minutes and not more than fifteen minutes, or approximately between 1515 and 1530.

III. THE HILAC BUILDING

Building 71 at the Berkeley site is commonly known as the Hilac Building. The hilac (heavy-ion linear accelerator) was completed in 1957 -- an investment of $1,400,000--for research by bombardments with heavy ions such as carbon or nitrogen. The major part of the building is a single bay about 250 by 50 ft, containing the accelerator tank, the experimenters' target equipment, and a storage and receiving area, all serviced by an overhead 10-ton crane. Figures 1, 2, and 3 indicate the building plan and the internal arrangement.

IV. THE CAVE AND EXPERIMENTAL EQUIPMENT

The spill can best be visualized by reference to Fig. 4. The schematic representation shows how the beam from the hilac is brought to the research foil or target, and how this target is interconnected to the auxiliary experimental equipment. The overlay shows the box enclosing the energy-degrading foils. The heat generated in the foils through beam absorption makes it necessary to cool them by circulating helium. This box permits the beam to enter through the 0.1-mil Ni foil labeled "vacuum window" and leave by the 0.1-mil Ni foil marked "collimator and window." This box is maintained at approximately atmospheric pressure of He circulated as indicated. Startup is preceded by closing valve No. 2 and opening valve No. 3 and opening valve No. 1 to purge the box of air. Then No. 2 valve is opened and No. 3 closed for operating conditions.

On the occasion of the spill No. 3 was closed after purge but No. 2 was not opened, and the helium pressure in the box built up to an estimated 9 lb/in.^{2}, resulting in rupture of the collimator window and allowing a burst of helium to strike the exceedingly fragile targets. These involved approximately 10^{11} dpm of Cm^{244}. Various tests and calculations (discussed later in the report) indicate that the Cm was immediately dispersed, largely as submicron particles.

The exact location of the experimental setup described was in the "cave" marked "Hades" in Fig. 1. This encompasses an area of 50 ft^2 congested with electronic, television, and related experimental equipment. Hades is a small segment of the main cave area shown in Fig. 1 with "front" and "back" caves marked; the whole cave area is identifiable in Fig. 3, where the loose 12-by-12-in. timbers, 20 ft long, serve as a roof for the caves and also as neutron shielding in the interim pending construction of permanent shielding.

The shielding between caves and for the passageway is from 1 to 2 ft of concrete. Additional steel shielding separated all other beam ports from the one beam port in use for curium bombardment. A labyrinth door served to close Hades from the passageway.

The ventilation of the hilac main bay is intended primarily to remove heat from the accelerator tanks. Air is sucked in through louvers in the wall of the basement beneath the tank, flows up through gratings around the tank, and is discharged by exhaust fans high up on the opposite wall of the bay. At the time of the incident, the Hades cave had no ventilation other than convection through the

doorway or through the spaces between the concrete wall blocks and between the roof timbers. More adequate ventilation had been recommended by the Health Chemistry Department, but had not been installed. (This ventilation has since been accomplished.)

V. EVALUATION OF THE HEALTH HAZARD

The following is an attempt to assess the possible exposure to personnel in the center and rear caves of the hilac during the initial stages of the spill. It must be emphasized that only an order-of-magnitude number is possible through such calculations because of the large number of unknowns and uncertainties inherent in air sampling, the complete spectrum of particle sizes involved (from radioautographs), the exact geographic positions and breathing rates of personnel involved, the turn-over rates of the building air supply, etc. Therefore, use the following results with caution.

For the following tables, assume:

(1) Air sampling rate of 4 cfm or 1.13×10^{5} ml/min.

(2) Homogeneous mixture of air-borne activity throughout the cave volume.

(3) Breathing rate of personnel of 2.1×10^{4} ml/min.

(4) Ten-minute exposure of personnel to cave environment in question.

Findings in the Rear Cave

Sample on: 1040 7/3

off: 0930 7/7

Sampling time: 5.7×10^{3} min

Estimated total activity on filter paper: 7×10^{6} dpm or 3.2 μC

	Air conc. in cave area (μC/ml)	Personnel exposure, 10 min (μC)
Activity buildup throughout sampling period	5×10^{-9}	0.001
Complete activity buildup during first hour of sampling period	5×10^{-7}	0.1
Complete activity buildup during first 10 min of sampling period	3×10^{-6}	0.6
Complete activity buildup during first 1 min of sampling period	3×10^{-5}	0.6 (for 1-min exposure)

Findings in the Center Cave

Sample on: 1040 7/3

off: 0930 7/4

Sampling time: 1.4×10^{3} min

Estimated total activity on filter paper: 8×10^{6} dpm or 3.6 μC

	Air conc. in cave area (μC/ml)	Personnel exposure, 10 min (μC)
Activity buildup throughout sampling period	2.0×10^{-8}	0.005
Complete activity buildup during first hour of sampling period	5×10^{-7}	0.1
Complete activity buildup during first 10 min of sampling period	3.2×10^{-6}	0.7
Complete activity buildup during first 1 min of sampling period	3.2×10^{-5}	0.7 (for 1-min exposure)

From preliminary available data, it is believed that the activity buildup on the filter papers is more likely to have occurred between the first 10 min and the first hour of sampling time. Consequently, the personnel exposure more likely lies between the limits of 0.1 and 1 μC.

From the decay scheme shown in Appendix A it can be seen that the Cm^{244} daughters need not be considered in this case. Further, the contribution to the hazard by the 5% of heavier isotopes referred to in the Physicist's statement is not believed to alter the evaluation of Cm^{244} alone.

The maximum permissible intake of soluble Cm^{244} (the worst possible form) for a short-period inhalation exposure is 0.33 μC, as calculated according to the methods of K. Z. Morgan, W. S. Snyder, and M. R. Ford, A/CONF/8/P/79, USA, July 1955. The biological and radiation data used in arriving at this figure are as published in "Report of Committee on Permissible Dose for Internal Radiation--1958 Revision" of the ICRP.

The significance of this number, 0.33 μC, is that it is calculated that this amount of inhaled Cm^{244} will deliver a dose of 150 rem in 70 years to the critical organ, the bone. The constants used, as obtained from the ICRP report, are:

Biological half life, 7.3×10^4 days

Effective energy per disintegration: 300 Mev (includes RBE value of 10 and nonuniform distribution factor of 5)

Fraction of that inhaled which reaches bone: 0.075.

VI. DECONTAMINATION PROCEDURES

On Monday, July 6, 1959, a full program was initiated by Health Chemistry at the hilac (which had been closed and barricaded since the spill on Friday) to bring the contamination from the curium spill under control. The spill had occurred during the afternoon of Friday, July 3, 1959. An evaluation of all possible sources of information indicated that the spill was quite widespread on the inside of the building, which has 15,800 ft^2 of floor area. This included three areas, the main high-bay area where the accelerator is located, with shop; the Chemistry area; and the basement.

As it was known that the contamination was quite widespread within the building, the decision was made to start decon procedures from two separate points with two separate crews, one on the day shift (8 a.m. to 5 p.m.) and one on the swing shift (4:00 p.m. to midnight).

Health Chemistry personnel participating in this cleanup operation were required to wear coveralls, booties, head covering, and respirators* at all times within the contaminated area. In addition the sleeves were taped at the wrists and the bottoms of the legs of the coveralls were completely taped from the booties up to the ankles, and at least one pair of rubber gloves was worn under work gloves.

Two types of alpha meters were used, both of Lawrence Radiation Laboratory design, one having a top range of 20,000 cpm, the other (a transistorized instrument) having a top range of 10^6 cpm. Both types of meters had been equipped with small aural amplifiers, which made for more efficient handling and detection of contamination. There were approximately 14 meters in constant use.

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*Model No. MSA Dustflo Ultra Filter respirator with type "H" Ultra Filter Cartridge CM77668.

The day crew, consisting of 23 persons, started at the entrance of the building to area No. 2 (indicated in Fig. 1). The first operation was to locate and tape down any contamination found in the control room, which contains the main public address system for the building—a two-way system—so that instructions could be given over the PA system to all personnel working in the building, and workers could communicate with the control center.

Other personnel started down the walkway, (or aisle,) surveying and taping down any contamination and clearing a 10-ft-wide path as they progressed toward area No. 5 (Fig. 1). Generally the contamination in this area ranged from a few hundred counts to 10^4. Immediately behind the crew that was locating and taping down the activity, another group laid down 48-in.-wide kraft building paper (with a tar membrane), so that the future working crews would always be working on clean paper.

A supply of equipment was established in the entry hallway (just inside of the doors of the building, next to the control room), which was the first point of entry. This consisted of extra equipment such as coveralls, booties, respirators, marking pencils, 1-in. and 4-in. masking tape, head covering, cement sacks for contaminated materials, razor blades, scissors, extra meters, absorbent paper, and Oakite liquidette and various other decontamination reagents. This entryway was the checking and suiting-up station for persons entering and leaving the area.

Continuing down the aisleway into section No. 5, as shown in Fig. 1, the crew encountered higher levels of activity, particularly at the entrance of area No. 6, where the spill occurred. In view of the levels, which ranged from several thousand counts to approximately 10^5 in some instances, it was decided that continued work in this area should be modified slightly; personnel would have fresh-air-supply masks rather than the ordinary respirator as indicated above. Full-face full-vision pressure-regulated masks were connected to fresh-air-supply units* from a clean source or from an adequately filtered intake.

One group, working under these conditions, started on the cave area No. 6, which has a mutual concrete-block wall, with many wide cracks and openings, between it and the rear cave. Area No. 6 was slightly irregular in size, comprising approximately 50 ft^2 of floor space, which was very crowded with electronics racks, cabinets, the collimated-beam apparatus, target assembly, electrical power feed-in, power supplies, and the initial target assembly where the spill occurred.

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*MSA displacement blower EB14812 and Bell and Gossett compressor with modified demand regulator.

In view of the high level of activity and the congestion caused by this equipment and apparatus in such a small area, it was necessary to limit the inside operations to three people. This team comprised a monitor and two other workers to dismantle and remove all equipment and strip this cave area clean. As previously indicated, there was no hope of bringing this area under control until the major portion of the gross contamination, which included the above-mentioned equipment, was removed. The crew inside surveyed and taped the more accessible high-level spots on the equipment. This was then passed to a crew of two monitors outside the cave, who immediately resurveyed and bagged the contaminated equipment, and transferred it to the front of the building for immediate removal by pickup truck to a restricted holding area near the decontamination headquarters to await further decision as to decontamination or disposal. The spill area was so contaminated that it required constant work under the above-mentioned conditions, involving 4 to 6 people, for approximately 12 days.

It should be pointed out that the two pickup trucks (on which the beds were taped with building paper) were handled by Health Chemistry personnel, and all contaminated material was removed from the building by Health Chemistry personnel and transported to the holding area by Health Chemistry personnel. In short, at no time was any contaminated object not under control by Health Chemistry personnel.

In conjunction with the operations of the day crew mentioned above, the swing-shift crew started from another entrance to the building, adjacent to the Chemistry section, into area No. 1 in Fig. 1. Thus both crews worked gradually toward a meeting at the rear part of the building, the intent being to offer an area of containment, according to our philosophy here at Lawrence Radiation Laboratory to work into an area having an accessible corridor, free from loose contamination, from an outside entrance of a building. The third entrance to the building, a large roll-up metal door, was contemplated as another avenue of entrance into the building, but it was not used because of the very size of the opening, which would allow for air turbulence that might move the contamination around to such a degree as to greatly hamper the tying down or control of the activity, and quite possibly also might cause recontamination in the areas that had been entered on the clean paper laid on the floor.

The decontamination team assigned to area No. 1 started working their way in, surveying the floors as they went along and taping down any activity found on the floors. They also branched off to the side as they progressed (a) to make initial surveys in the chemistry laboratories and other rooms, and (b) to block off all mutual doors and corridors leading from the main hilac area. Following closely behind the survey team, the papering team laid down kraft building paper and taped it to the floor. (The procedure was to place the roll of paper on the floor, tape down one end of it, and then unroll the paper right behind the survey team.) When the area was covered with paper the crew took rolls of 4-in. masking tape and went down both sides, taping both edges of the paper to the floor and both ends of the roll to the floor. This was to insure (a) that no contamination could come out from underneath the paper, and (b) that the paper was fairly firmly fixed to the floor so that there would be no tendency for people walking on the paper to rip it or have it slide out from under them.

This initial survey was confined to the floor and areas readily accessible from the floor. As soon as it was determined that the floor and other accessible areas were contained and controlled, the survey team started checking and taping down the overhead, particularly all horizontal surfaces. This job was made more difficult by the fact that this area is broken up by partitions, and it was necessary to dismiss the idea of a scaffold and conduct the overhead survey on ladders.

It should be emphasized that by surveying the floor in this fashion and blocking off the various lead-in corridors and doors, the crew had the chemistry section isolated so that it could not be recontaminated; moreover any traffic in the area had to come (except for any emergency) from that one entrance, where there was a Health Chemist stationed at all times monitoring people who came out of the area and permitting only authorized working clean-up personnel (mostly Health Chemists) to enter the area.

For purposes of clarification and identification we might describe area No. 6 as the center cave commonly known as Hades. (See Fig. 1) Area No. 5 includes the area or cave immediately forward of it (toward the control room), the "Front Cave," where the deflection magnet is located. The "Back Cave" is immediately behind area No. 6 (toward the rear of the building); it is a large area, actually including more than just the territory directly behind area No. 6.

Work was continuing in area No. 6 (Hades) while some work was started on the front cave, which is somewhat L-shaped and in which the main piece of apparatus is a beam-deflecting magnet which occupies about 60% of the room area. It can be readily seen that a piece of equipment of this size and gross weight could not be removed. The decision was made to survey this area, including the magnet, and to tie down all activity (which was less than 10^5 cpm general contamination) with tape, carry out the smaller pieces of apparatus, and then remove the remaining activity later by standard deconning methods. This procedure put the front cave under control and containment and secured this area from any further release of contamination.

The steel wall common to the rear cave and Hades (area No. 6) had large crevices and openings in it which led to the second highest level of contamination in the building, generally about 10^5 to 10^6 cpm. This rear cave was now being worked upon by personnel using fresh-air-supply masks. The same procedure was applied here as in area No. 6, namely two or three people working inside the cave and passing equipment out to be bagged, taped, surveyed, and transported to the restricted holding area for later decontamination.

It should be remembered that the day crew was still doing work in areas No. 2, No. 5, and No. 6, and at the same time some surveying of the floor surfaces had extended into area No. 4 (Fig. 1). The night crew on the swing shift had progressed to the rear of area No. 1 and was also surveying and checking into area No. 4 from their vantage point. This included the floor area and some of the walls and some of the overhead immediately adjacent to the Accelerator Technicians' area and to the men's room and the janitor's room.

It was then apparent that some of the people working on the day shift and some of the people on the night shift had met, so that they were working in common areas, particularly in the forepart of section No. 4.

By the beginning of the second week, July 13, it was decided to eliminate the swing shift (4:00 p.m. to midnight) for the following reasons:

(a) they had resurveyed, deconned, and cleared the Chemistry area (section No. 1, Fig. 1);

(b) the temperature built up in the building during the day did not dissipate during the night, as expected, therefore working conditions were somewhat unsatisfactory for swing shift, and

(c) operations in general had proceeded to the point where the best utilization of all Health Chemistry personnel would be during the day shift in the remaining areas of contamination. (The work week consisted of 5 days, 8 hours a day, for all personnel, whether on the day shift or swing shift).

Beginning the second week more people were assigned to section No. 4 for work in the experimental area and Accelerator Technicians' shop. The experimental area, starting at the back door and extending to the rear wall of the rear cave (an area approximately 20 by 80 ft), proved to be one of the more difficult areas to bring under control, because of

(a) the accumulated experimental apparatus, previously used over a period of years and not removed;

(b) the associated work benches, tools, and equipment in this area;

(c) the normal debris, consisting of odds and ends of the accelerator machine itself and of the associated equipment that had been left there from previous alterations and redesigns. This area had been used as a sort of dumping area for the whole of the hilac crew, including the Accelerator Technicians. In addition, this area was a receiving area for all materials for the whole building. The general contamination in this entire area ran from 10^4 to 10^5.

The Accelerator Technicians' shop presented a further difficult problem because of the locations of drill presses, punch presses, machine lathes, milling machines, sheet metal binders, sheet metal brakes, wall cabinets, benches, and hoods. The total number of pieces of miscellaneous equipment was 10 machines, 18 work benches, and 20 ft of wall cabinets 3 ft wide. In addition there was one hood 14 ft long by 4 ft wide by 3 ft high with a 7.5-ft stack 2.5 ft in diameter. It was necessary to follow the same decontamination procedure in the Accelerator Technicians' shop as before. After all the machines had been completely decontaminated they were covered (to protect against any activity from the overhead), and then the paper on the floor was pulled up, the taped-down areas were decontaminated, and fresh paper was laid down. This cleared the Accelerator Technicians' shop with the exception of the overhead area. The overhead area was vacuum cleaned, then it was monitored, and the remaining active contamination spots were taped down. In the final step the tape was removed from each hot spot in turn and that spot was deconned, and then the entire area was given a final survey. This cleared the Accelerator Technicians' shop.

By this time we had a much better idea of what the various levels of contamination had been and a better idea of how the distribution occurred. We might point out some of these conclusions.

At the time of the spill the large metal door at the rear of the building was open and five exhaust fans along the north side of the high bay were in operation, moving an exhaust air stream of 25,000 cfm.* These exhaust fans fit into a vertical frame of the building and exhaust onto the lower roof over area No. 1. (In addition, other fans that were on at the time of the spill accounted for another 6000 cfm, making a total air movement of approximately 31,000 cfm.)

The exhaust fans were found to be contaminated, in the range of 10^3 to 10^5 cpm. The blades were given a thorough vacuum cleaning and the remaining contamination was taped. These fans were then removed by a combination of personnel from Health Chemistry and the Sheet Metal Shop, with one crew working on the outside, standing on the lower roof level, and another crew working on the inside, assisting in the unbolting of the frames and the lowering of the fans to the receiving group on the lower roof. They were then transported under Health Chemistry supervision to a restricted area for later decontamination.

The air exhaust from these five large blowers located along the north side of the high bay had picked up some of the contamination and released it to the surface of the lower roof, which covers the control room area indicated by Section A, Fig. 1. The general contamination found on this lower roof surface was from 10^3 to about 5×10^4 cpm. The lower roof, approximately 9000 ft^2, is covered with tar and gravel. Further investigation showed that this contamination was confined to the surface of the lower roof. A survey of the upper roof level and a survey of the adjacent ground areas substantiated this finding.

It was decided that some means must be used to permanently tie down this contamination on the lower roof. It did not seem feasible or practical to remove the present tar and gravel covering, which was in fairly good condition except for the contamination. It was finally decided to re-cover the existing roof with more tar and gravel, thus sandwiching the contamination between two layers which would prevent its escaping. The new covering for the roof consisted of about 8 tons of gravel and 1250 gallons of tar emulsion. The method of application was as follows:

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*These fans are American Blower Model A Venturi Propeller fans, 31 by 31 in., rated at 5,000 cfm each.

The tar emulsion (in 55-gallon drums) was raised to the roof by a fork lift and spread over the contaminated roof area by maintenance personnel with floor and garage push brooms. After the roof was completely covered with the asphalt emulsion, the gravel was spread evenly over the roof by shovel. This re-covering added approximately 25,000 lb load to the roof area, but Plant Engineering personnel had assured us that the building roof structure was more than adequate to sustain the added weight.

Maintenance personnel working on the roof were required to wear coveralls, head covering, canvas gloves, and rubber knee boots. At all times they were under the supervision and control of Health Chemistry. Two Health Chemistry monitors were stationed there to survey personnel working on the roof at the end of each operation or before leaving the roof for any reason. All equipment used on the roof was subsequently collected by Health Chemistry, surveyed, and appropriately disposed of. The total cost for this roof re-covering job has been estimated as $2,428.

Because of the necessity of removing the blowers (as previously described), it was evident that we would have to start vacuum cleaning, surveying, and removing activity from the overhead crane, its tracks, and any exposed horizontal surface that might be affected by the moving of the crane from one end of the building to the other. For this peculiar situation it was necessary to build a wooden platform on the crane from which to use a Pullman Industrial Vacuum Cleaner (Model JB 252 CV Vac Mobile, which has a suction of approximately 62 in., water gage). A Health Chemistry team composed of three men was used: (a) a man to operate the crane, (b) a man to operate the vacuum cleaner, and (c) a man to survey and monitor. The platform was used as a traveling surveying, vacuuming, and deconning station. The team started at the west end of the building directly over the Control Room. The first work was assisting in the removal of the exhaust blowers. They vacuumed these exhaust blowers and then taped down all activity not removed by vacuuming. After the five units had been removed from the wall the team returned and started at the west end of the building, vacuuming the underside of the roof. The area where the crane operated was approximately 250 ft long and 47 ft wide. This vacuuming, surveying, and deconning from the crane continued for about a week and a half under rather adverse conditions. The crane was within 4.5 ft of the roof itself, so that persons working on the platform were always in a kneeling position. Secondly, the heat build-up

close to the inside of the roof was such that temperatures were considerably higher than at floor level. Third, the inaccessibility of some of these areas required extreme exertion.

During some of the activities already described, another small group of three Health Chemistry people had been surveying the large wooden beams that covered the three cave areas comprising areas No. 5 and No. 6 on the attached drawing. There were 28 of these beams, each 12 in. square by 20 ft long. They had a very rough finish, and some had cracks that ranged from 1/4 to 3/4 in. wide running lengthwise along the beam. These beams were in use as temporary neutron shield pending installation of more permanent shielding. With wooden beams of this size there was of course some warping, which resulted in rather large openings between them. Some of the openings were directly over area No. 6, where the spill occurred. Air currents in the building allowed the contamination to be pulled up between the beams and spread generally on all the beams as well as over the rest of the building (as indicated in Fig. 1).

A preliminary survey indicated that the contamination on these beams presented a real problem. We used a second Pullman vacuum cleaner to go over the top surface of each of these beams. At this point the beams were resurveyed and any activity located was taped down. Removing the tape also removed some of the activity, but not to the extent that the beams were contamination-free. Therefore it was decided to use a technique that had been successful in the past at Lawrence Radiation Laboratory,namely, applying a spray of equal parts of shellac and alcohol. For this operation we used two low-pressure Indian backpack sprayers with extremely-low-velocity fine spray nozzles, which gave us a fog spray effect. This spray was wet enough to hold the activity down against the wood surfaces of the beams and fine enough to minimize any release of the contamination. It dried in a few minutes, after which another survey indicated no swipable activity; however, another coat was applied to insure a better covering of the wood.

Following this method of either removing or containing the activity, each beam in succession was raised by the crane while a crew vacuumed all sides, then was carried to the rear of the building, where another crew gave the entire beam another spray application. These beams were temporarily stored in the rear of the building while the surfaces where the beams had rested were checked and

deconned. The removal of the beams commenced in area No. 6, which included the site of the initial spill, and as the work progressed more beams were removed. The cave areas were deconned to the point where they were under complete control and containment.

During the work described just above, it became apparent that the methods being used for the containment of the spill activity were beginning to meet with greater success than originally expected. This was indicated by the fact that the ten Filter Queens (air-sampling stations throughout the building) were showing a diminishing level of activity as the work progressed day by day; by this time they were reading only slightly above background. Some other evidence that the activity was being contained was the lesser number of booties and coveralls that were found to be contaminated during these later phases of the cleanup.

Evaluations of the work progression at this stage of cleanup indicated that areas No. 4, No. 5, and No. 6 could be considered under preliminary control or containment, and it was decided to go back for the second and third phases of cleanup in areas No. 2 and No. 3.

Area No. 2 consisted largely of the open aisle leading from the control room back to the front edge of the cave area. In this section some of the kraft paper, having by this time handled considerable traffic in and out of the working area, had been slightly torn. This was rolled up and put into active waste. A resurvey of the horizontal surfaces located very little contamination; what was found now, together with what had originally been taped down, was deconned, and fresh paper was placed all along this aisle and taped securely to the floor.

Area No. 3, comprising the High-Level Counting Room, the Electrical Maintenance Shop, and a portion of the Electronics Shop, was surveyed completely, and some of the duct work was found to be contaminated. The intake of the air-conditioning unit showed contamination on the filters and intake side. These were removed --fortunately only one section of the duct work and refrigeration unit had to be taken out. A thorough survey indicated that most of the activity was trapped on the intake side of the refrigeration coil or on the intake side of the heating coil, these two units being in series with the refrigeration and heating system for the electronic equipment in the room. The dismantling of this duct work and related equipment was handled by a combination of personnel from the Health Chemistry Department and the Sheet Metal Shop.

All the higher horizontal surfaces in area No. 4 were now checked, and all that remained to be done was to remove building paper from all apparatus

and resurvey (for the third time) prior to declaring it an area that could be worked in by workmen in a normal manner.

In the three cave areas, the second and third resurveys following removal of all possible equipment were in progress and nearing completion. At the same time engineering discussions were going on as to possible means of reactivating the caves for the accelerator program.

In the basement area there were numerous spots of activity in the range of 500 to 10^3 cpm, but not quite as widespread as in some of the other areas. An air inlet from the basement allowed air currents to flow up from the basement toward the exhaust fans on the north side of the high bay, but even with the air flow certain eddies of air must have allowed some contamination to be deposited in the very congested floor area of the basement. This congested area contained diffusion pumps, vacuum pumps, and various other apparatus and machinery necessary to the operation of the accelerator. This basement area was vacuumed, surveyed, taped, deconned, resurveyed and made ready for workmen to come back into the area for their previously planned reconditioning operations.

Meanwhile another crew had removed all activity on the top side of the stripper area, and other groups had made the final check-out of areas No. 5 and No. 6, which comprised all three caves. After painting of the floors (preparatory to mastipave covering) and re-installation of some of the equipment necessary for the researchers' work, the building was opened to normal operations. A reinforced staff of Health Chemistry personnel was made available to check all outgoing equipment and to make periodic checks of personnel moving around the building, as an added precaution against any possibility that some activity might have been overlooked by the groups in the original cleanup and might be picked up as operations were resumed.

In review it should be pointed out that the hilac Chemistry Group was permitted to reenter the building after the first week, and that the Accelerator Technicians at the hilac were permitted to resume operation on a reduced scale at the end of the second week, preliminary to full operation of the entire hilac at the end of the third week. This was approximately July 27, 1959.

A partial list of the equipment that was removed from the hilac to the holding area for later decontamination or disposal includes

helium vapor detectors
vaporizing units
rf resonator cavitators
oscilloscopes
kv power supplies
regulator power supplies
ion-gage supplies
C^{13} storage and recovery assemblies
collimator pipes
target assemblies
vacuum pump refrigerating units
banks of miscellaneous electronics equipment
TV cameras
TV camera remote assemblies
helium carts
large blowers
miscellaneous blowers
miscellaneous vacuum pumps
roof duct work and air-exhaust equipment.

The cleanup of equipment removed from the hilac for decontamination was completed by August 14, 1959. Approximately 90 to 96% of the equipment that was grossly contaminated was deconned and returned to service. This materially decreased early estimates of equipment loss.

VII. AIR AND ENVIRONMENTAL SAMPLING

Beginning Monday, July 6, additional air samplers were installed in Building 71, bringing the total to 11. The progress of air contamination was assessed daily or more often and reported continuously. All available decontamination vacuum cleaners and air-supplied respirators were turned over to the decontaminators. Our two emergency 750-cfm portable filter-exhausters were taken to the work area.

Twenty-four samples of vegetation, soil, and subsoil were taken from north and east of Building 71 on July 13 for analysis. Sampling locations are shown in Fig. 5. Analysis of the samples is tabulated in Appendix B.

Work is continuing to perfect the data already reported and to supply new measurements and estimations. This encompasses

(a) determination by two methods--nuclear track emulsion studies and microscopic studies--of the particle sizes of alpha-active material and the distribution or frequency of the various sizes;

(b) chemical digestion of the collected air samples to establish the quantitative validity of the first counting;

(c) replicate counting by two techniques--with a gas-flow proportional counter and with a scintillation counter (ZnS).

Numerical and photogrammetric data are being derived from these studies for a subsequent report.

VIII. MEDICAL AND BIO-ASSAY ASPECTS

(Preliminary medical report prepared by Howard G. Parker, M. D.)

The curium exposure outlined in other sections of this report was primarily an inhalation risk. Ingestion of the material could also constitute a risk, but regardless of chemical form would ordinarily be less serious, by a factor of at least 10^4, than inhalation of small particles. Since the hydroxide and oxide have very slight solubility in water, one would predict initially that the majority of small particles reaching the alveoli would be retained in lung, while some fraction, roughly 10%, would be absorbed and contribute to the systemic body burden, particularly in bone.[1]

No data are available on the behavior of aerosols of curium compounds inhaled by animals. Quantitative work on such exposure depends at present on our knowledge from animal data that curium is no more hazardous than plutonium (perhaps slightly less so per microcurie),[2] on human work using plutonium excretion to estimate body burden, and on animal work with inhaled aerosols of PuO_2, ThO_2, CeO_2, and similar compounds.[1]

The maximum permissible amounts of curium based on considerations of this kind are 0.1μC for bone[3] and 0.014μC for lung[4] (see below re Cm^{244}/Cm^{246} ratio).

An initial evaluation of the incident was made on the basis of the history of exposure, nose swipes, rapid survey of urine specimens (first 24 hours) for alpha activity, and complete blood count. This indicated that the risk was small for each of the five individuals indicated by Health Chemistry as most likely of the 27 potential exposures to be exposed significantly. The negative urinalysis (by the quick method) for these five indicated that systemic curium burdens must be less than the maximum permissible amount, but gave little reassurance as to lung burden. This much information, however, indicated that immediate risk was low, and that efforts at therapy would not be indicated. There was no longer need for haste.

The initial study of the activities present (Cm^{244} and Cm^{246}) indicated that they would be unsuitable for gamma-ray analysis of the systemic or lung burden with the whole-body counter unless retained amounts were well over 1/2 μC.

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[1] W. R. Langham, The Application of Excretion Analyses to the Determination of Body Burden of Radioactive Isotopes, Brit. J. Radiol. Suppl. 7, Part V, (1957).

[2] Scott, Axelrod, and Hamilton, The Metabolism of Curium in the Rat, J. Biol. Chem. 177, 325 (1949).

[3] From NCRP Handbook 69.

[4] Estimated by the author, assuming uniform distribution in lung.

Approximately 10^5 cpm of the source material from the accident was obtained and checked with a NaI crystal and 100-channel analyzer, confirming the estimate that gamma-ray analysis was not likely to be helpful. This meant that one must rely on analysis of excreta for biological estimates of amounts retained in order to estimate the lifetime radiation exposure from these small amounts. The ratio of Cm^{244} to Cm^{246} (95:5), the relative physical half-lives of these isotopes, and their biological effects are such that one makes no significant error in assuming all the material to be Cm^{244}, and our initial estimates are on that basis.

A single 24-hour urine sample was obtained from each of twenty individuals for Cm analysis by the slower but more sensitive routine method ($BiPO_4$ and LaF coprecipitation of 24-hour urine). No detectable activity was found in the urine of any of the twenty lesser exposures. Serial stool and urine collection was instituted for Cm analysis by the same method in seven individuals--the five originally studied plus two whose nose swabs were not entirely negative.

In each of the seven some activity was found in stool specimens, and for six of the seven the results of the more sensitive assay (when they became available) showed activity in the urine. However, the amounts confirmed the initial estimate of the problem--risk low, treatment not indicated.

To get the best possible biological estimate of lung burden, bioassay of serial collections of excreta will continue for a few months in the three individuals with the highest excretion rates. Even then, in the absence of specific data on inhaled curium hydroxide in humans, the calculations give only rough estimates. Data being accumulated by others on particle size and on the ratio of hydroxide to oxide, nitrate, and other chemical species in the inhaled material will eventually aid the evaluation of the health hazard.

The bioassay to date is considerably less adequate for quantitative calculation than what we expect to have in 4 to 5 months. It has been used to estimate the upper limit of exposure; it indicates that the experimenter, who had the highest urine count (12 dpm per 24-hour urine in first 24 hours, 3 dpm per stool specimen on day 4), could have a systemic burden of curium as large as 0.003 μC, which is 1/30 the maximum permissible. The lung burden, estimated from PuO_2 data, gives a best estimate in this individual of 0.03 μC or two times the maximum permissible amount (assuming 10% absorption). It is then

most improbable that he could have over 0.3 μC, which is twenty times the maximum permissible amount (assuming only 1% absorbed instead of 10%). A study of what excretion data are now available suggests strongly the likelihood of much less risk to lung than two times permissible, although one can't yet quantitate the effect. The ratios of focal to urinary activity suggest that the inhaled curium compounds must be considerably better at passing from lung to blood than the PuO_2 we use for our calculations, and if this is true the risk to lung is smaller than the above best estimate.

The air-sampling data now available from Health Chemistry fix the probable extreme upper limit of material inhaled by the experimenter around 0.7 μC, which is 60 times permissible. With 0.7 μC inhaled, and a maximum of 25% of that likely to be retained for any prolonged period, 0.2 μC or 15 times the permissible amount could be retained in the lung with a half time of elimination of 6 months or more. A number of factors could operate to reduce the lung exposure below this upper limit. The area of uncertainty between 15 times permissible and the less than permissible suggested by current bioassay data must be explored at length, but the last word on the subject will almost certainly be on the basis of measurements made on the exposed individuals rather than on the air sampling. If after more extensive bioassay any individual is found to have retained more than one-half the permissible amount, this will of course be made the subject of a special report to the AEC.

As mentioned above, I do not feel that therapy of any kind is indicated at these levels of exposure. Bioassay data will be collected and correlated with knowledge of particle size and chemical constitution. It constitutes valuable confirmatory evidence regarding the exposure, and may offer some help in the event of another inhalation incident with this material.

I gratefully acknowledge the following assistance. Dr. Max Biggs and Mrs. Isabelle Dupzyk performed the numerous low-level curium bioassays for us. Dr. Thornton Sargent assisted in evaluation of the gamma-ray counting possibilities, and Mrs. Elsa Isaac performed the rapid-assay procedures and arranged for collections and shipping of specimens.

IX. FINANCIAL LOSSES

Labor costs--decontamination		
Direct:		
30 man-months at $ 500	$15,000	
Indirect:		
20 man-months at $ 500	10,000	
		$25,000
Material costs		
Supplies for decontamination	3,000	
Equipment and materials lost through contamination	2,000	
Reroofing	2,500	
		$ 7,500
Expenditures for restoration (overhead not included)		$32,500
Value of lost beam time (Loss in research time):		
288 hours at $90		$25,920
Total losses attributed to hilac spill		$58,420

APPENDIX A

Decay Scheme of Curium-244

Nuclide	Half life	Activity	Energy
Cm^{244}	18y	α	~5.8 Mev
Pu^{240}	6000y	α	~5.1 Mev
U^{236}	2×10^{7} y	α	~4.5 Mev
Th^{232}	10^{10} y	α	
Ra^{228}	6.7y	β, γ	
Ac^{228}	6 hour	β, γ	
Th^{228}	1.9y	α	
Ra^{224}	3.64 day	α	
Rn^{220}	54 sec	α	
Po^{216}	0.2 sec	α, β	
Pb^{212}	10.6 hour	β	or At^{216}, 10^{-4} sec, α
Bi^{212}	60 min	α, β	
Tl^{208}	3 min	β	or Po^{212}, 10^{-7} sec, α
Pb^{208}	stable		

APPENDIX B

Radioassay Procedures

I. Nose Swipes

Since alpha activity was the primary concern in this case, only alpha counts were made. Alpha counting was done by the zinc sulfide scintillator method. The detector head was originally specially designed to count at the bottom of a 50-ml beaker, but it also lends itself readily to making raw counts on undigested nose swipes. The zinc sulfide is sprayed on one circular face of a lucite right cylinder about 1-3/8 in. in diameter by 2 in. long. The lucite cylinder is housed in a brass tube with a 1/4-mil aluminum foil over the sulfided end and the window of a photomultiplier tube at the other end. Pulses from the tube feed through a preamplifier to a standard scaler. The device counts at a geometry-efficiency of $24 \pm 2.4\%$. All nose swipes were given a preliminary raw count for 5 min by rotating the swipe at about 5 to 10 rpm. The counting background was 0.5 ± 0.4 at 90% confidence level for a 5-min count. Any count less than 0.6 cpm (3 counts in 5 min) was interpreted as follows:

Maximum total count (including error)	$0.6 + 0.4 = 1.0$ cpm
Minimum background (including error)	$0.5 - 0.4 = 0.1$ cpm
Maximum difference	0.9 cpm

$$\text{Maximum disintegration rate} = \frac{\text{Maximum counting rate}}{\text{Minimum efficiency}} = \frac{0.9}{0.216} = 4.2$$

Therefore all counts less than 0.6 cpm were reported as < 5 dpm.

Since there were some 60 nose swipes and since the positive value of negative nose swipes is questionable at best, expenditure of time and equipment involved in further treatment of nose swipes showing < 5 dpm on the preliminary count was not considered worth while.

Nose swipes showing more than 5 dpm were further treated by wet ashing. Wet ashing consisted of treating the swipe in a 50-ml beaker with about 5 cc $HClO_4$ (70%) and 10 cc HNO_3 (70%) and boiling to dryness. The beaker was then counted for 1 to 60 min (as determined by the statistics of the counting rate) on the counter described above. Agreement of the count on the wet-ash residue with the raw preliminary count was excellent except in one case, in which the final count was about 10 times high. This lack of agreement may have been statistical or it may have been due to partial coverage by fiber or mucous of the disintegrating particle or to maldistribution over the swab.

II. Water

Water samples were assayed by boiling samples of about 1 liter to < 50 ml, then transferring to < 50-ml beakers, evaporating to dryness, and counting on the device described above. Crud-correction factors were determined by determining the number of alpha-stopping layers at the bottom of the beaker. An α-stopping layer is considered to be 7 mg/cm^2. The crud-correction factor is then $C = W/7A$, where W is the weight of crud in mg, and A is the area of the beaker bottom. That such a simple crud correction is far from rigorous is well realized. An integral expression to determine the distribution of alpha particles through a crud layer is in the process of attempted solution, but as yet has not been solved.

Beta counting is done by placing and end-window Geiger tube inside the beaker and counting at 8 ± 0.8% geometry efficiency.

III. Grass

Grass samples were wet ashed and counted in 50-ml beaker as noted above.

IV. Soil

The single soil sample was treated with $HClO_4$ + HNO_3 to dispose of organics, then treated with 48% HF to volatilize the silica. J. Wallman of the Chemistry section gave his assurance that no volatile Cm fluorides are formed under these conditions. After volatilization of the organics and silica, the residue was treated with aqua regia, boiled to dryness, and partially dissolved in HNO_3. NH_4OH was added to precipitate aluminum as the hydroxide. The aluminum hydroxide was then converted to insoluble alumina by heating to 800°C in a furnace. The Cm was then extracted (it is assumed) with boiling 70% HNO_3, combined with the supernate from the Al precipitation, boiled to dryness, heated further to drive

off NH_4^+ salts, and counted in a 50-ml beaker. Even after removal of the organics, silica, and alumina the remaining crud had a density of about 70 mg/cm^2, requiring a correction of ×10. This residue was probably mostly calcium and sodium salts.

V. Tool-Soaking Solution

This solution contained so much dissolved solid that it was treated in the same manner, after a preliminary drying, as the soil sample. The resultant crud had a density of 8 mg/cm^2, requiring a correction of ×1.1.

VI. Respirators

Respirators were disassembled and both sides of the filter were surveyed under the zinc sulfide detector. The large area required a slightly different technique than was used in revolving nose swipes. Small-area increments were exposed to the detector for 1-min counts. If any count was observed, the area increment was allowed to remain under the detector for 5 min total. An attempt was made to wet ash the hot segment of the one respirator showing more than 5 dpm per area increment. It was apparent from the lack of crud removal that the original count could not be improved. Further treatment was discontinued.

Radioassay Findings

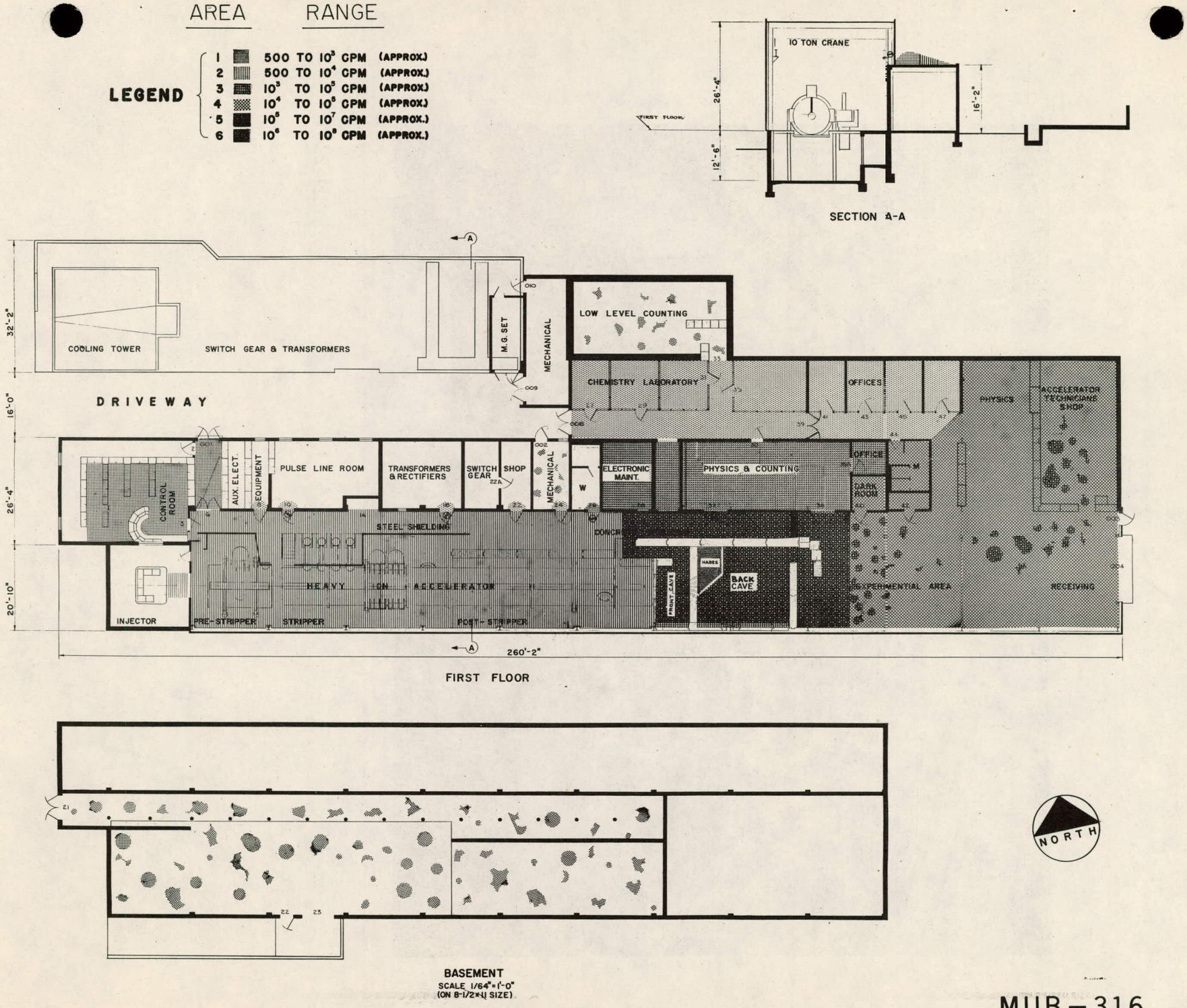
Summary of radioassay results from Cm^{244} spill, 7/3/59

Kind of sample	No. of samples run	No. of samples "positive"	"Positive" criteria[a]	Activity range of "positive" samples
Nose Swipes	58	7	5 dpm	4 ± 2 to 8800 ± 1200 dpm
Respirators	5	1	5 dpm	1000 ± 300 dpm
Soil[b]	2	0	13 dpm/g	
Grass[b]	7	5	1.3 dpm/g	1.3 ± .4 to 6.7± 1.6 dpm/g
Cooling Water	2	0	20 dpm/l[c]	
Algae from drain	1	0	4 dpm/g	
Tool Dip	1	1	20 dpm/l	50 ± 10 dpm/l

[a] All values here reported refer to alpha activity only. Differences in criteria are due to crud deposits, size of sample, and other conditions affecting counting.

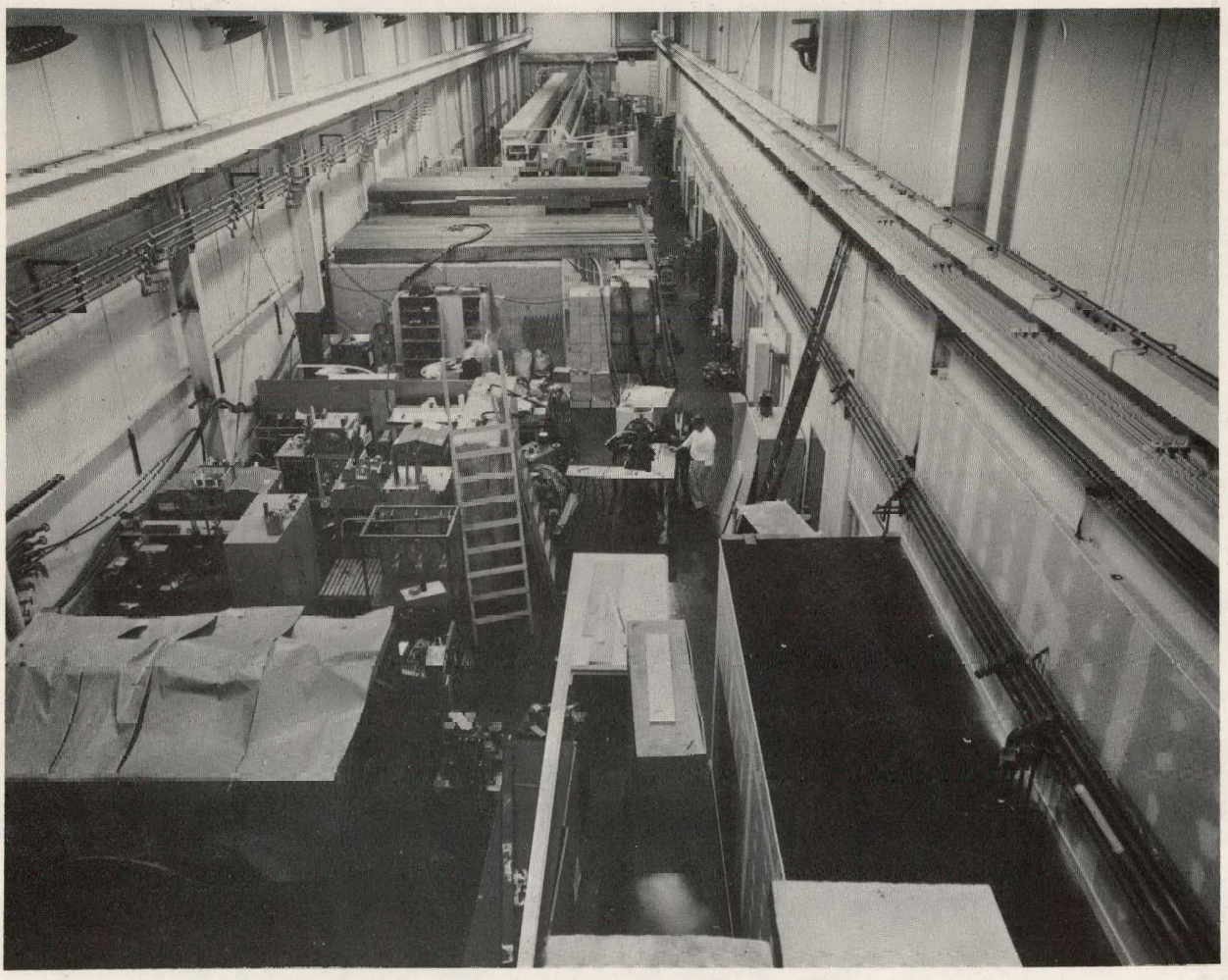
[b] Further soil and grass samples still in process.

[c] One sample too small for good evaluation.


AREA RANGE
LEGEND
1 500 TO 10³ GPM (APPROX.)
2 500 TO 10⁴ GPM (APPROX.)
3 10³ TO 10⁵ GPM (APPROX.)
4 10⁴ TO 10⁶ GPM (APPROX.)
5 10⁵ TO 10⁷ GPM (APPROX.)
6 10⁶ TO 10⁸ GPM (APPROX.)
10 TON CRANE
FIRST FLOOR
26'-4"
12'-6"
16'-2"
SECTION A-A
COOLING TOWER
SWITCH GEAR & TRANSFORMERS
M.G. SET
MECHANICAL
LOW LEVEL COUNTING
CHEMISTRY LABORATORY
OFFICES
PHYSICS
ACCELERATOR TECHNICIANS SHOP
DRIVEWAY
32'-2"
16'-0"
26'-4"
20'-10"
CONTROL ROOM
AUX. ELECT. EQUIPMENT
PULSE LINE ROOM
TRANSFORMERS & RECTIFIERS
SWITCH GEAR
SHOP
MECHANICAL
W
ELECTRONIC MAINT.
PHYSICS & COUNTING
OFFICE
DARK ROOM
STEEL SHIELDING
CONCR
HEAVY ION ACCELERATOR
INJECTOR
PRE-STRIPPER
STRIPPER
POST-STRIPPER
FRONT CAVE
HADES
BACK CAVE
EXPERIMENTAL AREA
RECEIVING
260'-2"
FIRST FLOOR
BASEMENT
SCALE 1/64"=1'-0"
(ON 8-1/2"x11" SIZE)
NORTH

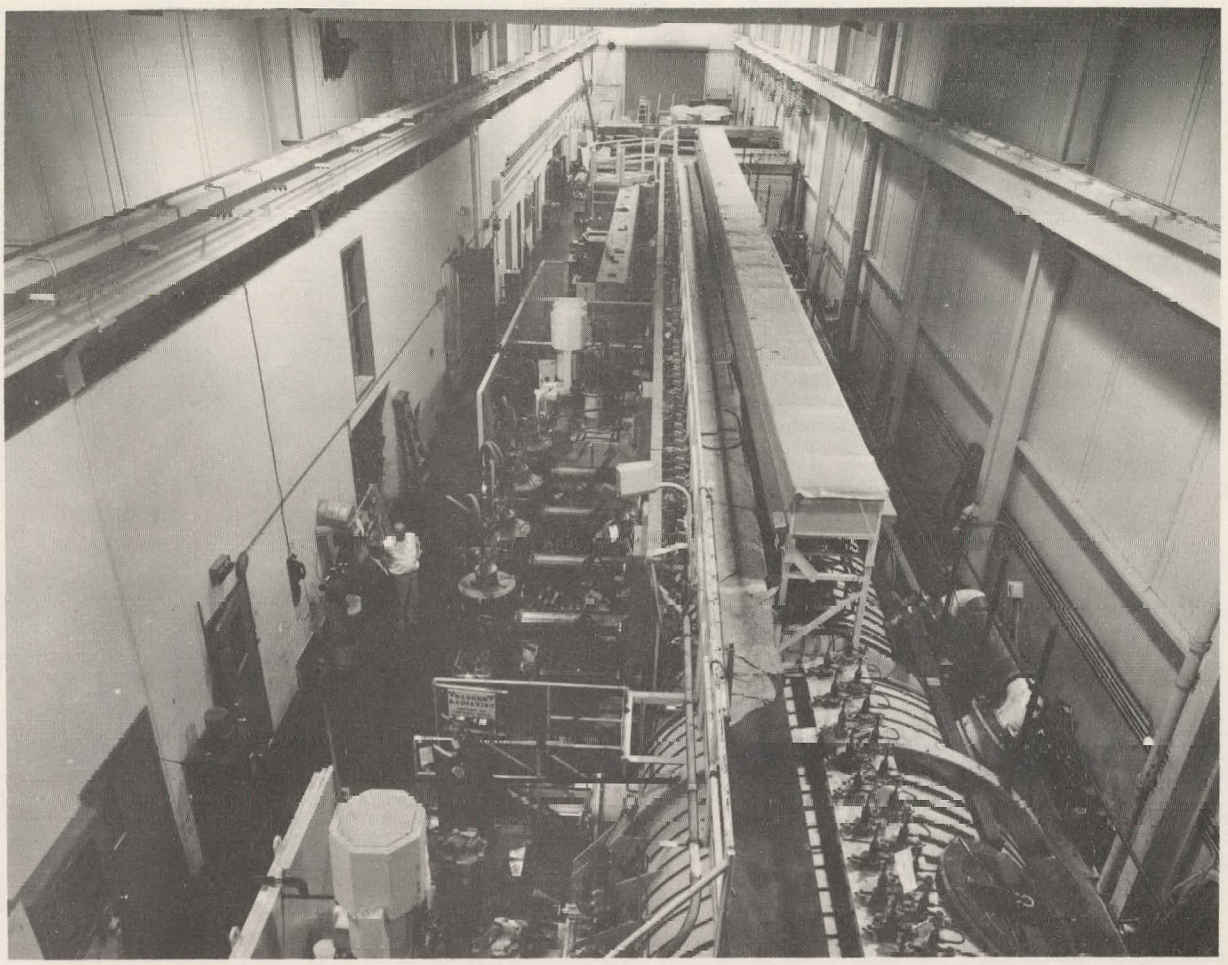
MUB-316

Fig. 1



ZN-2251

Fig. 2



ZN-2276

Fig. 3

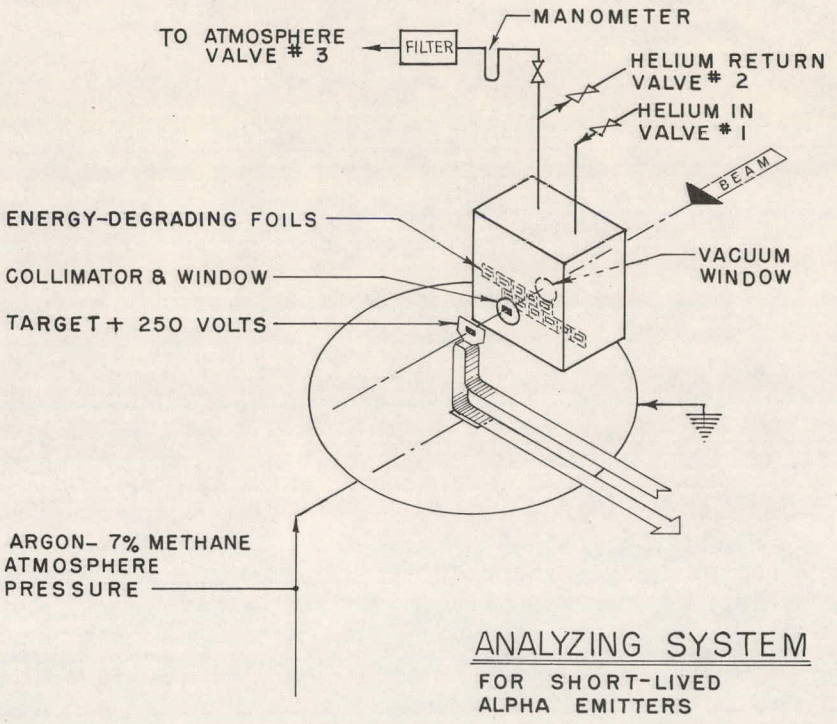

TO ATMOSPHERE
VALVE # 3
FILTER
MANOMETER
HELIUM RETURN
VALVE # 2
HELIUM IN
VALVE # 1
BEAM
ENERGY-DEGRADING FOILS
COLLIMATOR & WINDOW
TARGET + 250 VOLTS
VACUUM
WINDOW
ARGON- 7% METHANE
ATMOSPHERE
PRESSURE
ANALYZING SYSTEM
FOR SHORT-LIVED
ALPHA EMITTERS
MU-18485

Fig. 4

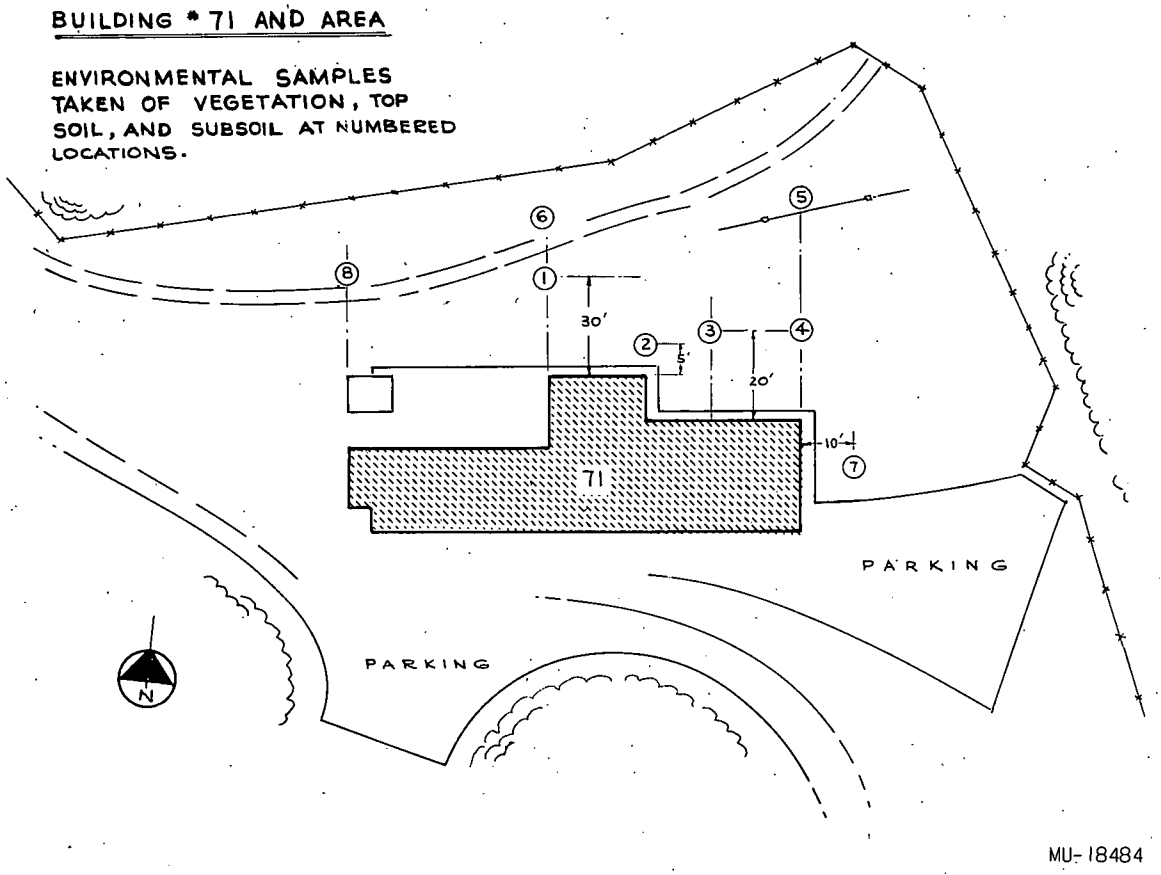

BUILDING * 71 AND AREA
ENVIRONMENTAL SAMPLES TAKEN OF VEGETATION, TOP SOIL, AND SUBSOIL AT NUMBERED LOCATIONS.
6
5
8
1
30'
2
5'
3
4
20'
10'
7
71
PARKING
PARKING
N
MU-18484

Fig. 5

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