Lawrence Livermore Laboratory

CLEANUP OF RADIOACTIVE MOD SPILL
U20aa POSTSHOT DRILLING SITE
NTS

MASTER

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March 1977

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CLEANUP OF RADIOACTIVE MUD SPILL

U20aa POSTSHOT DRILLING SITE

NTS

by

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Health & Safety Group

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SUMMARY

Radioactive decontamination of a large rugged terrain on the NTS (Area 20) was undertaken during the Summer of 1976. Several decontamination methods were used and their effectiveness, as measured by the fraction of radioactivity remaining (FR), ranged from 10^{-1} to 10^{-3} , depending upon the method used and type of terrain. Front end loading was most efficient in large relatively flat areas of fine grain, compact dirt with an FR of about 10^{-2} . Shoveling and bagging achieved FRs of 10^{-2} in locations of fine grain, compact dirt. However, if dirt was coarse grain or gravel-like, the contaminated mud/water had seeped to considerable depths, making shoveling impractical. Flushing with water was the method chosen for rocky surfaces and was the primary method of decontamination in Area 4. FRs down to 10^{-3} were achieved on smooth surfaces and about 10^{-1} in cracks. Vacuuming was very effective in flat areas with fine grain compact dirt achieving FRs down to 10^{-3} , but was a very slow process compared to front end loading.

Approximately 900 man days were expended on this cleanup, and 2584 yd³ of contaminated dirt were removed. A similar amount of clean dirt was transported from about two miles away to cover the crater burial site, mud sump and areas containing residual radiation above 1 mrem/hr contact. Total quantity of residual radioactivity present 6 months following the spill and after decontamination was estimated as 900 millicuries of Ru/Rh-106 and 0.034 millicuries Ru-103.

No person was exposed to doses of radiation (external or internal) above the maximum allowable limits listed in ERDAM 0524. Estimates based upon hand dose measurements indicate that no individual should have received more than 584 mrem to hands. Since the NTS film badges of individuals working at this project showed a maximum of 80 mrem during the third quarter of 1976, no person received more than 80 mrem whole body during the entire cleanup project. Maximum air concentration during cleanup operations was 5.67×10^{-11} $\mu\text{Ci/cc}$ of Ru-103 and Ru/Rh-106, which were the only radionuclides present in measurable quantities. This amounts to approximately 1% MPC_a for 40 hours per week occupational exposure.

I. INTRODUCTION

On 16 May 1976, a spill of radioactively contaminated mud occurred at the U20aa postshot drilling site. This report describes methods used to cleanup the contaminated mud, their relative effectiveness and the radiation protection measures taken prior to and during the cleanup procedures.

II. GENERAL DESCRIPTION

The areas contaminated during postshot drilling at U20aa were the drill pad (Area 1, Figure 1), a fan-shaped area immediately northeast of the drill pad (Area 2), a flat area northeast of the fan-shaped area (Area 3) and part of a canyon northeast of the flat area (Areas 4, 5 and 6). The contaminated mud flow was approximately 760 m long with variable width from about 60 m on the drill pad and fan-shaped area to less than 1 m at several canyon locations. The plates at the end of the report illustrate the spill area. It should be noted that occasionally the mud sump and normally a portion of the drill pad and the area immediately beneath the drill rig are contaminated during the sampling phase of postshot drilling. Radiological cleanup in these locations is, therefore, standard operating procedure.

On 14 June 1976, an earthen dam was constructed in the canyon approximately 15 m downstream from the termination of the contaminated mud flow to prevent further movement of the mud should heavy rain storms

occur (Plate 12). It is about 50 m long, 5 m deep and 8 m wide at the top and was to retain a collection and settling pond for the contaminated mud should it be dislocated due to rains. A spillway was constructed to prevent the dam from washing out and was thought to be justified by the mud's low water solubility causing rapid settling. It had earth hardner applied overall and Cal-Seal cement put on the spillway to prevent water erosion. The dam was completed prior to any significant precipitation in the area.

Cleanup operations commenced on 12 July 1976, using front end loaders, road scrapers, dump trucks, water trucks with hose, a 13 yd³ vacuum cleaner, shovels and bags (Plates 5, 7, 9, 10). Decontamination methods and effectiveness are discussed in Section III, "DECONTAMINATION EFFECTIVENESS." Decontamination of the flat area downstream of the drill pad (Area 3) was first accomplished and the light-colored drill mud hauled to the subsidence crater for burial in a prepared location. The prepared area was about 50 m x 50 m and was located in the deepest part of the crater approximately 14 m below surface ground level.⁽¹⁾

The cleanup operation proceeded to the canyon area, an area of rough terrain with large boulders and a stream bed (Area 4). Further down the canyon there was an area of relatively level ground with several large pine trees (Areas 5 and 6).

After the canyon was decontaminated to practicable levels, cleanup operations were moved to the fan-shaped area (Area 2) and the drill pad (Area 1). The contaminated mud was thickest immediately below the drill pad where it was up to 13" deep. The drill pad was scraped and the contaminated mud hauled to the crater disposal area.

The final cleanup phase consisted of decontaminating all roads inside the radiation exclusion area, decontamination of all vehicles and equipment used in cleanup operations and covering all locations where decontamination to less than 1 mrem/hr* contact was impractical or impossible with adequate amounts of clean dirt (Plate 11). Both the mud sump and crater burial site were covered with clean dirt sufficient to give a dose at contact of less than 1 mrem/hr. Prior to departing the area, fences and signs indicating buried contaminated material were placed around the drill hole cellar, mud sump and crater burial site.

*The dose rate in mrem/hr was determined from portable beta + gamma survey meters by assuming Roentgen/rad = 1 and an RBE of 1 for both betas and gammas. (2) In the case of TLD or film dosimeters, the only assumption required was that RBE = 1. The assumption that 1 Roentgen equal 1 rad will result in about a 4% overestimate in the dose to soft tissue. (3) The maximum exposure rate of 1 mrem/hr at contact was agreed upon by ERDA/NVCO prior to cleanup procedures at U20aa and equal the maximum pre-spill background level in this area as a result of Plowshare events during the 1960's.

III. DECONTAMINATION EFFECTIVENESS

This section evaluates the effectiveness of each decontamination method used at U20aa. Some of the problems of decontaminating a large area of rugged terrain are discussed. Table II summarizes the methods used, lists the estimated fraction remaining (FR) and the positive and negative aspects of each. The FR in this report is defined as the average activity following cleanup divided by average activity in same location prior to cleanup.

Prior to cleanup operations at U20aa, complete radiation surveys of the contaminated areas were performed by REECO Environmental Sciences. The beta + gamma dose rate at contact with mud ranged from 5 to 200 mrem/hr. Most readings were in the 100 to 200 mrem/hr range. After cleanup, area surveys were performed and residual radiation levels compared to the pre-cleanup levels to determine effectiveness of each method (Tables I and II). The post-cleanup surveys used to determine decontamination effectiveness were taken following a specific cleanup method and prior to covering with clean dirt. These should not be confused with the final surveys that were taken following completion of the project.⁽⁴⁾

A. Front End Loading

In level areas of considerable size (e.g., Areas 2, 3, 5 & 6), front end loading was by far the most efficient method. However, considerable time and money can be saved if highly skilled operators

are used who are familiar with radioactive decontamination procedures. Considerable time was lost in Area 5 due to the operator recontaminating areas previously cleaned by dropping contaminated mud during truck loading or unnecessarily driving the front end loader over the contaminated area.

Front end loading is also the method of choice in locations where the contaminant has seeped through the soil more than 1 to 2 inches. This was the case in Area 6 where the coarse grain sand and gravel had allowed the water-suspended mud to seep to depths up to 4 ft. Deep penetration of contaminated mud was also found along the sides and underneath large boulders. The mud had seeped alongside and down the rock/dirt interface. The contaminated boulders and dirt were removed as much as practicable using front end loaders and dump trucks. FRs of approximately 10^{-1} were achieved in this area.

B. Vacuuming

The vacuum cleaner was placed on the bed of a dump truck and had maximum capacity of 13 yd³ of dirt.⁽⁵⁾ The contaminated mud could be removed from the vacuum cleaner through normal dumping of the truck bed. It was highly effective in flat areas of relatively hard ground where significant soaking or seepage had not occurred. In such locations, the contaminated mud was picked up with FRs of approximately 3×10^{-3} . Due to the small chance of spreading con-

tamination (or recontamination) while using the vacuum, the vacuum cleaner does not require experienced operators. Since contaminants go only one way, they cannot be sluffed-off on clean areas as was often the case in front end loading.

The major negative aspect of vacuuming is that it is relatively slow compared to front end loading.

C. Shoveling & Bagging

In relatively small areas inaccessible to large equipment such as front end loaders or trucks, the contaminated mud was shoveled into bags and carried to a nearby truck for disposal. The personnel protection measures taken during shoveling are described in Section IV of this report.

The effectiveness of shoveling was shown to be greatly dependent upon the porosity of soil and whether large partially subsurface boulders were present. In locations where the ground was fine grain or soil-like, the contaminated mud had not penetrated to more than an inch or two of the surface making shoveling a good method of choice and yielding FRS of approximately 10^{-2} . However, if the grain was coarse or when large partially subsurface boulders were present, the contaminated mud was found at depths exceeding 4 ft. The large grain (gravel-like) ground had allowed contaminated mud/water to penetrate and the large boulders allowed seepage along

the rock/soil interfaces. In such locations, the volume of contaminated ground was so large that removal of radioactivity to an acceptable level (1 mrem/hr) by shoveling and bagging was impractical. This was the case in Area 6. Therefore, a road was constructed to allow access for front end loaders and trucks.

Experience has shown that care should be taken not to recontaminate previously cleaned areas during shoveling operations. Personnel involved should be instructed on necessary precautions required to minimize recontamination.

D. Flushing with Water

In rocky canyon locations where digging or vacuuming was not practical or possible, a water truck was used to hose contaminated mud off the rocks. A small dike was constructed at the lower end of the rocky canyon area collecting the contaminated mud/water (Figure 1). Following a period of evaporation, the dry mud was scooped up with shovels, bagged and disposed. The rocky surfaces were readily decontaminated to less than 1 mrem/hr (contact) with FRs of approximately 10^{-3} , while the cracks and crevices could only be decontaminated to an average value of 15 mrem/hr (contact) or an FR of approximately 10^{-1} . In some locations of dirt and sand such as the catch basin above the dike, the contaminated mud/water had soaked into the gravel making shoveling to 1 mrem/hr impractical. In these situations, visible surface mud was removed

by shoveling and residual contamination covered with clean dirt such that dose rates at contact were less than 1 mrem/hr.

Overall effectiveness of decontamination is illustrated in Figure 2. The estimated activity remaining following decontamination vs time is shown by dotted lines; activity remaining vs time if no decontamination procedures were undertaken is illustrated by solid lines. The total quantity of residual activity present at 6 months following the spill and after decontamination was estimated as 900 millicuries Ru/Rh-106 and 0.034 millicuries Ru-103. The quantity $\Sigma FRw = 2.126 \times 10^{-2}$ in Figure 2 is the weighted fraction remaining and equals the sum of the products of the average fraction remaining per area and its corresponding fractional area. The quantity FRw was used to determine the total activity following decontamination procedures through the relationship: Activity following decontamination = Activity prior to decontamination $\times \Sigma FRw$.

TABLE I

AVERAGE DOSE RATES AT CONTACT FOLLOWING VARIOUS DECONTAMINATION METHODS

<u>METHOD</u>	<u>LOCATION</u>	<u>TERRAIN</u>	<u>AVERAGE DOSE RATE*</u>
Front End Loading	Area 2	Large subsurface boulders	5 mrem/hr
	Area 3	Flat compact dirt; fine grain	2 mrem/hr
	Area 5	Mixed fine grain, compact dirt & gravel - few boulders	2 mrem/hr
	Area 6	Flat, gravel-like & large boulders	10 mrem/hr
Shoveling	Area 4	Dirt or soil-like, fine grain	5 mrem/hr
	Area 5	Dirt or soil-like, fine grain	5 mrem/hr
	Area 6	Dirt, gravel-like, coarse grain	15 mrem/hr
Flushing	Area 4	Rocky surfaces	0.5 mrem/hr
	Area 4	Cracks in rocky surfaces	15 mrem/hr
Vacuuming	Area 1	Hot spots, droppings	0.1 mrem/hr
	Area 2	Subsurface rocks	0.5 mrem/hr
	Area 3	Hard subsurface rocks	0.5 mrem/hr

*The average dose rates were determined by taking the median value; e.g., if the dose rate ranges from 0.05 mrem/hr to 10 mrem/hr, average dose rate would be taken as 5 mrem/hr.

TABLE II

EFFECTIVENESS OF DECONTAMINATION METHODS

TERRAIN	DECONTAMINATION METHOD	ESTIMATED FRACTION REMAINING (FR)*	METHOD OF EVALUATION
Flat compact dirt, fine grain	Front end loader	10^{-2}	Positive: Rapid, good decon factor. Negative: Inexperienced driver can recontaminate clean areas.
	Vacuum	10^{-3}	Positive: High decon factor, good where subsurface boulders are present, no experienced operators required. Negative: Slow compared to FEL.
	Shovel & bags	10^{-2}	Positive: Good in locations inaccessible to heavy equipment. Negative: Slow; considerable care must be taken not to recontaminate cleaned areas (experienced personnel desirable).

*Fraction Remaining (FR) were determined by dividing the average dose rate at contact prior to decontamination into the average dose rate following decontamination. The average dose rate prior to decontamination was taken as 150 mrem/hr.

TABLE II, cont.

Flat ground, coarse grain or gravel-like	Front end loader	10^{-1} to 10^{-2}	Positive: Moves large amounts of dirt. Negative: Inexperienced driver can recontaminate clean areas.
	Vacuum	Not attempted	
	Shovel & bags	10^{-1}	Positive: Can be used in locations inaccessible to heavy equipment. Negative: Impractical in locations where deep penetration of contaminant has occurred.
Rocky Canyon (spring drainage bed)	Vacuum	Not attempted	Positive: Can be used in mud collection areas inaccessible to FEL by adding extension hose. Negative: Most rocky areas inaccessible to vacuum even with hose extension.
	Shovel & bags	10^{-2} (fine grain soil)	Positive: Good in locations where contaminated mud has collected. Negative: Usually too many rocks.
	Flushing with water hose or scrubbing with brooms/brushes	10^{-3} (rocky surfaces) 10^{-1} (cracks)	Positive: Good in areas where contamination is hidden under rocks or exposed on rocky surfaces. Negative: Care must be taken so contamination is not spread further; e.g., constructing a dam.

FIGURE 1
U20aa RADIOACTIVE MUD SPILL

Note -

Areas called out on sketch are areas designated in report and not areas of the Test Site.

FIGURE 2

COMPARISON OF ACTIVITY REMAINING
WITH OR WITHOUT DECONTAMINATION

IV. PERSONNEL PROTECTION

This section describes the radiation protection measures taken and their underlying justification during and prior to cleanup at U20aa.

A. Prior to Cleanup

Shortly after the spill, caution signs were placed encircling the contaminated area. Prior to commencing cleanup operations, a control station (trailer) was set up at the main access road (Plate 1). During working hours, the station was manned with at least one REECo Environmental Sciences monitor who controlled all individuals and equipment entering or leaving the contaminated area by logging in/out, issuing pocket dosimeters and experimental film badges, monitoring for contamination of exiting personnel or equipment, and ensuring that proper dress procedures of Anti-C clothing were followed. Contamination monitoring of personnel leaving the exclusion area was accomplished with a portal monitor⁽⁶⁾ containing several GM pancake detectors (beta + gamma sensitive) at the control station entrance. Portal monitors had both audible and visual alarms and were set to trip at less than 0.1 mR/hr.

Samples of radioactive mud were analyzed by gamma spectroscopy using a Ge(Li) detector. It was determined through peak identification and half-life determination that the only resolvable radionuclides present were Ru-103 and Ru/Rh-106.⁽⁷⁾ At the time of release, about 86% of the activity was due to Ru-103 and 14%

due to Ru/Rh-106 (Figure 2). The mud was also analyzed for its solubility in water at about 80 °F (normal daytime temperature at Pahute Mesa during July/August). The mud was found to be highly insoluble. These isotopes have an MPC in air (40 hr/wk) of 8×10^{-8} and 6×10^{-9} $\mu\text{Ci/cc}$, respectively.⁽⁸⁾

In order to determine whether air suspension of contaminated mud occurred due to wind currents, M-102 air samplers⁽⁹⁾ were run in several locations for two days (7-10-76 & 7-11-76) prior to beginning cleanup. The M-102 air samplers are portable, gasoline-powered air blowers with filter holders of interchangeable size. Filters used in the present operation were 7" diameter paper + 4" diameter activated charcoal cartridge with an air flow rate of approximately 20 cfm. Data from the analyzed filters are given in Table III. Air concentration of Ru-103 & 106 during these two days was less than 0.01% MPC_a for Ru-106. Since the MPC_a for Ru-106 is the most conservative, it was used in all air concentration evaluations. I-131 observed on the M-102 air sample of 7-10-76 is believed not to originate from the U20aa test. Background concentration of I-131 in air was less than 3×10^{-14} $\mu\text{Ci/cc}$ for the southern Nevada region during this time period⁽¹⁰⁾, and the observed value of 9.85×10^{-14} $\mu\text{Ci/cc} \pm 85\%$ for I-131 falls within the maximum background value of 3×10^{-14} $\mu\text{Ci/cc}$ at the 95% confidence level. This along with the fact that I-131 was not observed in any other air sample nor in any of the several gamma spectra taken during contaminant

identification indicates that I-131 was not a contaminant in the U20aa radioactive mud spill.

External gamma/beta dose rate was also determined prior to cleanup operations. Film badges were placed at 1 m height in locations considered to give a maximum exposure rate. Table IV gives the results. Maximum possible dose rates that one could expect by standing on the contaminated mud for 8 hrs per day were $(0.25 \times 10.9) + 2.7^*(8 \text{ hr/day})(5 \text{ days/wk}) = 217 \text{ mrem/wk}$ to the skin and less than $(2.7 \text{ mrem/hr})(8 \text{ hr/day})(5 \text{ days/wk}) = 108 \text{ mrem/wk}$ to whole body. Since this dose could only be received during the time that visible surface contamination was present (which was estimated to be about 10 working days), no one should receive more than 216 mrem to whole or $(434) + 216 = 650 \text{ mrem}$ to skin. The dose from the 3.54 MeV (max.) beta from Ru/Rh-106 was included in the maximum skin prediction. These doses have considerable conservatism since only a small portion of the time would be spent by any individual in such locations. Most of the radioactive mud would be scooped up using front end loaders, at which time personnel would be instructed to stand back from the contaminated area. However, these doses were used as the maximum possible estimates for safety planning purposes.

*The value 0.25 is the approximate fraction of the 3.54 MeV (max.) beta transmitted through the clothing consisting of Anti-C clothing in addition to normal clothes. The values of 10.9 and 2.7 were obtained from Table IV.

The potential radiation exposures (external and internal) were considered acceptable and work was allowed to commence. Air concentrations and external gamma dose were continuously monitored such that one would quickly detect any unforeseen changes in radiation exposure levels as cleanup began.

B. During Cleanup

Cleanup commenced on 7-12-76 using a front end loader and truck in Area 3 (Figure 1). Since the potential air suspension problem from front end loading was not known, the driver was placed in full face mask until the immediate atmosphere could be sampled. A 25 minute sample was taken next to the driver using a 2 liter/min lapel air sampler.⁽¹¹⁾ Results are given in Table V (7-12-76) and show that beta activity was not significantly different from background at the 95% confidence level. Calculations using the air flow rate of 2 liters/min and counting efficiency of 33% showed 1% MPC to be distinguishable from background at the 95% level. This was considered acceptable air activity during front end loading and respiratory equipment was not required.

M-102 air samplers were positioned downwind in proximity to all active work areas and filters changed on a daily basis. The lapel air samplers, being compact in size, were used in operations such as front end loading and vacuuming where they could be placed on personnel or equipment to give a more representative sample of

the air contamination level in close proximity to working personnel. The data collected from the air samplers are given in Tables III and V. It is observed that the maximum concentration from lapel air samplers was 5.67×10^{-11} $\mu\text{Ci/cc}$ or approximately 1% MPC_a ; from M-102 samplers was 7.1×10^{-12} $\mu\text{Ci/cc}$ or 0.12% MPC_a . The eight-fold difference may be due to the closer proximity of the lapel samplers to the working location.

A portion of the cleanup procedure involved shoveling and bagging radioactive mud. During this process, LiF teflon TLDs were worn on fingers (underneath gloves) for the first three days by those handling the bags. Table VI gives their hand exposure levels. Maximum beta + gamma dose rate to hands was 116.7 mrem/day. The bagging process lasted a total of about 5 days; therefore, no one should have received more than 584 mrem to hands. The dose to other extremities should be considerably less than this.

Throughout the cleanup operation, pocket dosimeters and experimental film badges (in addition to normal film badges) were issued to all personnel entering the contaminated area. Pocket dosimeters were read out and recorded at the end of each shift and experimental badges changed and read out on a weekly basis. All experimental badges had a weekly dose of less than the reportable limit of 30 mrem beta + gamma. Doses from regular NTS badges are difficult to analyze due to the chance that an

individual may have been exposed to radiation at other jobs.

However, the maximum total dose (beta + gamma) received by any individual working at U20aa during the third quarter of 1976 (which includes the entire cleanup operation) as measured by their NTS film badges was equal to 80 mrem.

TABLE III

M-102 AIR SAMPLES

<u>DATE</u>	<u>LOCATION*</u>	<u>RADIONUCLIDE[†]</u>	<u>ACTIVITY (μCi/cc)</u>	<u>PERCENT ERROR</u>
7-10-76	1	Ru-103 & 106	5.64×10^{-13}	9.5
	1	I-131	9.85×10^{-14}	85
	2	Ru-103 & 106	4.77×10^{-13}	10.5
	3	Ru-103 & 106	1.42×10^{-12}	5.6
<hr/>				
7-11-76	1	Ru-103 & 106	1.40×10^{-12}	6.5
	2	Ru-103 & 106	2.22×10^{-12}	5.1
	3	Ru-103 & 106	4.21×10^{-12}	3.6
<hr/>				
7-12-76	1	Ru-103 & 106	4.89×10^{-12}	3.1
	2	Ru-103 & 106	5.62×10^{-13}	10.2
	3	Ru-103 & 106	1.23×10^{-13}	28.2
<hr/>				
7-13-76	1	Ru-103 & 106	2.13×10^{-12}	4.3
	2	Ru-103 & 106	1.75×10^{-13}	18.5
	3	Ru-103 & 106	7.10×10^{-12}	2.8
	4	Ru-103 & 106	2.75×10^{-12}	6.6
<hr/>				
7-14-76	1	Ru-103 & 106	5.68×10^{-16}	15.5
	2	Ru-103 & 106	9.87×10^{-16}	10.9
	4	Ru-103 & 106	1.11×10^{-15}	10.2

TABLE III, cont.

<u>DATE</u>	<u>LOCATION</u>	<u>RADIONUCLIDE</u>	<u>ACTIVITY (μCi/cc)</u>	<u>PERCENT ERROR</u>
7-15-76	1	Ru-103 & 106	3.65×10^{-12}	3.4
	2	Ru-103 & 106	3.49×10^{-13}	12.7
	4	Ru-103 & 106	1.17×10^{-13}	26.8
<hr/>				
7-16-76	1	Ru-103 & 106	7.94×10^{-13}	7.8
	2	Ru-103 & 106	6.75×10^{-13}	8.5
	4	Ru-103 & 106	2.19×10^{-13}	17.2
<hr/>				
7-19-76	1	Ru-103 & 106	1.20×10^{-13}	4.3
	2	Ru-103 & 106	5.06×10^{-14}	6.8
	4	Ru-103 & 106	1.80×10^{-14}	12.4
<hr/>				
7-20-76	1	Ru-103 & 106	1.18×10^{-12}	5.1
	2	Ru-103 & 106	2.96×10^{-13}	11.1
	4	Ru-103 & 106	4.36×10^{-13}	9.2
<hr/>				
7-21-76	1	Ru-103 & 106	2.24×10^{-13}	9.2
	2	Ru-103 & 106	4.92×10^{-13}	6.0
	4	Ru-103 & 106	$< 1.1 \times 10^{-14}$	
	5	Ru-103 & 106	1.13×10^{-12}	7.7
	5	Ru-103 & 106	2.59×10^{-13}	6.7

TABLE III, cont.

<u>DATE</u>	<u>LOCATION</u>	<u>RADIONUCLIDE</u>	<u>ACTIVITY</u> <u>(μCi/cc)</u>	<u>PERCENT</u> <u>ERROR</u>
7-22-76	1	Ru-103 & 106	2.72×10^{-13}	11.0
	2	Ru-103 & 106	9.93×10^{-13}	5.3
	5	Ru-103 & 106	4.08×10^{-12}	4.4
	5	Ru-103 & 106	2.75×10^{-12}	3.9
	6	Ru-103 & 106	1.74×10^{-12}	11.8
<hr/>				
7-23-76	1	Ru-103 & 106	1.20×10^{-14}	37.7
	5	Ru-103 & 106	2.4×10^{-12}	1.6
	6	Ru-103 & 106	1.97×10^{-14}	25.6
<hr/>				
7-26-76	1	Ru-103 & 106	7.20×10^{-14}	25.4
	2	Ru-103 & 106	4.84×10^{-13}	7.5
	5	Ru-103 & 106	2.89×10^{-13}	10.9
	6	Ru-103 & 106	8.12×10^{-14}	25.4
<hr/>				
7-28-76	1	Ru-103 & 106	6.91×10^{-15}	53.1
	2	Ru-103 & 106	5.55×10^{-14}	11.6
	5	Ru-103 & 106	9.87×10^{-14}	8.5
	6	Ru-103 & 106	1.1×10^{-13}	7.9
<hr/>				
7-29-76	2	Ru-103 & 106	1.44×10^{-13}	7.0
	4	Ru-103 & 106	4.31×10^{-13}	3.9

TABLE III, cont.

<u>DATE</u>	<u>LOCATION</u>	<u>RADIONUCLIDE</u>	<u>ACTIVITY</u> ($\mu\text{Ci/cc}$)	<u>PERCENT</u> <u>ERROR</u>
7-29-76	5	Ru-103 & 106	5.33×10^{-14}	12.9
	6	Ru-103 & 106	5.28×10^{-13}	3.6
7-30-76	2	Ru-103 & 106	1.31×10^{-14}	33.3
	4	Ru-103 & 106	$< 3.6 \times 10^{-15}$	
	5	Ru-103 & 106	1.39×10^{-14}	31.8
	6	Ru-103 & 106	5.95×10^{-14}	11.6
8-2-76	2	Ru-103 & 106	5.32×10^{-13}	7.3
	4	Ru-103 & 106	2.52×10^{-13}	11.4
	5	Ru-103 & 106	3.06×10^{-14}	55.2
	6	Ru-103 & 106	1.26×10^{-12}	4.8
8-3-76	2	Ru-103 & 106	1.21×10^{-13}	7.8
	4	Ru-103 & 106	4.90×10^{-14}	13.2
	5	Ru-103 & 106	5.13×10^{-14}	13.0
	6	Ru-103 & 106	3.60×10^{-13}	4.4
8-4-76	2	Ru-103 & 106	3.83×10^{-13}	8.8
	4	Ru-103 & 106	4.61×10^{-13}	8.7
	5	Ru-103 & 106	4.65×10^{-13}	8.0
	6	Ru-103 & 106	5.26×10^{-13}	7.6

TABLE III, cont.

<u>DATE</u>	<u>LOCATION</u>	<u>RADIONUCLIDE</u>	<u>ACTIVITY</u> ($\mu\text{Ci/cc}$)	<u>PERCENT</u> <u>ERROR</u>
8-5-76	2	Ru-103 & 106	4.73×10^{-13}	7.9
	4	Ru-103 & 106	1.33×10^{-13}	17.2
	5	Ru-103 & 106	1.68×10^{-13}	14.7
	6	Ru-103 & 106	3.07×10^{-13}	10.4
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8-6-76	2	Ru-103 & 106	5.74×10^{-13}	7.0
	4	Ru-103 & 106	8.61×10^{-14}	23.1
	5	Ru-103 & 106	1.44×10^{-13}	16.2
	6	Ru-103 & 106	1.56×10^{-13}	15.3
<hr/>				
8-9-76	2	Ru-103 & 106	8.61×10^{-14}	23.1
	4	Ru-103 & 106	4.88×10^{-14}	36.1
	5	Ru-103 & 106	4.21×10^{-13}	8.6
	6	Ru-103 & 106	7.79×10^{-14}	26.1
<hr/>				
8-10-76	1	Ru-103 & 106	1.30×10^{-13}	17.7
	2	Ru-103 & 106	2.16×10^{-14}	72.4
	4	Ru-103 & 106	6.39×10^{-14}	29.5
	5	Ru-103 & 106	2.34×10^{-13}	12.1
<hr/>				
8-11-76	1	Ru-103 & 106	2.54×10^{-13}	11.2
	2	Ru-103 & 106	7.63×10^{-14}	25.0

TABLE III, cont.

<u>DATE</u>	<u>LOCATION</u>	<u>RADIONUCLIDE</u>	<u>ACTIVITY</u> <u>(μCi/cc)</u>	<u>PERCENT</u> <u>ERROR</u>
8-11-76	5	Ru-103 & 106	1.43×10^{-13}	16.1
<hr/>				
8-12-76	1	Ru-103 & 106	3.47×10^{-13}	12.2
	2	Ru-103 & 106	7.85×10^{-14}	34.6
<hr/>				
8-13-76	1	Ru-103 & 106	4.48×10^{-13}	8.0
	2	Ru-103 & 106	2.25×10^{-13}	9.6
<hr/>				
8-16-76	1	Ru-103 & 106	5.98×10^{-13}	8.6
	2	Ru-103 & 106	5.15×10^{-13}	9.3
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* - Area location where sample collected (Figure 1).

† - Gamma spectrum analysis have shown that the contaminant consists almost entirely of Ru-103 and Ru/Rh-106. The gross beta activity could, therefore, be used in determining the μ Ci/cc.

TABLE IV

FILM BADGES PLACED IN CONTAMINATED AREA FOR 51 HRS AT 1 M ABOVE GROUND LEVEL

<u>BADGE NO.</u>	<u>AVERAGE MREM/HR*</u>	
	<u>BETA</u>	<u>GAMMA</u>
1	10.9	2.2
2	9.1	2.7
3	7.3	2.2

(1)
*RBE for beta assumed to equal unity

TABLE V

LAPEL AIR SAMPLES

<u>DATE</u>	<u>LOCATION*</u>	<u>SAMPLE PERIOD</u>	<u>RADIONUCLIDE[†]</u>	<u>TOTAL CPM</u>	<u>BACKGROUND^{††} CPM $\pm$ 2 σ</u>	<u>NET CPM</u>	<u>DPM</u>	<u>μCi/cc</u>
7-12-76	FEL-A3	25 min	Ru-103 & 106	113 $\pm$ 21	115 $\pm$ 7	0	none detectable	
	FEL-A3	4 hrs	Ru-103 & 106	Background ^{†††}		0	none detectable	
7-14-76	FEL-A3	AM; 3 hrs	Ru-103 & 106	Background ^{†††}		0	none detectable	
	FEL-A3	PM; 3 hrs	Ru-103 & 106	Background ^{†††}		0	none detectable	
7-15-76	VET-A4	50 min	Ru-103 & 106	98 $\pm$ 20	98 $\pm$ 6	0	none detectable	
7-19-76	FEL-A3	5 hrs	Ru-103 & 106	101 $\pm$ 20	100 $\pm$ 6	0	none detectable	
7-20-76	FEL-A3	3 hrs; 10 min	Ru-103 & 106	Background ^{†††}		0	none detectable	
	VET-A4	2.5 hrs	Ru-103 & 106	Background ^{†††}		0	none detectable	
	Shoveling A5	2.5 hrs	Ru-103 & 106	107 $\pm$ 21	105 $\pm$ 6	0	none detectable	
7-21-76	Shoveling A5	3 hrs; 10 min	Ru-103 & 106	97 $\pm$ 20	96 $\pm$ 6	0	none detectable	
	Road Grader A2	3 hrs; 10 min	Ru-103 & 106	101 $\pm$ 20	96 $\pm$ 6	0	none detectable	
	Shoveling A5	3 hrs	Ru-103 & 106	112 $\pm$ 21	96 $\pm$ 6	0	none detectable	

TABLE V, cont.

<u>DATE</u>	<u>LOCATION</u>	<u>SAMPLE PERIOD</u>	<u>RADIONUCLIDE</u>	<u>TOTAL CPM</u>	<u>BACKGROUND CPM $\pm 2 \sigma$</u>	<u>NET CPM</u>	<u>DPM</u>	<u>$\mu\text{Ci/cc}$</u>
7-21-76	Road Grader A2	3 hrs	Ru-103 & 106	101 $\pm$ 20	96 $\pm$ 6	0	none detectable	
7-22-76	FEL-A2	3 hrs	Ru-103 & 106	105 $\pm$ 21	108 $\pm$ 7	0	none detectable	
	Road Grader A2	3 hrs	Ru-103 & 106	107 $\pm$ 21	108 $\pm$ 7	0	none detectable	
	FEL-A2	2.5 hrs	Ru-103 & 106	112 $\pm$ 21	98 $\pm$ 6	0	none detectable	
	Road Grader A2	2.5 hrs	Ru-103 & 106	94 $\pm$ 19	98 $\pm$ 6	0	none detectable	
7-23-76	FEL-A2	3.25 hrs	Ru-103 & 106	104 $\pm$ 20	97 $\pm$ 6	0	none detectable	
	FEL-A2	3.25 hrs	Ru-103 & 106	95 $\pm$ 20	97 $\pm$ 6	0	none detectable	
7-26-76	FEL#1-A2	4 hrs	Ru-103 & 106	105 $\pm$ 21	102 $\pm$ 6	0	none detectable	
	FEL#2-A5	4 hrs	Ru-103 & 106	103 $\pm$ 20	102 $\pm$ 6	0	none detectable	
	FEL#1-A2	3 hrs	Ru-103 & 106	116 $\pm$ 22	102 $\pm$ 6	0	none detectable	
	Dozer #1 A2	3 hrs	Ru-103 & 106	96 $\pm$ 20	102 $\pm$ 6	0	none detectable	
7-28-76	FEL#1-A2	4 hrs	Ru-103 & 106	92 $\pm$ 19	98 $\pm$ 6	0	none detectable	
	FEL#2-A5	4 hrs	Ru-103 & 106	99 $\pm$ 20	98 $\pm$ 6	0	none detectable	
	FEL#1-A2	3.5 hrs	Ru-103 & 106	102 $\pm$ 20	98 $\pm$ 6	0	none detectable	
	FEL#2-A5	3.5 hrs	Ru-103 & 106	100 $\pm$ 20	98 $\pm$ 6	0	none detectable	

TABLE V, cont.

<u>DATE</u>	<u>LOCATION</u>	<u>SAMPLE PERIOD</u>	<u>RADIONUCLIDE</u>	<u>TOTAL CPM</u>	<u>BACKGROUND CPM $\pm 2 \sigma$</u>	<u>NET CPM</u>	<u>CPM</u>	<u>$\mu\text{Ci/cc}$</u>
7-29-76	FEL#1-A2	4 hrs	Ru-103 & 106	98 $\pm$ 20	101 $\pm$ 6	0	none detectable	
	FEL#2-A5	4 hrs	Ru-103 & 106	104 $\pm$ 20	101 $\pm$ 6	0	none detectable	
	FEL#1-A2	3.5 hrs	Ru-103 & 106	129 $\pm$ 23	101 $\pm$ 6	28	84	9.0×10^{-11}
	FEL#2-A5	3.5 hrs	Ru-103 & 106	97 $\pm$ 20	101 $\pm$ 6	0	none detectable	
<hr/>								
7-30-76	FEL #1-A2	4 hrs	Ru-103 & 106	93 $\pm$ 19	101 $\pm$ 6	0	none detectable	
	FEL#2-A5	4 hrs	Ru-103 & 106	103 $\pm$ 20	101 $\pm$ 6	0	none detectable	
	Dozer-A2	4 hrs	Ru-103 & 106	94 $\pm$ 19	101 $\pm$ 6	0	none detectable	
	FEL#1-A2	3 hrs	Ru-103 & 106	99 $\pm$ 20	98 $\pm$ 6	0	none detectable	
	FEL#2-A5	3 hrs	Ru-103 & 106	104 $\pm$ 20	98 $\pm$ 6	0	none detectable	
	Dozer-A2	3 hrs	Ru-103 & 106	104 $\pm$ 20	98 $\pm$ 6	0	none detectable	
<hr/>								
8-2-76	FEL#1-A1	3.5 hrs	Ru-103 & 106	100 $\pm$ 20	102 $\pm$ 6	0	none detectable	
	FEL#2-A5	3.5 hrs	Ru-103 & 106	98 $\pm$ 20	102 $\pm$ 6	0	none detectable	
	Dozer-A1	3.5 hrs	Ru-103 & 106	101 $\pm$ 20	102 $\pm$ 6	0	none detectable	
	FEL#1-A1	3.5 hrs	Ru-103 & 106	101 $\pm$ 20	102 $\pm$ 6	0	none detectable	
	Dozer-A1	3.5 hrs	Ru-103 & 106	96 $\pm$ 20	102 $\pm$ 6	0	none detectable	
<hr/>								
8-3-76	Dozer-A1	3.5 hrs	Ru-103 & 106	122 $\pm$ 22	102 $\pm$ 6	0	none detectable	
	FEL#1-A1	3.5 hrs	Ru-103 & 106	96 $\pm$ 20	102 $\pm$ 6	0	none detectable	
	FEL#2-A5	3.5 hrs	Ru-103 & 106	101 $\pm$ 20	102 $\pm$ 6	0	none detectable	
	Dozer-A5	3.5 hrs	Ru-103 & 106	116 $\pm$ 22	102 $\pm$ 6	0	none detectable	

TABLE V, cont.

<u>DATE</u>	<u>LOCATION</u>	<u>SAMPLE PERIOD</u>	<u>RADIONUCLIDE</u>	<u>TOTAL CPM</u>	<u>BACKGROUND CPM $\pm 2 \sigma$</u>	<u>NET CPM</u>	<u>DPM</u>	<u>$\mu\text{Ci/cc}$</u>
8-4-76	FEL#1-A5	6 hrs	Ru-103 & 106	103 $\pm$ 20	101 $\pm$ 6	0	none detectable	
	FEL#2-A5	6 hrs	Ru-103 & 106	99 $\pm$ 20	101 $\pm$ 6	0	none detectable	
8-5-76	FEL#1-A5	6 hrs	Ru-103 & 106	107 $\pm$ 21	96 $\pm$ 6	0	none detectable	
	FEL#2-A6	6 hrs	Ru-103 & 106	108 $\pm$ 21	96 $\pm$ 6	0	none detectable	
8-6-76	FEL#1-A5	6 hrs	Ru-103 & 106	129 $\pm$ 23	99 $\pm$ 6	30	91	5.67x10 ⁻¹
	FEL#2-A6	6 hrs	Ru-103 & 106	110 $\pm$ 21	99 $\pm$ 6	0	none detectable	
8-9-76	FEL#1-A5	6 hrs	Ru-103 & 106	91 $\pm$ 19	101 $\pm$ 6	0	none detectable	
	FEL#2-A2	6 hrs	Ru-103 & 106	120 $\pm$ 22	101 $\pm$ 6	0	none detectable	
	Grader	6 hrs	Ru-103 & 106	99 $\pm$ 20	101 $\pm$ 6	0	none detectable	
8-10-76	FEL#1-A6	6 hrs	Ru-103 & 106	94 $\pm$ 19	95 $\pm$ 6	0	none detectable	
	FEL#2-A2	6 hrs	Ru-103 & 106	98 $\pm$ 20	95 $\pm$ 6	0	none detectable	
	Grader	6 hrs	Ru-103 & 106	102 $\pm$ 20	95 $\pm$ 6	0	none detectable	
3-11-76	FEL#1-A6	6 hrs	Ru-103 & 106	102 $\pm$ 20	101 $\pm$ 6	0	none detectable	
	FEL#2-A2	6 hrs	Ru-103 & 106	99 $\pm$ 20	101 $\pm$ 6	0	none detectable	
3-12-76	FEL#1-A6	6 hrs	Ru-103 & 106	96 $\pm$ 20	103 $\pm$ 6	0	none detectable	
	FEL#2-A2	6 hrs	Ru-103 & 106	112 $\pm$ 21	103 $\pm$ 6	0	none detectable	

TABLE V, cont.

<u>DATE</u>	<u>LOCATION</u>	<u>SAMPLE PERIOD</u>	<u>RADIONUCLIDE</u>	<u>TOTAL CPM</u>	<u>BACKGROUND CPM $\pm 2 \sigma$</u>	<u>NET CPM</u>	<u>DPM</u>	<u>μCi/cc</u>
8-16-76	FEL#1	6 hrs	Ru-103 & 106	104 $\pm$ 20	102 $\pm$ 6	0		none detectable

* - FEL is Front End Loader; VET is Vacuum Elephant Trunk; A1, A2, etc., are the area locations at which the air samples were taken and are shown on the attached map.

+ - It has been shown that almost all activity was due to Ru-103 & 106. The gross beta count was therefore used.

++ - Background was counted for 10 minutes. Two sigma (2σ) equals the uncertainty in the 10 minute background count at the 95% confidence level.

+++ - The actual number of CPM was not written down in the logbook. The monitor performing the counting determined the air sample to be within the statistical limits of background radiation.

TABLE VI

HAND EXPOSURE DURING BAGGING PROCEDURE
(TLDs worn for 3 days)

<u>PERSON</u>	<u>AVERAGE MREM/DAY*</u>	
	<u>RIGHT HAND</u>	<u>LEFT HAND</u>
1	71.7	76.7
2	70.0	81.7
3	73.3	70.0
4	76.7	85.0
5	76.7	†
6	76.7	†
7	80.8	108.3
8	96.7	116.7
9	116.7	51.7
10	76.7	116.2

* - RBE of beta component assumed to equal unity⁽¹⁾

† - TLDs lost or destroyed

NOTICE

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RADIOLOGICAL CONTROL STATION

PLATE 2

U23aa CRATER - RADIOACTIVE MUD
REPOSITORY

PLATE 3

MUD SUMP - PRIOR TO CLEANUP
PROCEDURES

FOLLOWING INITIAL MUD REMOVAL
IN AREA 3

VACUUM CLEANING SYSTEM

PLATE 9

DURING CLEANUP IN AREA 4 -
SHOVELLING & BAGGING

PLATE 10

DURING CLEANUP IN AREA 5 -
SHOVELING & BAGGING

EARTHEN DAM & END OF
CONTAMINATED MUD FLOW

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