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Radiological Assessment of Worker Doses During Sludge Mobilization and Removal at the Melton Valley Storage Tanks

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FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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Health Sciences Research Division

RADIOLOGICAL ASSESSMENT OF WORKER DOSES DURING SLUDGE MOBILIZATION AND REMOVAL AT THE MELTON VALLEY STORAGE TANKS

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ABSTRACT

This report presents an assessment of potential radiation doses to workers during mobilization and removal of contaminated sludges from the Melton Valley Storage Tanks at Oak Ridge National Laboratory. The assessment is based on (1) measurements of radionuclide concentrations in sludge and supernatant liquid samples from the waste storage tanks, (2) measurements of gamma radiation levels in various areas that will be accessed by workers during normal activities, (3) calculations of gamma radiation levels for particular exposure situations, especially when the available measurements are not applicable, and (4) assumed scenarios for worker activities in radiation areas. Only doses from external exposure are estimated in this assessment. Doses from internal exposure are assumed to be controlled by containment of radioactive materials or respiratory protection of workers and are not estimated.

The assumed exposure scenarios for workers involve (1) installation of equipment in the pump and valve vault, located next to the vaults for the waste storage tanks, or on top of the roof of the tank vaults and (2) routine maintenance of equipment during use. The assessment indicates that the collective dose to workers during installation of equipment in the pump and valve vault could exceed 300 person-rem (3 person-Sv) if the gamma radiation levels in the vault at the present time, which are due primarily to internal contamination of piping in the vault, are not reduced. The collective dose during installation of equipment on top of the roof of the tank vaults could be about 200 person-rem (2 person-Sv), although the dose during these activities could be reduced by about an order of magnitude if the supernatant liquid in the tanks is first treated to remove most of the ^{137}Cs. The collective dose during the other work activities should be less than 40 person-rem (0.4 person-Sv).

This assessment also considers a credible accident scenario involving leakage of sludge and supernatant liquid onto the floor of the pump and valve vault and subsequent exposures of workers during repair of the leak. The collective dose for this accident scenario is estimated to be about 1 person-rem (0.01 person-Sv). Doses during subsequent decontamination of the vault were not estimated, because the high radiation levels in the vault presumably would necessitate the use of robotic equipment during these activities.

The estimates of collective dose obtained from this assessment may not represent expected doses to workers during sludge mobilization and removal activities, because the estimates are subject to considerable uncertainty, particularly in regard to the gamma radiation levels at some of the locations where workers would be exposed. In general, the dose estimates for the assumed exposure scenarios are intended to be somewhat conservative, especially for work activities on top of the roof of the tank vaults, and they should be interpreted only as indicators of the potential magnitude of doses that might be experienced and the considerable care that will be required in protecting workers during sludge mobilization and removal from the Melton Valley Storage Tanks.

ABBREVIATIONS AND ACRONYMS

ALARA	as low as reasonably achievable
Bq	becquerel
C	centigrade
Ci	curie
DOE	U.S. Department of Energy
dpm	disintegration per minute
ft	foot
g	gram
gal	gallon
gpm	gallon per minute
h	hour
HEPA	high efficiency particulate (filter)
hp	horsepower
ICRP	International Commission on Radiological Protection
ID	inside diameter
in.	inch
L	liter
M	molarity
m	meter
min	minute
MVST	Melton Valley Storage Tank
NRC	U.S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
P&VV	pump and valve vault
R	roentgen
Sv	sievert
TLD	thermoluminescent dosimeter
TRU	transuranic (waste)
WIPP	Waste Isolation Pilot Plant

1. INTRODUCTION

Current waste management plans at Oak Ridge National Laboratory (ORNL) call for the processing of sludges containing transuranic (TRU) radioactive waste, which are stored in the Melton Valley Storage Tanks along with low-level liquid waste, for disposal at the Waste Isolation Pilot Plant (WIPP) facility in New Mexico (ORNL 1995). Prior to shipment to the WIPP facility, the processed TRU waste must meet the waste acceptance criteria established for that facility by the U.S. Department of Energy (DOE 1996).

The Melton Valley Storage Tanks are horizontal cylindrical tanks, each with a capacity of 50,000 gal (1.9×10^5 L). The tanks are 12 ft (3.7 m) in diameter and more than 61 ft (19 m) long. The sludges containing TRU waste to be processed must be removed from the waste storage tanks and transferred to a separate processing facility. However, the waste storage tanks were not designed to provide sludge mobilization and removal capability, they contain internal obstructions and have limited external access points, and there are high radiation fields near the storage tanks. Thus, removal of the sludges from the waste storage tanks must be done with considerable care and planning.

The purpose of this report is to provide information on potential radiation doses that might be experienced by workers during sludge mobilization and removal from the Melton Valley Storage Tanks. The dose assessments are based on measurements of radiation fields near the storage tanks and supplemental calculations for situations where measurements are not available. The measurements and calculations are used to estimate collective doses to workers for a variety of defined activities (i.e., scenarios) involved in sludge removal. The defined exposure scenarios are based primarily on so-called Option 3 from the 1995 ORNL planning document (ORNL 1995), and they assume that the first tank to be treated for sludge removal is Melton Valley Storage Tank W-26 (see Section 2).

The information on radiation doses provided in this report is intended for use in planning of work activities during sludge mobilization and removal to insure that workers are adequately protected in accordance with radiation protection requirements established by the U.S. Department of Energy (DOE 1993) or the U.S. Nuclear Regulatory Commission (NRC 1991). It must be recognized, however, that the dose estimates provided in this report, as well as the information used in obtaining these estimates, are subject to considerable uncertainty. Some important sources of uncertainty in the dose estimates include the limited information on the concentrations of important radionuclides in the sludges and the subjective nature of the various worker exposure scenarios considered in the dose assessments. Hence, the dose estimates serve only as indicators of the potential magnitude of doses that might be experienced and the considerable care that will be required in protecting workers during sludge mobilization and removal activities.

2. MELTON VALLEY STORAGE TANKS

The area near the Melton Valley Storage Tanks (MVSTs) is shown in Fig. 2.1. The large concrete pad toward the bottom of the photograph is the roof of the MVST vaults and the adjoining pump and value vault (P&VV), and the large building next to the pad is Building 7860 (the new Hydrofracture Facility). There are eight MVSTs, identified as W-24 through W-31, with four tanks located in each of two underground concrete vaults (see Figs. 2.2 and 2.3). One suction leg and one discharge nozzle extend from each tank to the P&VV, which is contiguous to both tank vaults on the south side. The waste tanks have several additional nozzles that have been extended into the P&VV and blanked off at the wall. The construction of the tanks is shown in more detail in Fig. 4.1 of Section 4.

External access to the MVST vaults and waste storage tanks is limited. There is one 3-in. pipe nozzle to each tank, designated as G-3 (see Fig. 4.1), which is used as an installation point for sludge level detection instrumentation or as a sampling nozzle when the sludge level detection instrumentation is removed. The only other access to each waste tank from the vault roof is through a 3½-ft by 3½-ft concrete vault plug and covered manhole-sized tank nozzle (19 in. ID) located about 17 ft from the north end of the tanks. This nozzle, which is designated as C (see Fig. 4.1), is blanked off and has not been used since the original construction of the waste storage tanks.

A temporary structure near the center of the large concrete pad (see Figs. 2.1 and 2.2) serves as a pump house and was constructed to pump liquid wastes from tanks W-29 and W-30 using the G-3 nozzles during the Liquid Waste Solidification Program at ORNL (Reece 1994). The pump house and associated piping currently block access to these two tanks through the G-3 nozzles or the concrete vault plugs and manhole-sized tank nozzles described above. During sludge mobilization and removal, the pump house will be moved about 16 ft toward the south, and the piping in the pump house will be modified to permit access to tanks W-29 and W-30 through the G-3 and C nozzles.

The sludge in the MVSTs varies in radionuclide composition, physical consistency, and depth (see Fig. 2.4). The sludges have been sampled on three occasions over the past ten years (Peretz et al. 1986; Sears et al. 1990; Ceo et al. 1990). These reports state that at least two tanks (W-27 and W-31) have hard sludges, and that the soft sludges in the tanks, after being mixed ultrasonically, varied in consistency from "prepared mustard" to "peanut butter." However, samples can only be taken from each tank through the G-3 nozzle, and it is not known if the sludge samples are representative of sludges at other locations within each tank. Sears et al. (1990) also sampled the supernatant liquids (also referred to as supernates) in the tanks. Since additional liquid wastes have been added to the tanks since that time, the supernatant liquids in six of the tanks (W-24 through W-28 and W-31) were recently sampled again, and the preliminary "March 1996" data have been reported by Moore (1996).

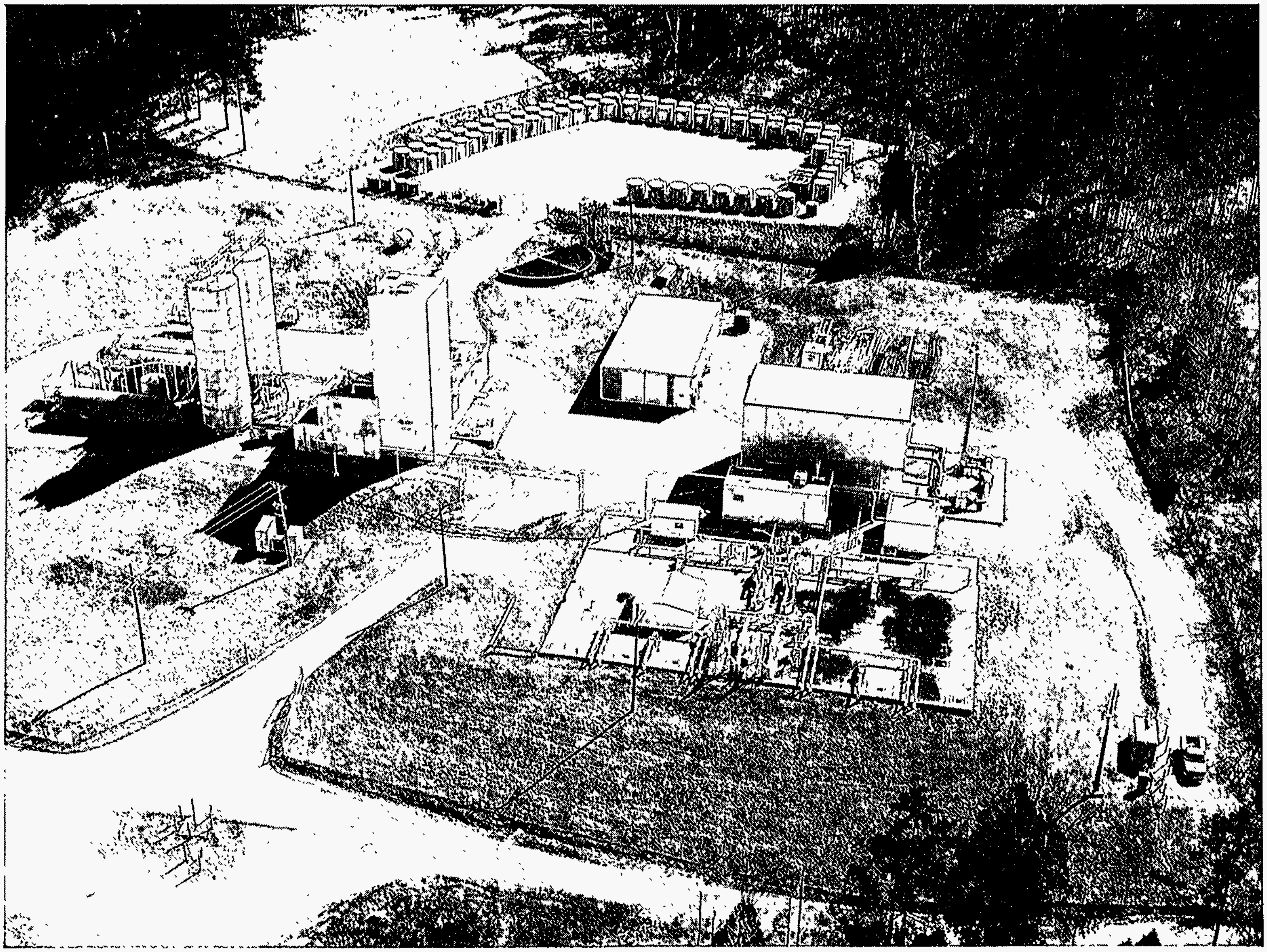

Fig. 2.1. **Photograph showing area near Melton Valley Storage Tanks.** Large concrete pad toward bottom of photograph is roof of tank vaults and adjoining pump and valve vault, and large structure next to pad is Building 7860.

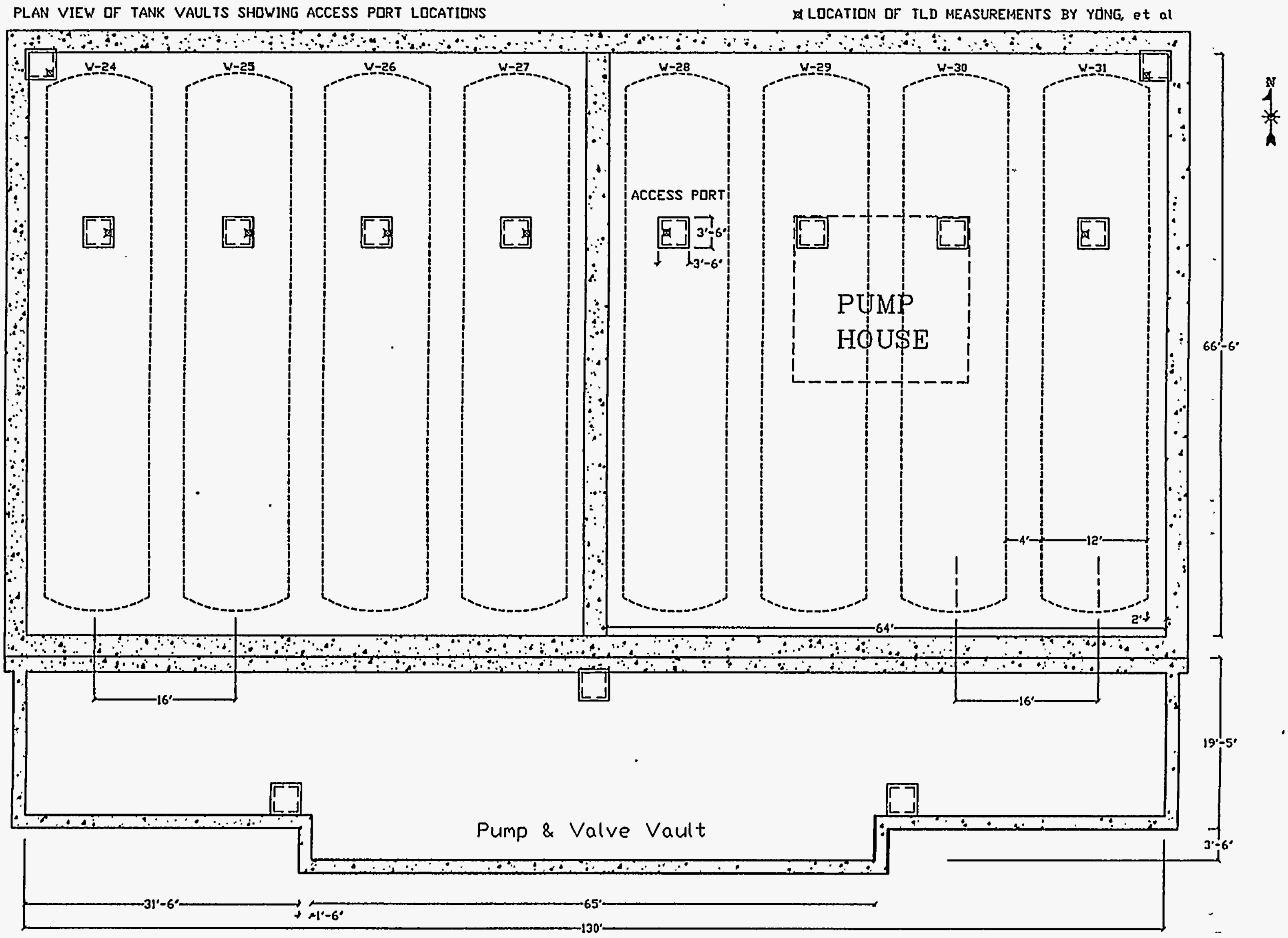

Fig. 2.2. **Plan view showing pump and valve vault and east and west vaults containing eight Melton Valley Storage Tanks.** Drawing was compiled from existing ORNL engineering schematics for use in this report, and dimensions or completeness may not be accurate for any other purpose.

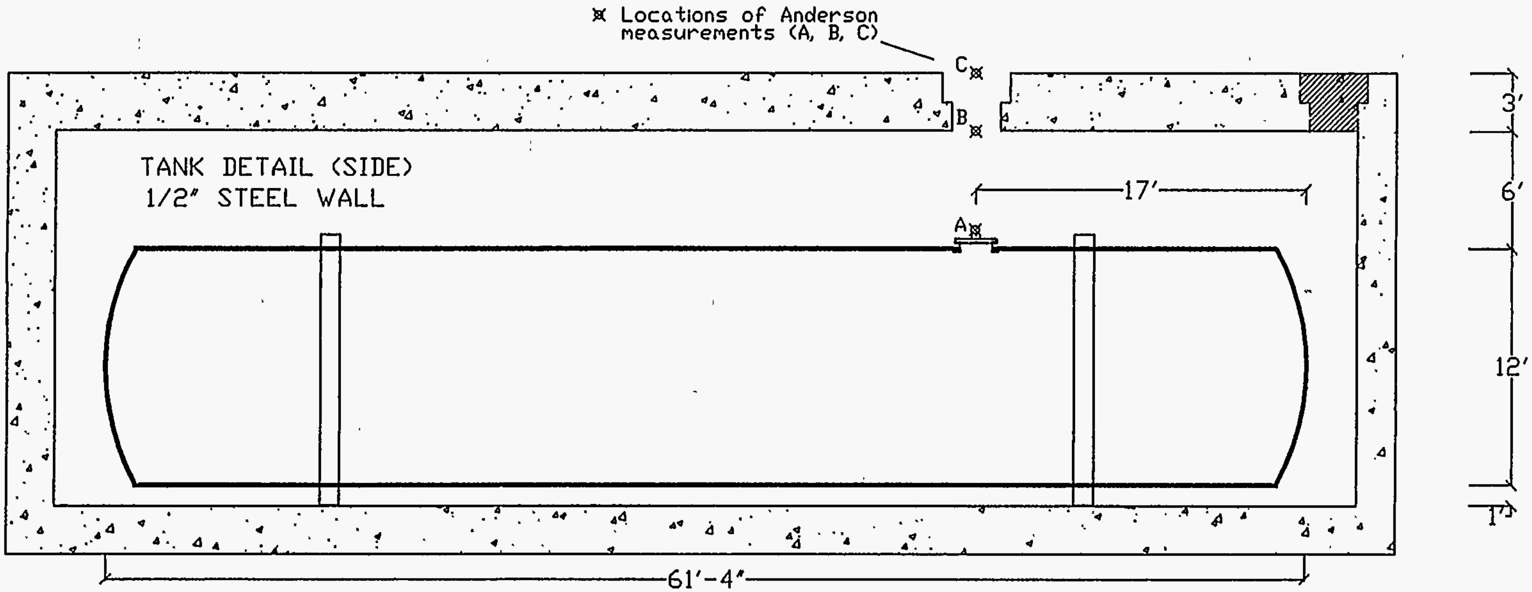

Fig. 2.3. Side view of waste storage tank showing tank and vault wall detail. Drawing was compiled from existing ORNL engineering schematics for use in this report, and dimensions or completeness may not be accurate for any other purpose.

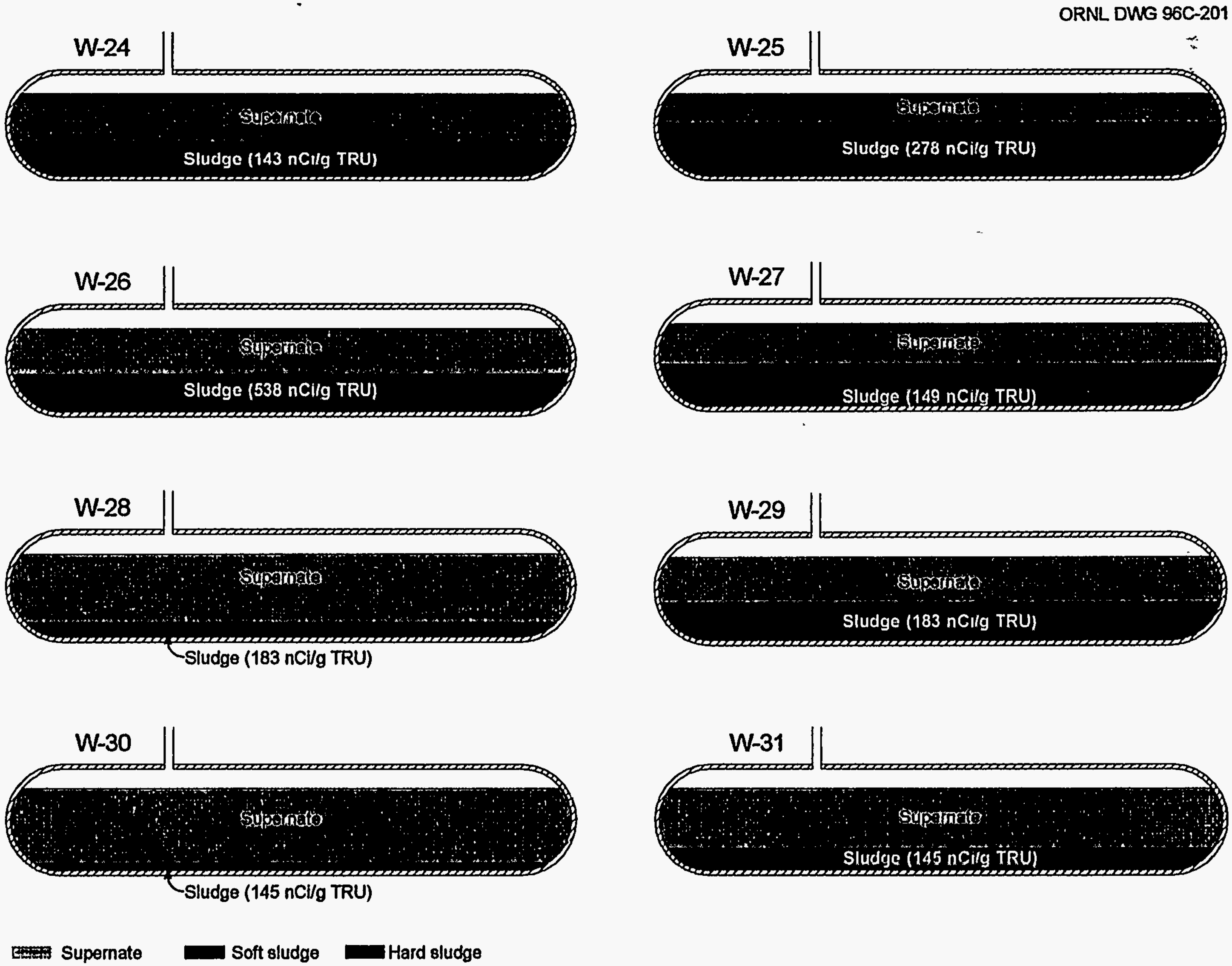

Fig. 2.4. Schematic showing approximate levels and concentrations of transuranic (TRU) radionuclides in sludges in Melton Valley Storage Tanks. One nanocurie per gram (nCi/g) is equal to 37 becquerels per gram (Bq/g). Actual supernatant liquid levels in tanks may be different from those depicted in the figure.

3. RADIOLOGICAL MEASUREMENTS

This section describes the measurements of radiation levels that have been made on samples of sludges and supernatant liquids from the Melton Valley Storage Tanks (MVSTs) and in the MVST vaults and the pump and valve vault (P&VV).

3.1 Sludge and Supernatant Samples

In the study by Sears et al. (1990), one or more samples of sludges and supernatant liquids were taken from the waste tanks, and exposure rates at contact with the unshielded samples were measured in the field. Exposure-rate measurements also were made on subsamples of the sludges after they had been dried overnight in a laboratory at 115°C. The results of these measurements are summarized in Table 3.1.

The supernatant liquids were collected in 250-mL sample jars. Exposure rates on contact with the full sample jars, as measured in the field, were 0.1-0.5 R/h, except the exposure rates for samples from tank W-26 were 1.2 R/h (Sears et al. 1990, Table A.2).

The field measurements of exposure rates for the wet sludges were 0.1-2.8 R/h per 250-mL sample (Sears et al. 1990, Table A.3), and exposure rates of up to 50 R/h per gram were observed in the laboratory for dried subsamples of the sludges. The increase in exposure rates from the dried subsamples was due primarily to beta particles from the decay of ^{90}Sr/^{90}Y, which were attenuated by water in the wet sludges (Sears et al. 1990, p. 28).

These data are indicative of the high concentrations of radionuclides in the contents of the waste storage tanks and the high radiation levels that could occur during sludge mobilization and removal operations.

3.2 Pump and Valve Vault

The results from a recent radiation survey of the P&VV (Anderson 1995) are summarized in Table 3.2. The P&VV is classified as both a high radiation area and a high contamination area. The layout of the P&VV is shown in Fig. 4.4 of Section 4.

Smears for transferable contamination were made on the floor, walls, piping, and two 200-gpm Moyno[1] progressing cavity pumps in the P&VV. The alpha-particle contamination per 100-cm^2 area on all surfaces was less than 20 dpm (0.3 Bq). For beta particles, the transferable contamination per 100 cm^2 was 300 to 150,000 dpm (5 to 2,500 Bq) on the pumps, piping, and walls, and 400,000 dpm (6,700 Bq) or more on the floor.

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[1] Moyno is a registered trademark of Robbins & Myers, Inc., P.O. Box 960, Springfield, OH 45501-0960.

Liquids are pumped to and from the eight waste storage tanks via a 6-in. suction pipe and a 4-in. discharge pipe that run the full length of the P&VV. These pipes are connected to the two Moyno pumps, which have a common manifold and can be operated individually or in tandem. Permanent shielding has been installed around these pumps to reduce the gamma radiation exposure to workers from other sources in the vault during maintenance on the pumps.

Gamma radiation levels were measured in contact with the 4-in. and 6-in. piping at three locations in the P&VV and in open work areas at six locations along the length of the P&VV. Except for one location at the center of the P&VV, the gamma radiation levels in contact with the 4-in. and 6-in. piping were 1-1.5 R/h, and the levels in the open work areas were 75-250 mR/h. At the center of the P&VV, the gamma radiation levels in the open work areas were 200-500 mR/h, and the levels in contact with the piping were 1-5 R/h.

The high gamma radiation levels in the P&VV presumably result, at least in part, from residual contamination in the piping. Thus, it may be possible to reduce the radiation levels by rinsing the existing pipes with clear supernatant and process water. However, the potential reduction in radiation levels in the P&VV by rinsing of the existing pipes has yet to be determined, and no credit is taken in this analysis for any such reductions.

3.3 Storage Tank Vaults

Yong et al. (1996a) have reported a series of recent in-situ measurements of radiation levels for both gamma rays and neutrons in the MVST vaults. The measurements were made through the vault plug openings in the northeast and northwest corners of the tank vaults and through the vault plug openings over tanks W-24, W-25, W-26, W-27, W-28, and W-31 (see Fig. 2.2). A variety of radiation detectors were used in these measurements including (1) thermoluminescent dosimeters (TLDs) and a Shonka ionization chamber for gamma radiation dosimetry, (2) a high-purity germanium detector for gamma-ray spectrometry, and (3) a ^{3}He proportional counter, bubble neutron dosimeters, and a Snoopy detector for neutron dosimetry.

The exposure-rate measurements for gamma rays and the dose-rate measurements for neutrons were made at 3-ft (1-m) intervals along the 22-ft (7-m) distance between the bottom and top of the MVST vaults, and the gamma-ray spectra were measured at the top of the vaults through the vault plug openings. The results of the measurements are summarized as follows:

- Gamma-ray exposure rates were 1-10 R/h, except the exposure rate at one point near tank W-26 was 23 R/h. The dose rates were usually the highest near the sludges.

- Dose rates for neutrons, as measured by the Snoopy detectors, were less than the detection limit of about 5 mrem/h and, thus, appear to be insignificant compared with the dose rates from gamma rays.

- Thermal, epithermal, and fast neutrons were detected at levels near the sludges. However, the neutron flux is very low and neutron dose rates could not be measured at the top of the tanks.

- Gamma-ray spectra measured at the top of the vault roof through the vault plug openings were dominated by ^{60}Co and ^{137}Cs/^{137m}Ba.

In addition, several instruments were contaminated during the measurements, which indicates that the vaults themselves are highly contaminated.

3.4 Manhole Access Areas of Storage Tank Vaults

A recent radiation survey of the manhole access areas to the MVST vaults has been reported (Anderson 1996a). The bottom of the concrete vault plugs had no smearable activity. Transferable activity was found on the bottom of the vaults, but reliable smear samples could not be obtained.

Gamma-ray exposure rates were measured at the three locations above the waste storage tanks shown in Fig. 2.3, and the results are summarized in Table 3.3. The exposure rates were 1.5-5 R/h at the center of the manhole plate on top of the tanks (Location A), 1-2 R/h at the bottom of the vault roof and center of the vault plug opening (Location B), and 0.38-1 R/h at the top of the vault roof and center of the vault plug opening (Location C). An extension ion chamber was used in making these measurements.

Readings also were taken with visual dosimeters on top of the vault roof at the edge and center of the vault plug openings to tanks W-24 and W-25. The dosimeters were placed 6 in. (15 cm) and 18 in. (46 cm) above the top of the vault roof. Along the edge of the vault plug openings, the average exposure rate was 2.2 mR/min (~0.1 R/h) at a height of 6 in. (15 cm) and 3 mR/min (~0.2 R/h) at 18 in. (46 cm), and the average exposure rate along the center line of the vault plug openings was 9 mR/min (~0.5 R/h) at a height of 6 in. (15 cm) and 6.4 mR/min (~0.4 R/h) at 18 in. (46 cm).

3.5 Radiation Area on Top of Storage Tank Vaults

A recent radiation survey on top of the MVST vaults also has been reported (Anderson 1996b). From large-area smears, transferable beta-particle contamination ranged from less than 200 to 10,000 dpm (3 to 170 Bq). The top of the MVST vaults is being decontaminated and will be designated only as a radiation area following decontamination. The exposure rates at a height of 3 ft (1 m) above the top of the vaults were 1-5 mR/h, except for locations near the high efficiency particulate (HEPA) filter banks serving the off-gas ventilation system for the waste storage tanks. The exposure rate near the HEPA filters varies with the age of the filters. The exposure rate was 30 mR/h at the time of the most recent survey (Anderson 1996b), but it has been observed to be as high as 0.1 R/h in the past (Yong 1996b).

Table 3.1. Exposure rates at contact with sludge and supernatant samples[a]

Sample component	Exposure rate
Supernatant liquids[b]	0.1-1.2 R/h per 250 mL sample
Wet sludges[c]	0.1-2.8 R/h per 250 mL sample
Dry sludges[c]	$\leq$50 R/h per gram (sub-sample)

[a] Measurements reported by Sears et al. (1990).

[b] Samples from all eight storage tanks, W-24 through W-31.

[c] Samples from six storage tanks, W-24 through W-28 and W-31.

Table 3.2. Radiation measurements in pump and valve vault[a]

Type of radiation and location of measurements	Range of measurements
Transferable alpha-particle contamination on pumps, piping, walls, and floor	<20 dpm/100 cm^2
Transferable beta-particle contamination on pumps, piping, and walls	300-150,000 dpm/100 cm^2
Transferable beta-particle contamination on floor	≥400,000 dpm/100 cm^2
Gamma radiation level in contact with pipes	1-5 R/h
Gamma radiation level in open work areas	75-500 mR/h

[a] Measurements reported by Anderson (1995).

Table 3.3. Exposure rates for manhole access areas to storage tanks[a]

Tank	Exposure rate (R/h)		
	Location (A)[b]	Location (B)[c]	Location (C)[d]
W-24	3.5	2	1
W-25	5	2	1
W-26	5	2	1
W-27	2.5	1	0.5
W-28	1.5	1.2	0.38
W-29	Not available	Not available	Not available
W-30	Not available	Not available	Not available
W-31	1.5	1.2	0.35

[a] Measurements reported by Anderson (1996a).

[b] Location (A) is on top of manhole plate, center of manhole to tank (see Fig. 2.3).

[c] Location (B) is at bottom of vault roof, center of vault plug opening (see Fig. 2.3).

[d] Location (C) is at top of vault roof, center of vault plug opening (see Fig. 2.3).

4. WORKER EXPOSURE SCENARIOS

Estimates of radiation doses to workers during sludge mobilization and removal activities are based on assumed exposure scenarios, which basically are assumptions about the amounts of time that workers will spend in various locations of elevated radiation levels during defined activities. This section describes the exposure scenarios during normal work activities assumed in this assessment. These scenarios are based primarily on so-called Option 3 from the 1995 ORNL planning document (ORNL 1995).

The first step in mobilizing the sludge is to remove the blind flange from the manhole (or nozzle C) of a waste tank (see Fig. 4.1). The flange bolts from the manhole will be removed using remotely operated tooling. The second step is to install a spool piece that will extend the manhole to the roof the vault (see Figs. 4.2 and 4.3). The spool piece will be welded in place using a remotely operated welder and, thus, will become a permanent part of the existing waste tank. The third step is to install the sluicer-mixer system into the tank through the manhole using a mobile crane, until the jet-mixer nears the sludge layer. At this point, the system will be activated in the "submerged-jet" mode to form a crater in the sludge layer, and the system then will be lowered into its final position for mobilization of the remaining sludge though sluicing action (see Figs. 4.2 and 4.3). The fourth step is to modify the piping in the pump and valve vault (P&VV), as discussed in Section 4.1.

Radiation doses are estimated in this assessment only for workers who would be directly engaged in the activities described above. Doses to other workers, such as health physics and supervisory personnel, are not considered. However, because these other workers should spend less time in radiation areas, their doses should be considerably less than those for the workers engaged in the activities considered.

4.1 Sludge Manifold Hookup in Pump and Valve Vault

A new sludge manifold system will be attached to the existing piping in the P&VV (see Fig. 4.4). The existing piping will be rinsed with clear supernatant and process water to cleanse the interior of existing contaminants as much as possible. However, some contamination should remain, especially in joints and crevices in the existing flanges and valves. The new manifold will consist of a 4-in. diameter discharge header with six 3-in. diameter valved branches (for nozzles A-1 through A-6) and a support frame. Each of the 3-in. branches is connected together downstream of the valves to allow individual nozzles to be used as suction or discharge points. The manifold system will be located in an open area between the existing piping to the pumps and tanks (see Fig. 4.4). Two sludge manifolds will be used: one in the west side of the P&VV, as shown in Fig. 4.4, and the other in the east side, which will be a mirror image of the one in the west side.

Installation of the two sludge manifold systems will involve the various activities described in the following sections.

4.1.1 Activity 1

There will be eight occurrences of this activity, once for each of the waste storage tanks. The valved manifold system will be connected to the currently blanked off nozzles at the tank vault wall using flexible jumpers. There are six blanked off nozzles for each of the eight tanks. The jumpers will be fabricated from stainless steel flanges, appropriate spool pieces, and heavy wall chemical hose or metal hose.

4.1.2 Activity 2

There will be two occurrences of this activity, once in the west side of the P&VV and once in the east side. Hose or flexible pipe will be connected to the suction (6-in.) and discharge (4-in.) piping for the Moyno pumps at existing flanged connections in the P&VV.

4.1.3 Activity 3

There will be one occurrence of this activity in the west side of the P&VV. In order to connect the suction portion of the Moyno pumps, the 2-in. line from the existing waste oil storage tank will be disconnected, blind flanged with a full face gasket, and moved to another area of the P&VV.

4.1.4 Activity 4

There will be two occurrences of this activity, once in the west side of the P&VV and once in the east side. Two pressure transducers will be installed to monitor suspended solids during sludge mobilization and removal operations. One will be placed in the existing 4-in. discharge piping going to the west vault tanks. Installation of this meter will require cutting out a 3-ft (1-m) segment of the existing line, welding in appropriate reducers, flanges, and gaskets, and connecting the meter. The second pressure transducer will be placed at the interface between the new discharge manifold and the discharge-to-pump hose assembly.

4.1.5 Level of Effort for All Activities

It is estimated that all of the activities described above will require a four-person crew working a total of about 3400 person-hours, with 50% of the time spent in the radiation zone inside the P&VV and 50% of the time above the vault in an area just outside the P&VV.

4.2 Removal of Manhole Cover and Installation of Secondary Confinement and Spool Piece

The manhole cover on each waste tank will be removed and a spool piece installed to extend the manhole opening, which is the primary confinement boundary, to the top of the vault roof (see Fig. 4.2). New shielding plugs will be installed on the vault roof to mate with the manhole extensions. These operations may occur up to one year earlier than installation of the sluicer-mixer system and, thus, should involve a different work crew.

In these operations, there will be eight occurrences of the following activities, once for each of the waste storage tanks:

(1) Removal of the 3½-ft by 3½-ft concrete vault plug over the tank manhole;

(2) Removal of the stainless steel blind flange from the tank manhole;

(3) Installation of the manhole extension (approx. 30-in. ID) from the tank to vault roof and lid on extension;

(4) Installation of new shield plugs that mate with the manhole extensions;

(5) Provision of electrical power for the sluicer and sluicer pump power unit;

(6) Installation of a process water connection for back-flushing and rinsing.

It is estimated that these activities, which will take place on the roof of the vaults for the waste tanks, will require a four-person crew working a total of 3800 person-hours, with 25% of the time spent in the radiation zone near the manhole openings.

If necessary, temporary shielding will be provided during these activities, particularly around the open hatch over the tank manhole and the process water lines. Remotely operated tooling will be used to unbolt and detach the blind flange on the tank manhole after the 3½-ft by 3½-ft vault plug is removed and to weld the new manhole extensions in place. This work will be followed immediately by installation of the new shield plugs.

A secondary confinement enclosure will be installed over the manhole area at the top of the vault roof to allow continued air sweep through the vault without compromising the existing vault ventilation system. The secondary confinement system will be installed before the 3½-ft by 3½-ft vault plug is removed, it will be in place during the sluicer-mixer installation process, and it will remain in place until the sluicer-mixer system is dismantled, decontaminated, and moved.

4.3 Sluicer-Mixer Installation and Removal

A medium capacity sluicer-mixer closed-loop circulation system will be installed through the manhole extension down into the tank (see Fig. 4.3). The motive force for the system will be provided by a submerged, open-impeller centrifugal pump. The pump selected will be the largest that can be installed through the 19-in. ID manhole (approx. 500 gpm). A hydraulic motor attached to the pump will be powered by an electrically driven, 100-hp hydraulic power unit located on the vault roof. The hydraulic power unit will include speed control and reversing capability. The sluicer-mixer will be designed to provide a two opposed-nozzle submerged jet capability and a single-point sluicing capability.

The submerged jet will use two opposed nozzles to eliminate horizontal thrust on the unsupported end of the sluicer-mixer system and to simplify the structural requirements of the system (ORNL 1995, Fig. A5). The single-point sluicing jet nozzle will be sized at 1½ in., nominal, to propel the jet to the far end of the tanks, and it will have vertical and rotational adjustment capability. The thrust generated by the single-point sluicing nozzle will be transferred to the tank and vault roof through the sluicer-mixer support structure. The sluicer-mixer operational modes—submerged-jet or single-point sluicer—will be selected by valves built into the system (ORNL 1995, Fig. A5), and the flow rate through the system will be monitored by a pressure transducer, also built into the system.

In installing the sluicer-mixer, the system will be lowered into the tank through the manhole until the pump nears the sludge level. At this point, the system will be operated in the submerged-jet mode to form a crater in the sludge layer. The system then will be lowered into its final position for mobilizing the remaining sludge through single-point sluicing action.

During installation of the sluicer-mixer, there will be eight occurrences of the following activities, once for each of the eight storage tanks:

(1) Remove new shield plugs over manhole extension;

(2) Remove lid on manhole extension;

(3) Install wash-down system in manhole extension;

(4) Assemble sluicer-mixer in initial position;

(5) Attach electrical power and control cables;

(6) Attach process water and slurry lines.

Following mobilization of the sludge in the first waste tank, the sluicer-mixer and wash-down system will be removed from the tank, the lid on the manhole extension and new hatch cover will be replaced, and the sluicer-mixer will be prepared for use in the second tank, and similarly for the remaining waste storage tanks.

After initial use in the first waste tank, the sluicer-mixer system will be contaminated with sludge and supernatant. Therefore, during installation in seven of the eight waste tanks, handling of the sluicer-mixer will cause some additional worker exposures.

It is estimated that these activities for all tanks will require a four-person crew working a total of 1900 person-hours, with about 25% of the time spent in the radiation zone around and immediately above the open manhole extensions or in the radiation zone near the contaminated sluicer-mixer system.

4.4 Normal Operations

Operation of the sluicer-mixer system should not require workers to be located in a radiation zone, because the system will be designed for remote control. A remote video camera will be used to aim the sluicer nozzle and to monitor mobilization progress, and a pressure transducer in the flow stream will be used to determine the percent solids in the sludge mobilization stream. Portions of the sludge mobilization stream, when showing the proper mixture of solids and liquids, will be diverted and pumped to the waste solidification process system. After the liquid portion of the diverted waste stream is separated from the solids, it will be piped back to one of the storage tanks for further use in the sluicer-mixer operation. Remote operation of the sluicer-mixer system will preclude, for example, additional exposures of workers while collecting grab samples to determine flow stream quality. Radiation exposures while handling the grab samples following their collection can easily be controlled by appropriate shielding and by limiting exposure times.

Doses during operation of the sluicer-mixer system should be controlled in accordance with the ALARA principle (DOE 1993; NRC 1991) by proper design and administrative controls. Doses from exposure to waste transfer lines to and from the sludge solidification process should be controlled by lead jacketing, as is used now at the MVST facility, or by concrete trenching for any piping above ground. This report does not consider doses to workers during the sludge solidification process.

4.5 Maintenance Activities on Roof of Tank Vaults

Maintenance is defined as those activities undertaken to prevent unplanned outages, such as periodic replacement of units with new or repaired units within the system. Units that might be routinely maintained include those with rotating shaft seals, pumps, or motors.

Possible maintenance activities that would be performed on the roof of the tank vaults are given below, but this list may not be inclusive. An asterisk (*) indicates that the particular component should be contaminated during maintenance.

Activity	Resource burden
Replace worn pump rotor*	Two-person crew, 8 hours each, 25% of time in radiation zone, 10% of time in contact with unit.
Replace pump seal*	Two-person crew, 8 hours each, 25% of time in radiation zone, 10% of time in contact with unit.
Replace hydraulic motor bearing	Two-person crew, 8 hours each, 25% of time in radiation zone.

Replace hydraulic hose to motor*	Two-person crew, 4 hours each, 25% of time in radiation zone.
Replace valve*	Two-person crew, 8 hours each, 25% of time in radiation zone, 25% of time in contact with unit.
Replace valve operator	Two-person crew, 4 hours each, 25% of time in radiation zone.
Replace pressure transducer*	Two-person crew, 2 hours each, 25% of time in radiation zone, 25% of time in contact with unit.
Replace camera light*	Two-person crew, 2 hours each, 25% of time in radiation zone, 25% of time in contact with unit.
Replace video camera*	Two-person crew, 2 hours each, 25% of time in radiation zone.
Replace HEPA filters*	Two-person crew, 2 hours each, 25% of time in radiation zone, 10% of time in contact with unit.

These activities would typically be conducted once or twice per year over a period of approximately two years. The radiation zone referred to here is the radiation field at a working distance of about 50 cm (20 in.) from a contaminated component. Based on the existing radiation levels in the P&VV discussed in Section 3.2, the exposure rate from the contaminated components might be as high as 1 R/h on contact. However, the exposure rates on contact may be less in some instances, as discussed in Section 6.5.

The first eight items in the list given above are maintenance related to the submerged portion of the sluicer-mixer system (i.e., the portion located within the waste storage tank and the manhole extension to the tank). Decontamination of the sluicer-mixer system prior to maintenance is discussed in Section 4.7. The internal surfaces of the system will be cleansed by back-flushing with clear supernatant and process water before it is removed from a waste storage tank, and the external surfaces will be cleansed by a wash-down with clear supernatant and process water as the system is being removed from a tank.

The next two items are maintenance related to the video camera that will be used to monitor sludge removal operations within the tanks. The camera will be inserted into the tanks through the G-3 nozzle (see Figs. 4.1–4.3). As noted in Section 2, the G-3 nozzle is already being used for sludge level detection. Since the level detection instrumentation and video camera do not have to operate at the same time, they will share the G-3 nozzle. The camera will have pan and tilt motions and will include some lighting. However, the main lighting for the camera will be attached to the support structure of the sluicer-mixer system.

The last item is maintenance related to the two HEPA-filter banks serving the off-gas ventilation system for the waste storage tanks. The HEPA-filter banks are located on the roof of the tank vaults near the temporary pump house and close to the front edge of the concrete pad, as shown in Fig. 2.1. The single-sluicer action will cause a heavy mist to form in the tanks, which may overload the demister in the off-gas ventilation system for the storage tanks and require the HEPA filters to be changed more often than usual. The mist from the tanks will be radioactive.

4.6 Maintenance Activities in Pump and Valve Vault

Routine maintenance activities in the P&VV could involve replacement of a leaking seal, a remote valve operator, or a flow meter, as listed below. Again, the components marked by an asterisk (*) should be contaminated during maintenance.

Activity	Resource burden
Replace flange seal*	Two-person crew, 8 hours each, 25% of time in radiation zone, 10% of time in contact with unit.
Replace valve operator	Two-person crew, 8 hours each, 25% of time in radiation zone, 10% of time in contact with unit.
Replace pressure transducer*	Two-person crew, 2 hours each, 25% of time in radiation zone, 25% of time in contact with unit.

These activities might occur once or twice per year over a period of approximately two years. The radiation zone referred to here is the area inside the P&VV. Based on the existing radiation levels in the P&VV discussed in Section 3.2, the exposure rate from the contaminated components might be as high as 1 R/h on contact.

4.7 Decontamination

The P&VV will not require decontamination unless there is an accidental leak or spill within the vault. The sluicer-mixer system will require decontamination when it is moved from one tank to the next, when it undergoes maintenance, and at the end of all sludge mobilization and removal operations.

Decontamination of the sluicer-mixer system will be somewhat limited in order to control the additional generation of large quantities of liquid waste and to prevent alteration of the contents of the waste tanks with acids, chelating agents, or other compounds normally associated with cleaning. It is important not to change the chemical and physical properties of the contents of the tanks to such an extent that the waste solidification process would be impaired or the final waste form would not meet the waste acceptance criteria for the intended disposal site (i.e., the WIPP facility).

However, a reasonable attempt will be made to decontaminate the sluicer-mixer system. The internal passages in the system will be flushed with process water in an attempt to remove undissolved waste materials and dilute the residual radioactivity. The external surfaces will be washed down as the system is pulled out of the tank through the manhole extension, with the rinse water allowed to fall into the tank.

One concept of maintenance would permit portions of the sluicer-mixer system that normally become contaminated to be pulled out of the manhole extension into a special container. This would allow storage or maintenance without exposing the sluicer-mixer system to the environment. Hands-on maintenance would be accomplished through glove ports. This system would have the additional capability for decontamination during maintenance, as well as bag-in, bag-out ports for replacement of parts. Worker exposure scenarios for this maintenance system have not been considered in this assessment, but they should closely parallel the types of remote-manipulator maintenance activities commonly performed at ORNL.

Final decontamination of the system for decommissioning probably will involve cleaning the contaminated portions of the sluicer-mixer to a reasonable level and disposal of the contaminated system components in a solid waste storage area at ORNL.

W-26 NOZZLE SCHEDULE

NAME	SIZE	TYPE
A-1	3"SCH 40	SLUDGE JET
A-2	3"SCH 40	SLUDGE JET
A-3	3"SCH 40	SLUDGE JET
A-4	3"SCH 40	SLUDGE JET
A-5	3"SCH 40	SLUDGE JET
A-6	3"SCH 40	SLUDGE JET
B	2"SCH 40	CHEMICAL ADDITION
C		FLANGED MANHOLE, 19"I.D.
D-1	2"SCH 40	TALL AIR SPARGER
D-2	2"SCH 40	SHORT AIR SPARGER & TEMP SENSOR WELL
D-3	2"SCH 40	TALL AIR SPARGER & TEMP SENSOR WELL
D-4	2"SCH 40	SHORT AIR SPARGER & TEMP SENSOR WELL
D-5	2"SCH 40	TALL AIR SPARGER & TEMP SENSOR WELL
E-1	2"SCH 40	SAMPLE RETURN
E-2	2"SCH 40	SPARE
E-3	4"SCH 40	SPARE
E-4	2"SCH 40	SUMP DISCHARGE (PUMP 200M)
E-5	4"SCH 40	PUMP DISCHARGE
F-1	6"SCH 40	PUMP SUCTION
F-2	6"SCH 40	SPARE
F-3	4"SCH 40	SPARE
F-4	4"SCH 40	SLUDGE SUCTION SPARE
G-1	2"SCH 40	PLUMMET LEVEL DEVICE
G-2	6"SCH 40	DENSITY AND LEVEL PROBE
G-3	6"SCH 40	SLUDGE LEVEL DETECTOR
S-1	4"SCH 40	LOW POINT SAMPLE SUCTION
S-2	4"SCH 40	25% FULL SAMPLE SUCTION
V-1	6"SCH 40	VENT INLET
V-2	6"SCH 40	VENT OUTLET
V-3	1"SCH 40	DEMISTER DRAIN
Z-1	6"SCH 40	OVERFLOW
Z-2	6"SCH 40	OVERFLOW

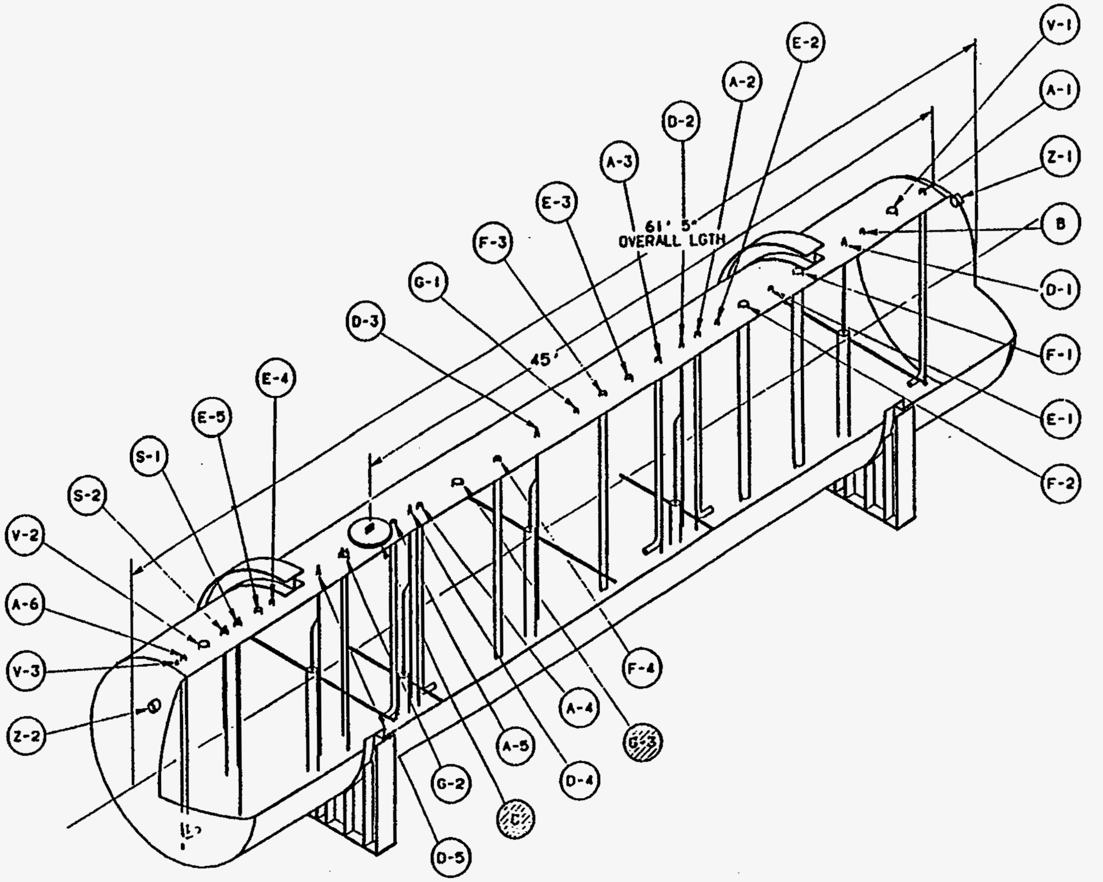

Fig. 4.1. Schematic of Melton Valley Storage Tank W-26.

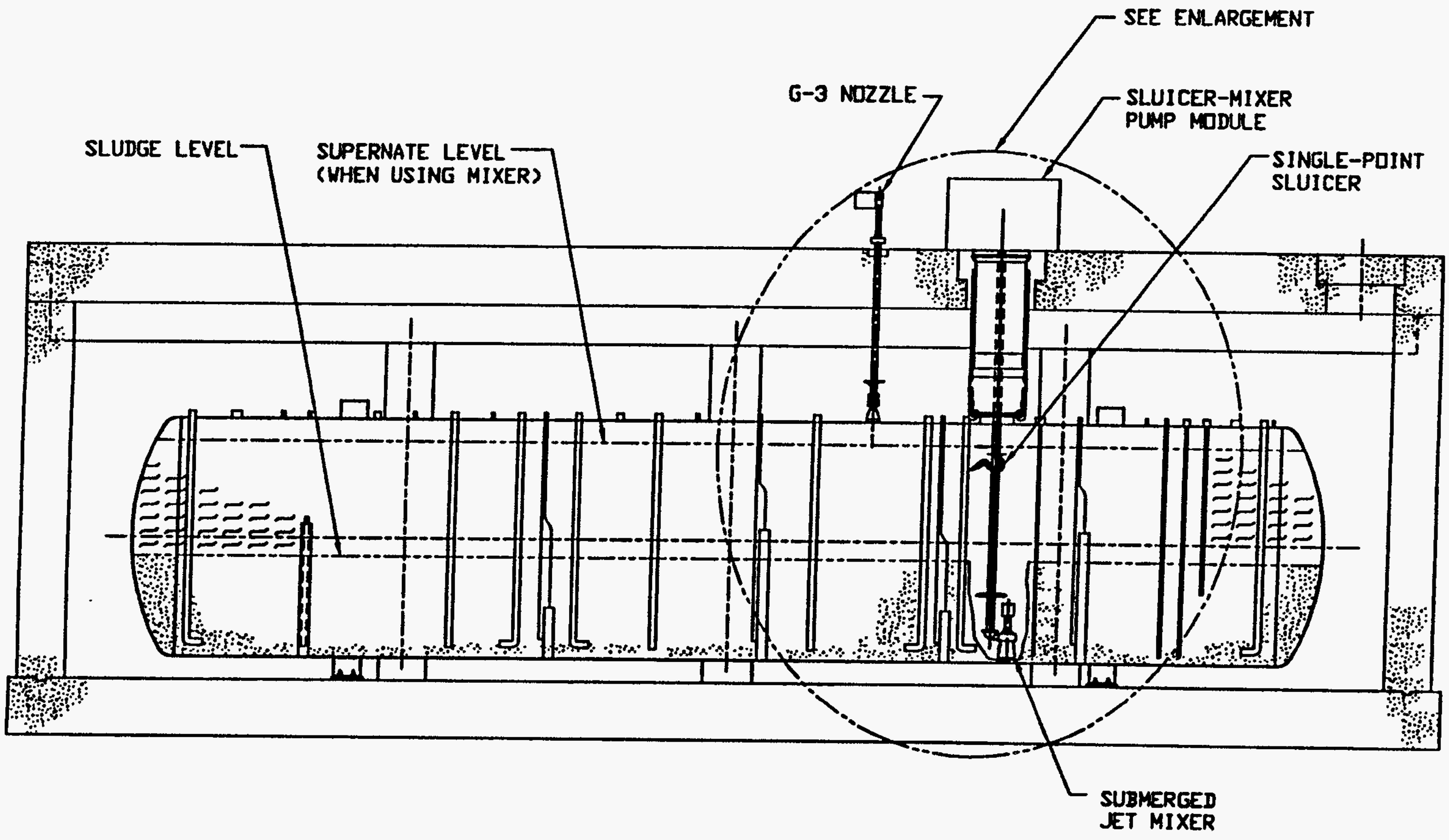

Fig. 4.2. Schematic of sluicer-mixer system installed in storage tank.

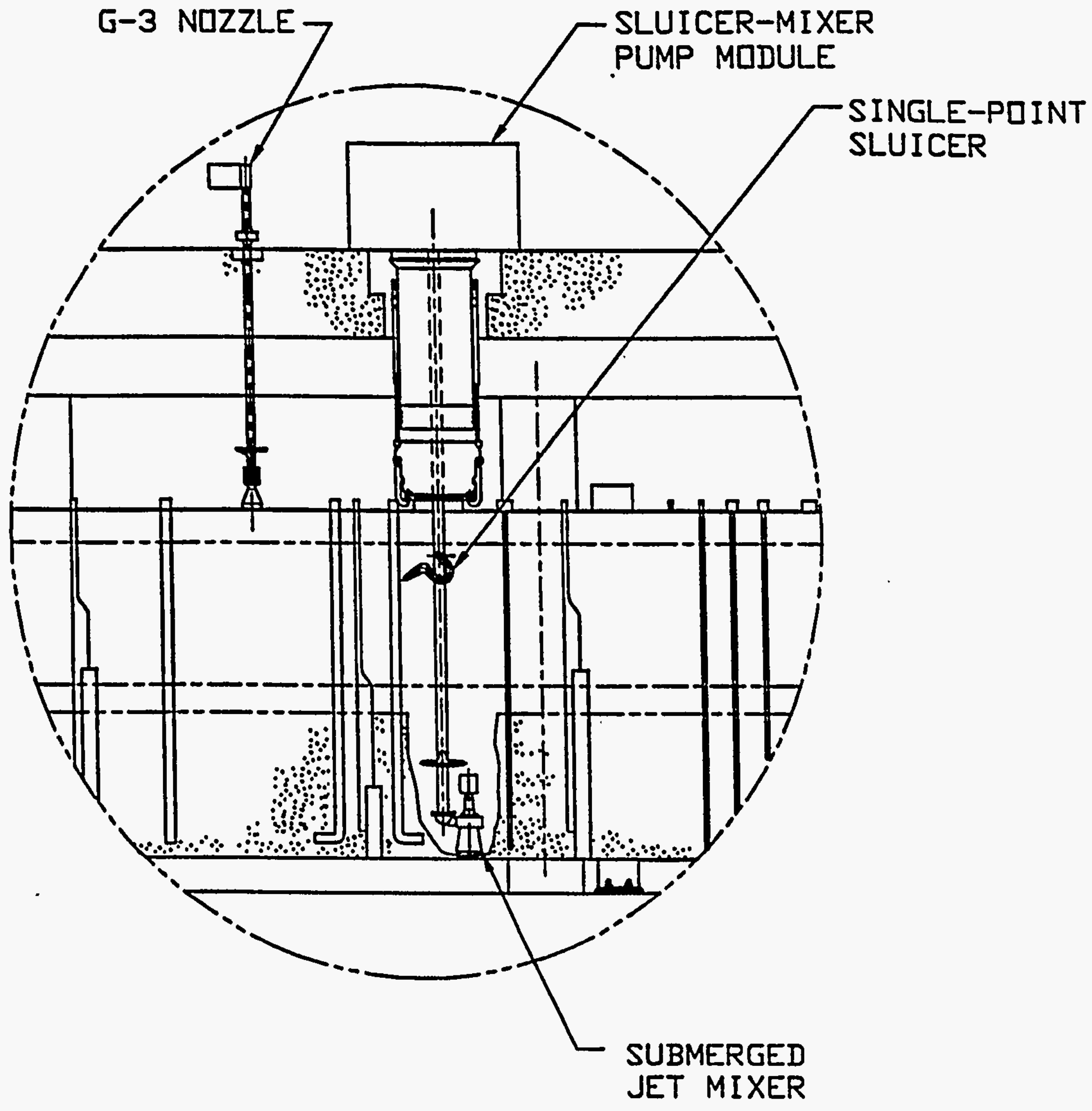

Fig. 4.3. Sluicer-mixer system enlargement.

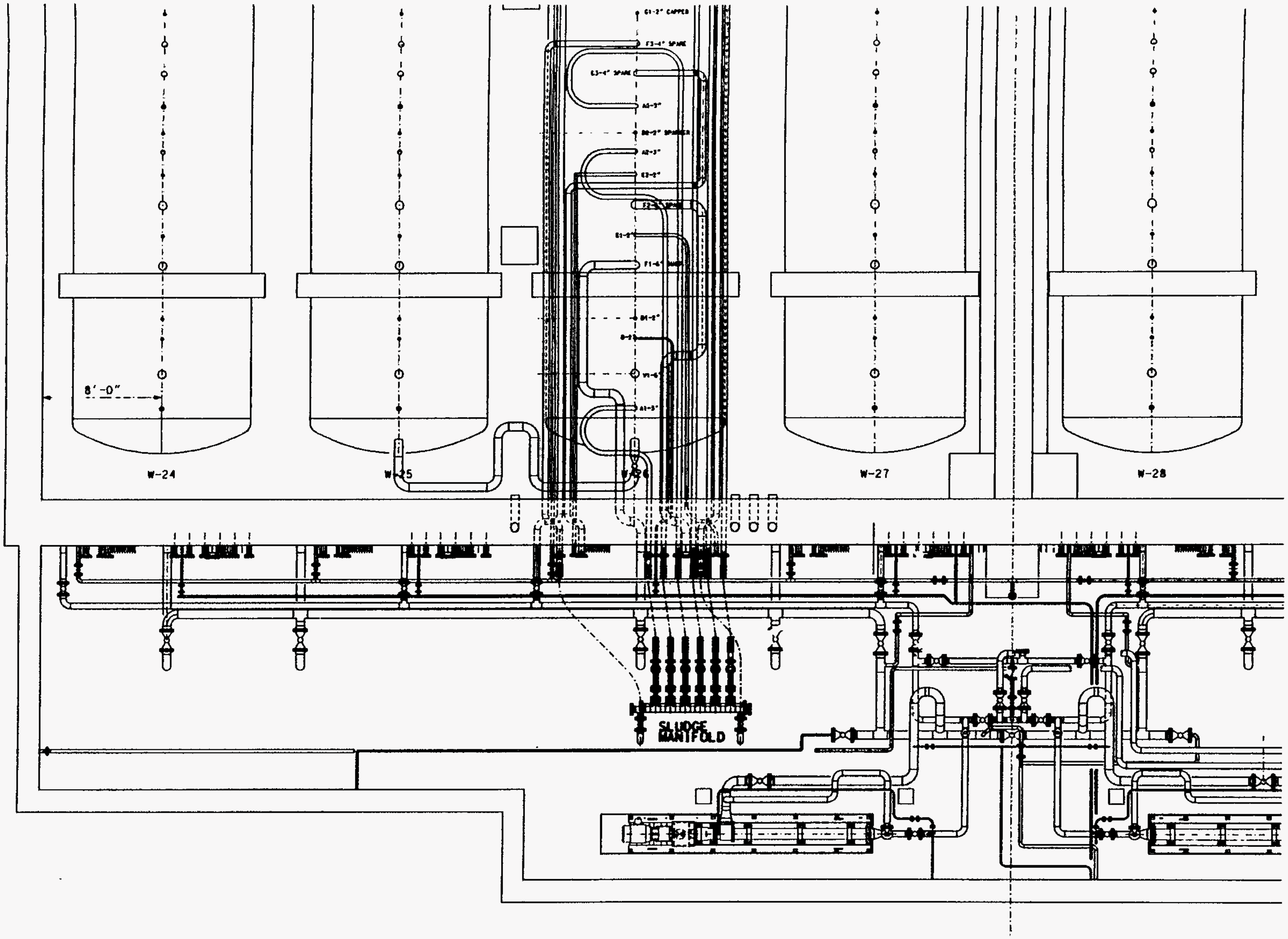

Fig. 4.4. Schematic showing hookup of new sludge manifold system to waste storage tank W-26 and existing piping in west side of pump and valve vault. Two Moyno pumps are located near center of vault and toward its outer wall, and sump pump is located in center of vault and toward its inner connecting wall with east and west tank vaults (see Fig. 2.2).

5. CREDIBLE ACCIDENT SCENARIO

In addition to exposures of workers during routine operations and maintenance discussed in Section 4, this assessment considers a credible accident scenario for sludge mobilization and removal at the Melton Valley Storage Tank (MVST) facility. This accident scenario involves a failure of a flanged connection on the sludge manifold in the pump and valve vault (P&VV). The defined activities following the credible accident are based primarily on experiences in dealing with similar situations during past operations at ORNL.

5.1 Accident Scenario

The assumed accident scenario occurs during withdrawal of sludge and supernatant liquid from tank W-26, which is the first tank on which the operation will be performed, and circulation of the charge back to a sludge jet in the same tank. At some time, the operator switches the flow from one sludge jet to another, but the line to the jet is plugged and the operator is not aware of the problem. The resulting pressure increase from the positive displacement Moyno pump causes a failure of the flange seal to the hose leading to the sludge manifold in the P&VV and the spraying of some of the contents of tank W-26 into the P&VV. The pump has a pressure relief valve set at about 60 psi, which is not sufficiently high to blow out the seal, but the assumed accident scenario is possible with a radiation damaged seal or if the relief valve is stuck closed and fails to relieve the pressure.

5.2 Accident Description

For the assumed accident, the entire contents of the tank could be discharged into the P&VV. However, there is level detection in the sump in the floor of the P&VV, and it is assumed that the sump works properly, but it also is assumed that it requires 30 minutes to identify the source of the leak before the pump is turned off.

The quantity of liquid discharged during the period of the accident would be about 1800 gal (60 gpm × 30 min). In accordance with current plans for sludge mobilization, the liquid is assumed to contain 10% sludge by weight. The liquid would flow toward the sump. Since the sump volume is 275 gal, the sump then would be filled and the floor of the P&VV would be covered to a depth of approximately 1¼ in. The liquid could be removed by use of the sump pump, but removal of the solids would require flushing with water and pumping, much like the removal of solids in the tanks. After removal of the water, the sludge would coat the floor of the vault and sump, and the floor might be coated to a depth of about ⅛ in. Because the liquid would be released from the failed flange seal under pressure, it should spray the entire vault floor and ceiling around the area of the pump leak prior to draining to the sump.

Since the vault plugs to the P&VV would be in place during operation, they would require removal prior to entry into the vault. There are five possible entry points. Two of them are through vault plugs over the two Moyno pumps, and the others are personnel access ways into the vault, one of which is over the sump. The vault openings over the two Moyno pumps are not shown in Fig. 2.2.

After removal of the water by pumping, one of the vault plugs would be removed and the floor flushed with a water/detergent spray to provide some decontamination. It is estimated that decontamination would require approximately 80 hours of water spraying. Complete spray coverage of the P&VV floor is not possible from the top of the vault, even through all openings, but spray coverage of the vault in the area of the two Moyno pumps might remove about 90% of the activity in this area. Spray coverage of the vault under the personnel accessways and the sump also might remove 90% of the activity remaining in other central areas where direct spray contact is possible and where material could be flushed toward the sump. Other areas (e.g., the ends of the vault) might have only 0-50% of the activity removed. Since personnel entry to repair the accident would be required, the floor would be covered with a 1-in. layer of water after decontamination to suppress exposure to beta particles from the remaining contamination.

An alternative to hands-on decontamination would be the use of a robotic vehicle. Such vehicles are commercially available on reasonably short notice and could be used for decontamination of the ends of the vault. Interferences with existing piping in the P&VV would be a problem, but sufficiently small robotic vehicles could be found.

If the solids were distributed evenly in the sump and vault, 29 gal would remain on the floor after decontamination. This estimate assumes that 90% of the activity is removed from the central area (one area of 65 ft × 22 ft) and 25% of the activity is removed from the ends of the vault (two areas of 33 ft × 16 ft).

Personnel entry into the vault would be required to repair the leaking seal. It is estimated that a two-person team working for 0.5 h would be required to make the repair.

6. RADIOLOGICAL CALCULATIONS

Estimates of external dose to workers from exposure to the contents of the waste storage tanks and to contamination in the pump and valve vault (P&VV) at the present time can be based on the measured radiation levels in these areas described in Section 3. However, during sludge mobilization and removal, doses from the work activities described in Sections 4 and 5 can only be estimated in advance using calculations. Calculations of radiation exposures near the storage tanks at the present time also are potentially useful in verifying the adequacy of existing analytical data on the radionuclide compositions of waste sludges. This section describes the radiological calculations performed in this assessment.

The radiological calculations were performed with the MicroShield[2] computer code, which runs on a personal computer (Worku and Negin 1995). The MicroShield code uses the point-kernel method with fluence buildup factors to evaluate shielding and exposure rates in air for a variety of source geometries (see, for example, Chilton et al. 1984). The code also provides estimates of the deep dose equivalent, shallow dose equivalent, and effective dose equivalent for an individual located in the radiation field using data from Publication 51 of the International Commission on Radiological Protection (ICRP 1987). The deep dose equivalent, which essentially is the same as the effective dose equivalent for high-energy gamma emitters, is used in this report unless stated otherwise.

Only external exposures of workers are estimated in this assessment. Although internal exposures also are a potentially important concern, this assessment assumes implicitly that such exposures will be controlled by proper containment of radioactive materials or by use of respiratory protection, and dose from internal exposure is not evaluated. Respiratory protection could be especially important, for example, in work areas with high levels of surface contamination or in performing maintenance activities on certain contaminated items (e.g., the sluicer-mixer system or the HEPA filters).

6.1 Sludge and Supernatant Samples

In the study by Sears et al. (1990), sludge and supernatant samples were collected from the waste storage tanks, and exposure rates for unshielded samples were measured in the field. To compare with the measurements, we have calculated the exposure rates using the analytical data on the samples from Sears et al. (1990) and the preliminary "March 1996" data reported by Moore (1996).

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[2] MicroShield is a trademark of Grove Engineering, Inc., 15215 Shady Grove Road, Rockville, MD 20850.

6.1.1 Supernatant Samples

The supernatant samples were collected in 250-ml glass jars. As summarized in Table 3.1, the exposure rates at contact with the sample jars were 0.1-0.5 R/h, except the exposure rates for samples from tank W-26 were 1.2 R/h.

The supernatant samples were essentially high-pH sodium/potassium salt solutions (Sears et al. 1990, p. 43). The principal anions were nitrate (3-5 *M*, with an average of 4 *M*). The total solids content, based on the weight of the residue after drying a measured volume of sample overnight at 115°C, was 330-480 mg/mL (Sears et al. 1990, p. 46). The measured density for the liquid wastes was 1.21-1.24 g/mL, except the density of the supernatant in tank W-28 was somewhat higher (1.28 g/mL).

In calculations using the MicroShield code, it was assumed that the glass sample jars for the supernatants had a diameter of 6 cm (about 2.5 in.) and a length of 8.9 cm (about 3.5 in.) and that the measurements were made with a "Cutie Pie" ionization survey instrument at an effective distance of 2 cm from the surface of the sample jar. It was further assumed, based on averages over all samples, that the supernatants had a density of 1.2 g/mL, the density of the solid residues was 0.45 g/mL, and the solids were 15% KNO_3 and 85% $NaNO_3$. Thus, the supernatant composition assumed in the calculations was 62.5% H_2O, 5.6% KNO_3, and 31.9% $NaNO_3$.

The measured and calculated exposure rates for the supernatant samples are presented in Tables 6.1 and 6.2. In Table 6.1, the preliminary "March 1996" data, when compared with the earlier data from Sears et al. (1990), clearly indicate that significant radioactivity had been added to the supernatants in tanks W-24 and W-25, and possibly in tank W-31, since 1990. The agreement was found to be excellent otherwise. As shown in Table 6.2, the exposure rates from the supernatant samples were found to be due primarily to ^{60}Co, ^{134}Cs, and ^{137}Cs/^{137m}Ba, and the same conclusion was obtained from the calculations based on the preliminary "March 1996" data reported by Moore (1996).

6.1.2 Sludge Samples

Sludge samples were collected using two different techniques. Hard sludge samples were collected in a stainless steel pipe with an inside diameter of 1.4 in. (3.6 cm) and a length of 10 in. (25 cm) (Sears et al. 1990, p. 19), and soft sludge samples were collected in a clear plastic tube with an inside diameter of 1 in. (2.5 cm) and a length of 20 in. (51 cm) (Ceo et al. 1990, p. 3). The results of the exposure rate measurements made in contact with the sludge samples and the analytical data on the sludge samples are given in Tables A.3 and 4.2.4, respectively, of the report by Sears et al. (1990), and the exposure rate measurements are summarized in Table 3.1.

The sludges contained 50-60% water, and the bulk densities of the wet sludges were 1.3-1.5 g/mL (Sears et al. 1990, p. 47). The total solids content of the sludges, based on the weight of the residue after drying of a measured volume of sample overnight at 115°C, was 400-500 mg/g, except the hard sludge in tank W-31 had a total solids content of 960 mg/g. The principal metals found in the sludges were sodium, potassium, calcium, magnesium, uranium, and thorium. The sodium and potassium combined was typically 40-60% by weight, the calcium and magnesium was 30-40%, and the uranium and thorium was 4-20%. The insolubilities of the metal hydroxides and carbonates largely account for the high concentrations of heavy metals (e.g., U, Th, and TRU and rare-earth radioisotopes), as well as the Ca and Mg, in the sludges (Sears et al. 1990, p. 43).

In the calculations using the MicroShield code, it was assumed, based on an average for all samples, that the density of the sludges was 1.35 g/ml, the density of the solid residues was 0.625 g/ml, and the solids were 67.6% $NaNO_3$, 6.6% KNO_3, 4.5% $Mg(OH)_2$, and 21.3% $Ca(OH)_2$. Thus, the sludge composition assumed in the calculations was 53.7% H_2O, 31.3% $NaNO_3$, 3.0% KNO_3, 2.1% $Mg(OH)_2$, and 9.9% $Ca(OH)_2$. It was further assumed that the measurements were made with a "Cutie Pie" ionization survey instrument at an effective distance of 2 cm from the surface of the sludge samples and that the dimensions of the sludge samples were those given above (i.e., 3.6 cm in diameter and 25 cm in length for hard sludge samples and 2.5 cm in diameter and 51 cm in length for soft sludge samples).

The measured and calculated exposure rates for the sludge samples are presented in Tables 6.3 and 6.4. The overall agreement is not as good as in the case of the supernatant samples (see Table 6.1), and the results for the sludge samples probably indicate that the sludges are not homogeneous (Sears et al. 1990, p. 2; Ceo et al. 1990, pp. 19-21). The exposure rates from the sludge samples were found to be due primarily to ^{60}Co, ^{95}Zr, ^{137}Cs/^{137m}Ba, ^{152}Eu, and ^{154}Eu (see Table 6.4).

6.2 Storage Tanks

In the study by Yong et al. (1996a) described in Section 3.3, TLDs and ion chambers were used to measure gamma exposure rates in the MVST vaults. Based on a review of these measurements and a comparison with the ion chamber measurements reported by Anderson (1996a), it was concluded that the ion chamber data were more credible. Therefore, the ion chamber data are used to evaluate the reliability of the analytical data on the supernatant and sludge samples.

The MicroShield code was used to calculate gamma exposure rates near the waste storage tanks based on the analytical data from supernatant and sludge samples collected near the center of the tanks (i.e., directly beneath the location of the G-3 nozzle shown in Figs. 4.1–4.3). The data on radionuclide compositions for the supernatants and sludges are presented in Tables 6.5 and 6.6, respectively. Considerable transfers of liquid waste to and from tanks W-29 and W-30 have occurred since the supernatant samples were collected and analyzed by Sears et al. (1990), but no supplemental samples have been collected to determine the effects of these transfers on the radioactivity in the liquid waste in these tanks (see Tables 6.1 and 6.5). Therefore, exposure rates were not calculated for these two tanks.

As discussed in Section 2, the waste storage tanks contain a liquid supernatant layer above one or more sludge layers. Differences between measurements of gamma exposure rates outside the tanks and calculated values based on sample results from the center of the tanks are assumed to provide an indication of how well the sample data represent the actual radionuclide compositions of the supernatants and sludges in the tanks. Calculations near the bottom of the tanks are assumed to provide insight into the accuracy of the sample data for the sludge layers, and calculations for measurement points above the tanks are assumed to provide the best comparison for radionuclide concentrations in the supernatants.

In the calculations of exposure rates near the waste storage tanks, the supernatant and sludge layers in a given tank were each represented by a single rectangular slab. The dimensions of the two slabs in the tanks were based on the total volumes of the tank contents reported by Maddox (1996) and the sludge volumes reported by Sears et al. (1990). The assumed depths and average widths for the slab approximations of the supernatant and sludge layers are given in Table 6.7. These data are based on the calculated tank volume as a function of depth shown in Fig. 6.1. The physical characteristics and chemical compositions of the supernatants and sludges were assumed to be the same as those described in Section 6.1.1 and 6.1.2.

6.2.1 Exposure Rates at Side of Tanks

In comparing measured and calculated exposure rates at the side of the tanks, measurement locations were selected that would reflect exposure contributions mainly from the sludge, mainly from the supernatant, or a combination of the supernatant and sludge. The calculated exposure rates are compared with the measured values in Table 6.8. Where measurements were not available, an estimate of the exposure rate at the location of interest was obtained by linear interpolation between measurements from above and below that location. As indicated in the table, the total exposure rate at some locations is the sum of contributions from the tank of concern and an immediately adjacent tank.

The results in Table 6.8 indicate that the calculated exposure rates tend to be higher than the measured values at locations where the exposure rate is dominated by the contribution from the sludges. In general, however, the calculations and measurements agree within an order of magnitude and most often within a factor of two. These results suggest that the sludge near the center of the tanks, where the sludge samples were collected, may contain higher concentrations of contaminants than the sludge in outer regions of the tanks, closer to where the measurements were made.

6.2.2 Exposure Rates Above Tanks

In comparing measured and calculated exposure rates above the waste storage tanks, measurement locations were selected that corresponded to ion chamber measurements made at locations A and B in Fig. 2.3. At these locations, only the supernatant layers in the tanks should contribute significantly to the exposure rate. Therefore, the sludge layers were not included in the calculations. As mentioned above, calculations were not made for locations above tanks W-29 and W-30, due to the lack of information concerning the contents of these tanks. The calculated exposure rates are compared with the measured values in Table 6.9.

The calculated and measured exposure rates above the tanks were found to be consistently within a factor of four and often within a factor of two. This agreement provides an added measure of confidence in the ion chamber measurements reported by Anderson (1996a) and summarized in Section 3.4.

6.2.3 Exposure Measurements Near Large Source

As described previously, the calculations of exposure rates near the waste storage tanks assumed that the supernatant and sludge layers could each be represented by a single rectangular slab. When calculating exposure rates near large sources, it is interesting to consider the contributions from various regions of the source to the total exposure rate at the measurement location. Therefore, additional calculations were performed for tank W-28 by dividing the contents into five slabs, as shown in Fig. 6.2, and the contribution to the exposure rate at the midpoint of the tank from each slab was calculated by accounting for the shielding provided by the other slabs. The results of the calculations shown in Fig. 6.3 indicate that the exposure rate is due mostly to the slabs nearest the location of interest, and that the other slabs are effectively shielded by the material in the immediate vicinity of the measurement location. This information is useful in understanding the effect of self-shielding when performing calculations such as those presented in this report.

It also is useful to compare the results from the five-slab calculations for tank W-28 with the two-slab approximation used in the calculations presented in this report. The calculated exposure rate for a five-slab source was 3.7 R/h, as compared with the two-slab approximation result of 4.8 R/h. Thus, the simplified two-slab calculation gives a result that agrees within 30% of that obtained using the more complex model, which indicates that the two-slab calculations are adequate for this assessment.

6.3 Sludge Mobilization

During sludge mobilization, the characteristics of the waste storage tanks will be changed in ways that can affect the exposure rates above the tanks. For example, mobilized sludge particles will become mixed with the supernatant in the tanks, and the amount of supernatant in the tanks also will be decreased significantly during part of the sludge mobilization process. The effects of these changes on the exposure rates above the tanks are investigated in the following two sections.

6.3.1 Suspension of Sludge Particles in Supernatant Liquid

Liquids will be drawn from a tank during sludge mobilization when the suspended sludge particles are in the range of 10-20% by volume. To investigate if sludge mobilization would alter the exposure rates on the roof of the MVST vaults, calculations were made for two tanks by assuming that the supernatant was mixed with 20% sludge by volume. The calculated exposure rates for 250-mL samples of supernatant and sludge from each tank given in Tables 6.1 and 6.3 were used to determine which tanks were the most appropriate for this investigation. Tank W-26 was chosen because it had the highest reported specific activity for gamma emitters in the sludge, while tank W-28 was chosen because it had the highest sludge-to-supernatant gamma exposure ratio, and mixing of the sludge with the supernatant thus should increase the total exposure rate from the supernatant by the largest amount for any tank.

For tank W-26, the exposure rate above the tank, from that tank only, prior to mixing of the sludge was calculated to be 8.9 R/h at contact and 5.0 R/h just inside the vault ceiling opening. For the supernatant containing 20% sludge by volume, the calculated exposure rates at these points were 7.7 R/h and 4.2 R/h, respectively. Thus, mixing of the sludge with the supernatant for tank W-26 apparently would decrease the exposure rate above the tank, but by less than 20%. Similarly, for tank W-28, the calculated exposure rates above the tank prior to mixing of the sludge were 4.4 R/h at contact and 2.2 R/h just inside the vault ceiling opening, and the exposure rates at these locations after mixing of the sludge with the supernatant were 6.3 R/h and 3.4 R/h, respectively. Thus, for this tank, mixing of the sludge with the supernatant apparently would increase the exposure rate above the tank by approximately 50%.

6.3.2 Removal of Supernatant Liquid During Single-Point Sluicing

During the initial phase of sludge mobilization in a waste tank, the sluicer-mixer system will be operated in the submerged-jet mode to form a crater in the sludge layer. However, after the crater is formed, the sludges will be mobilized using the single-point sluicer mode of operation, which requires that most of the supernatant liquid be removed from a tank so that the sludge is exposed directly to the liquid jet from the sluicer.

Calculations were performed to investigate the effects of removal of the entire supernatant layer on the exposure rates above the tanks. Table 6.10 gives the results of the calculations in comparison with the calculated exposure rates when the supernatant is present. The comparison shows that the exposure rates could decrease by as much as 80% above tank W-31 and increase at most by only 30% above tank W-28.

The calculations described in this section and in Section 6.3.1 indicate that the sludge mobilization process should not result in significant increases in exposure rates above the waste tanks, particularly on the roof of the MVST vaults. The exposure rates on the roof of the MVST vaults are currently in the range of 1-5 mR/h, except the exposure rates are considerably higher at locations near the HEPA filter banks serving the off-gas ventilation system for the waste storage tanks (see Section 3.5).

6.4 Removal of ^{137}Cs from Supernatant Liquids

Instead of using temporary shielding to reduce exposure rates near the open manholes on the roof of the vaults for the waste storage tanks (see Section 4.2), an alternative would be to treat the supernatant liquids in the tanks to remove the ^{137}Cs, using ion-exchange technology. To investigate the effects of such treatment on exposure rates, calculations above the tanks were performed by assuming that all radionuclides except ^{137}Cs/^{137m}Ba would remain in the supernatant after treatment. In Table 6.11, these "treated supernatant" (T) values are compared with "untreated supernatant" (U) values for the various tanks. The untreated supernatant values are the same as the so-called "current" values from Table 6.10. It can be seen from the ratio of the untreated to the treated supernatant values that the calculated exposure rates from the treated supernatants are reduced by factors of 6-30 for the individual tanks, or by an average factor of about 10 for all tanks. The effect of the treated supernatants on collective doses to workers during installation of equipment on the roof of the storage tank vaults is discussed further in Sections 7.2 and 7.3.

6.5 Sluicer-Mixer System

Specific information is not available at this time on the exact design and configuration of the sluicer-mixer system and its support structure. In this analysis, the sluicer-mixer system is assumed to consist of (1) a submerged open, impeller centrifugal pump, (2) a 6-in. ID feed line from the centrifugal pump to the opposed-nozzle submerged jet mixer and to a grinder unit and booster pump, (3) the grinder unit and booster pump, which are operated in tandem and located at the top of the 6-in. ID feed line, and (4) a 3-in. ID return line from the booster pump to the single-point sluicer, which is located near the middle of the 6-in ID feed line (see Figs. 4.2 and 4.3). The grinder unit is used to crush hard sludge particles in the liquid to the booster pump, and the booster pump is used to increase the nozzle pressure at the single-point sluicer so that the jet can easily reach the far end of the tanks located more than 44 ft (13 m) away.

It also was assumed that the feed and return lines would be 3-in. and 6-in. ID stainless steel pipes having wall thicknesses of ¼ in. and lengths of 8 ft and 16 ft, respectively. The centrifugal pump, booster pump, and grinder unit also were assumed to be constructed of stainless steel with average wall thicknesses of ¾ in. and to hold a total volume of about 1 gal (4 L) of liquid each. The pumps, grinder, and pipes will be back-flushed with clear supernatant and process water before they are removed from a waste storage tank, and the exterior surfaces will be washed down with clear supernatant and process water as they are removed from a tank (see Section 4.7).

6.5.1 Feed and Return Piping

In the calculations of exposure rates from the feed and return piping, it was assumed that a 100-μm thick layer of sludge from tank W-26 would remain on both the inside and the outside of each of the pipes. The inside of the piping would be contaminated along the entire length, while the outside would most likely be contaminated only up to the depth of the waste. However, to be conservative, the calculations assumed that the entire length of pipe was contaminated on both sides. The gamma exposure rates from both contaminated pipes were estimated at the end of the 3-in. return line and near the middle of the 6-in. ID feed line (i.e., at the location of the single-point sluicer) and at radial distances of 1 cm (0.4 in.), 50 cm (20 in.), and 1 m (40 in.) from the exterior pipe surfaces. The results of these calculations are summarized in Table 6.12. For an anterior/posterior irradiation geometry, the calculated exposure rates and dose-equivalent rates are about the same numerically (i.e., 1 R/h is approximately equal to 1 rem/h).

Although the assumed contamination of the sluicer-mixer system described above is mostly conjectural, the exposure rates are believed to be reasonable in the following sense. The calculated exposure rates on contact with the pipes of the sluicer-mixer system are considerably less than those measured in the P&VV (see Section 3.2). This is a reasonable result when one considers that the pipes in the P&VV are mounted horizontally and have not been flushed after use, whereas the pipes of the sluicer-mixer system are mounted vertically and will be back-flushed periodically to remove internal contamination from the sluicer-mixer system (see Section 4.7).

6.5.2 Centrifugal Pump, Grinder Unit, and Booster Pump

In the calculations of exposure rates near the centrifugal pump, grinder unit, and booster pump, it was assumed that the centrifugal pump also was contaminated on the outside by a 100-μm layer of sludge from tank W-26, but the outside of the grinder unit and booster pump were not contaminated because they are located in the manhole extensions away from waste in the tanks. However, it was assumed that the grinder and both pumps would contain 0.05 gal (0.2 L) of sludge from tank W-26 which is distributed evenly within the empty chambers of these items. The exposure rates were calculated at radial distances of 1 cm (0.4 in.), 50 cm (20 in.), and 1 m (40 in.) from the exterior surfaces of the centrifugal pump and the tandem combination of the grinder and booster pump. The results of these calculations also are summarized in Table 6.12. For an anterior/posterior irradiation geometry, the calculated exposure rates and dose-equivalent rates are about the same numerically (i.e., 1 R/h is approximately equal to 1 rem/h).

6.6 Credible Accident Scenario

A credible accident scenario for sludge mobilization and removal involves a failure of a flanged connection on the sludge manifold in the P&VV, as discussed in Section 5. Calculations were performed to estimate gamma exposure rates that could be encountered inside the P&VV if such an accident were to occur. In these calculations, it was assumed that the sump pump is operable and that the majority of the contamination is removed from the vault prior to opening any of the access ports. The potential exposure from bremsstrahlung production and contributions from other sources, such as contaminated piping inside the vault, were not considered in these calculations. The only contributions considered in the calculations are those associated with the accidental spill itself. However, significant gamma-ray scatter is expected inside an enclosed vault, and an additional increase on the order of 25-50% above the calculated values could occur.

6.6.1 Exposure Rate at Ceiling of Vault

A plan view of the P&VV is shown in Fig. 2.2. To estimate doses during initial access to the P&VV following the accident, such as would occur while flushing the floor to provide some decontamination, the exposure rate just inside the access openings on the vault roof was estimated. The exposure rate was calculated at a height of 19 ft above a 17-ft wide by 130-ft long area covered by a ⅛-in. thick planar source consisting of sludge from tank W-26 (see Table 6.6). The estimated exposure rate from the spill contamination alone at this location was 0.2 R/h. Since contamination of some wall surfaces could occur as a result of the assumed accident and significant photon scatter is expected inside the vault, an additional increase on the order of 25-50% above this value could occur.

6.6.2 Exposure Rate at Floor Level

As discussed in Section 5.2, it is assumed that 90% of the remaining sludge will be removed from the central 65-ft section of the P&VV and that 25% will be removed from each of the 32-ft end sections prior to entry into the vault to repair the leak. In addition to the initial cleaning prior to entry, the entire floor area is assumed to be covered with 1 in. of water to eliminate concerns about beta irradiation. Therefore, only gamma exposure rates were estimated.

The initial calculation was performed for the same contamination model as used in the previous pre-entry scenario, except the exposure rate was calculated in the center of the vault at 1 m (3 ft) above the floor. For a case where none of the sludge contamination has been removed, the estimated gamma exposure rate at this location was 1.1 R/h. The rotational irradiation geometry (ICRP 1987) for this exposure situation results in an estimated dose-equivalent rate at the same location of 0.9 rem/h (9 mSv/h).

By assuming that 90% of the contamination would be removed from the central 65-ft area of the vault by direct washing, the dose-equivalent rate at the center of the vault and 1 m (3 ft) above the floor was estimated to decrease to about 0.09 rem/h (0.9 mSv/h). Similarly, by assuming that only 25% of the contamination would be removed from the two 32-ft areas at each end of the vault, the dose-equivalent rate at the center of these areas and 1 m (3 ft) above the floor was estimated to decrease to about 0.7 rem/h (7 mSv/h). Thus, the dose-equivalent rate at 1 m (3 ft) above the floor would be expected to vary from about 0.09 to 0.7 rem/h (0.9 to 7 mSv/h) as one moved around the vault.

Table 6.1. Exposure rates at contact with 250-mL supernatant samples

Tank	Measured exposure rate (R/h)[a]	Calculated exposure rate (R/h)	
		1990 analytical data[b]	1996 analytical data[c]
W-24	0.12 - 0.18	0.16	0.94
W-25	0.19 - 0.26	0.25	1.04
W-26	1.20	1.55	1.09
W-27	0.10 - 0.20	0.16	0.25
W-28	0.48 - 0.50	0.46	0.47
W-29	0.11	0.17	Not Available
W-30	0.11	0.14	Not Available
W-31	0.18 - 0.19	0.18	0.38

[a] Field survey data on three or more samples per tank from Table A.2 of Sears et al. (1990).

[b] Values obtained using MicroShield computer code and analytical data on beta/gamma emitters in supernatant samples from Table 4.2.1 of Sears et al. (1990). These values can be compared with the measured exposure rates.

[c] Values obtained using MicroShield computer code and preliminary "March 1996" data on beta/gamma emitters in supernatant samples reported by Moore (1996). These values presumably reflect changes resulting from transfers of liquid wastes to and from waste tanks since measurements by Sears et al. (1990).

Table 6.2. Calculated exposure rates by radionuclide for tank W-26 supernatant sample

Radionuclide	Concentration[a] (Bq/mL)	Exposure Rate[b] (R/h)	Percent of exposure rate
^{60}Co	1.2e+4	3.7e−2	2.4
^{95}Nb	<1.4e+2	1.5e−4	<0.01
^{95}Zr	<2.7e+2	2.9e−4	0.02
^{106}Ru/^{106}Rh	<2.8e+3	7.8e−4	0.05
^{134}Cs	1.3e+4	2.8e−2	1.8
^{137}Cs/^{137m}Ba	2.1e+6	1.5e+0	95.6
^{144}Ce/^{144}Pr	<2.3e+2	8.0e−5	<0.01
^{152}Eu	<2.1e+2	3.0e−4	0.02
^{154}Eu	<2.4e+2	4.0e−4	0.03
^{155}Eu	<1.2e+3	3.8e−5	0.01
Total		1.6e+0	100.00

[a] See analytical data for tank W-26 supernatant sample in Table 4.2.1 of Sears et al. (1990).

[b] Values obtained using MicroShield computer code and analytical data for beta/gamma emitters in tank W-26 supernatant sample from Table 4.2.1 of Sears et al. (1990).

Table 6.3. Exposure rates at contact with 250-mL sludge samples

Tank	Exposure rate(R/h)	
	Measured[a]	Calculated[b]
W-24 Soft sludge	0.1 - 1.2	0.2
W-25 Soft sludge	0.5 - 1.3	0.3
W-26 Soft sludge	0.8 - 2.0	1.4
W-27 Soft sludge	0.1 - 0.2	0.2
W-27 Hard sludge	0.3	0.5
W-28 Soft sludge	0.8 - 1.2	1.2
W-29 Soft sludge	Not Available	Not Available
W-30 Soft sludge	Not Available	Not Available
W-31 Soft sludge	1.5 - 2.2	0.1
W-31 Hard sludge	2.8	0.6

[a] Field survey data for one or more samples per tank from Table A.3 of Sears et al. (1990).

[b] Values obtained using MicroShield computer code and analytical data for beta/gamma emitters in sludge samples from Table 4.2.4 of Sears et al. (1990).

Table 6.4. Calculated exposure rates by radionuclide for tank W-26 sludge sample

Radionuclide	Concentration[a] (Bq/g)	Exposure Rate[b] (R/h)	Percent of exposure rate
^{60}Co	1.0e+5	2.0e−1	14.3
^{95}Nb	7.5e+4	1.8e−3	0.1
^{95}Zr	<1.3e+5	8.8e−2	6.3
^{106}Ru/^{106}Rh	<2.6e+3	4.5e−3	0.3
^{134}Cs	3.0e+3	4.0e−3	0.3
^{137}Cs/^{137m}Ba	6.8e+5	3.1e−1	22.2
^{144}Ce/^{144}Pr	<1.2e+4	4.5e−4	0.1
^{152}Eu	4.9e+5	4.5e−1	31.8
^{154}Eu	3.2e+5	3.4e−1	24.2
^{155}Eu	7.5e+4	1.5e−3	0.1
Total		1.4e+0	100.0

[a] See analytical data for W-26 sludge sample in Table 4.2.1 of Sears et al. (1990).

[b] Values obtained using MicroShield computer code and analytical data on beta/gamma emitters in W-26 sludge sample from Table 4.2.1 of Sears et al. (1990).

Table 6.5. Analytical data on radionuclide concentrations in supernatant samples[a]

Tank	W-24	W-25	W-26	W-27	W-28	W-31
Beta/gamma emitters (Bq/mL)						
Gross beta	1.3e+6	1.4e+6	1.7e+6	5.3e+5	1.0e+6	6.0e+5
^{3}H	1.9e+2	1.9e+2	2.0e+2	1.3e+2	6.8e+1	1.0e+2
^{60}Co	3.2e+2	3.1e+2	2.7e+3	2.0e+3	4.9e+3	3.5e+2
^{90}Sr/^{90}Y	6.5e+2	1.1e+3	1.7e+4	6.6e+4	1.2e+5	8.7e+3
^{99}Tc	1.1e+3	1.2e+3	3.0e+3	4.1e+2	6.3e+2	9.1e+2
^{134}Cs	7.1e+4	8.2e+4	3.6e+4	1.4e+3	4.2e+3	1.6e+4
^{137}Cs	1.1e+6	1.2e+6	1.4e+6	3.3e+5	6.2e+5	4.8e+5
^{152}Eu	<2.3e+3	<2.4e+3	<2.5e+3	<1.2e+3	<1.7e+3	<1.5e+3
^{154}Eu	<8.9e+2	<9.5e+2	<9.9e+2	<4.7e+2	<6.5e+2	<5.8e+2
^{155}Eu	<1.4e+3	<1.5e+3	<1.6e+3	<7.4e+2	<1.1e+3	<9.0e+2
^{241}Am	<2.8e+3	<3.0e+3	<3.1e+3	<1.5e+3	<2.1e+3	<1.9e+3
Alpha emitters (Bq/mL)						
Gross alpha	<4.5e+1	<2.0e+1	8.2e+1	3.0e+2	1.8e+2	<2.9e+1

[a] Preliminary "March 1996" data reported by Moore (1996).

Table 6.6. Analytical data on radionuclide concentrations in soft (S) and hard (H) sludge samples[a]

Tank	W-24(S)	W-25(S)	W-26(S)	W-27(S)	W-27(H)	W-28(S)	W-31(S)	W-31(H)
Beta/gamma emitters (Bq/g)								
Gross beta	2.6e+6	4.0e+6	5.7e+6	1.4e+6	2.0e+6	2.4e+6	3.2e+6	1.1e+7
^{14}C	8.4e+2	1.7e+2	2.1e+2	1.9e+2	4.9e+2	7.6e+1	3.1e+2	1.1e+3
^{60}Co	3.4e+4	4.0e+4	1.0e+5	1.6e+4	2.5e+4	7.9e+4	8.1e+3	3.0e+4
^{95}Nb	<5.6e+2	<5.9e+2	<2.6e+3	<3.4e+3	<1.4e+3	<2.9e+3	<9.2e+2	<1.2e+3
^{95}Zr	<2.8e+3	<4.6e+3	<1.3e+5	<1.7e+3	<2.6e+3	<2.4e+4	<4.7e+3	<6.6e+3
^{106}Ru	<5.7e+3	<5.9e+3	<2.6e+3	<1.1e+4	<1.6e+4	<2.8e+4	<1.4e+4	<1.7e+4
^{134}Cs	<6.2e+2	7.1e+2	3.0e+3	<1.2e+3	<1.8e+3	<4.6e+3	3.6e+3	2.1e+3
^{137}Cs	2.0e+5	2.2e+5	6.8e+5	3.8e+5	5.7e+5	1.9e+5	2.4e+5	5.5e+5
^{144}Ce	<3.9e+3	<4.2e+3	<1.2e+4	<5.6e+3	<7.7e+3	<1.7e+4	<9.4e+3	<1.4e+4
^{152}Eu	6.2e+4	8.1e+4	4.9e+5	2.0e+4	2.4e+4	7.2e+5	<1.7e+4	2.7e+4
^{154}Eu	3.6e+4	5.1e+4	3.2e+5	1.3e+4	1.5e+4	3.2e+5	5.9e+3	2.1e+4
^{155}Eu	1.0e+4	1.6e+4	7.5e+4	1.3e+4	3.3e+3	9.7e+4	<5.9e+3	<8.7e+3
Alpha emitters (Bq/g)								
Gross alpha	2.3e+4	4.7e+4	9.1e+4	2.3e+4	3.1e+4	5.4e+4	2.3e+4	9.0e+4
^{233}U	5.2e+2	8.4e+2	6.7e+3	5.2e+2	6.2e+2	3.5e+3	5.1e+2	2.1e+3
^{235}U	<3.7e+3	<4.2e+3	<1.2e+4	<5.8e+3	<8.3e+3	<1.7e+4	<9.7e+3	<1.4e+4
^{239}Pu/^{240}Pu	1.5e+3	2.9e+3	5.1e+3	1.0e+3	1.9e+3	1.5e+3	8.8e+2	3.2e+3
^{238}Pu/^{241}Am	3.7e+3	7.4e+3	1.5e+4	4.4e+3	6.7e+3	5.3e+3	2.4e+3	1.1e+4
^{243}Cm	<3.6e+3	<3.9e+3	<1.3e+4	<6.5e+3	<1.0e+4	<1.4e+4	<8.4e+3	<1.3e+4
^{244}Cm	1.6e+4	3.3e+4	6.1e+4	1.6e+4	2.2e+4	3.8e+4	1.7e+4	6.9e+4

[a] Measurements reported by Sears et al. (1990).

Table 6.7. Average widths and depths of slab layers used to approximate sludge and supernatant contents in exposure rate calculations for storage tanks[a]

Tank	Sludge and supernatant[b]			Sludge[c]			Supernatant[d]		
	Total volume (gal)	Total volume (ft^3)	Total depth (ft)	Sludge volume (ft^3)	Sludge depth (ft)	Average width (ft)	Supernatant volume (ft^3)	Supernatant depth (ft)	Average width (ft)
W-24	22400	3000	5.5	1770	3.7	7.8	1230	1.8	11.1
W-25	44160	5910	9.8	3130	5.6	9.1	2780	4.2	10.8
W-26	44470	5950	9.8	2020	4.1	8.0	3930	5.7	11.2
W-27	44680	5970	9.9	2370	4.6	8.4	3600	5.3	11.0
W-28	44140	5900	9.8	510	1.5	5.5	5390	8.3	10.6
W-31	43920	5870	9.7	860	2.3	6.4	5010	7.4	10.9

[a] Depths and widths of various sludge and supernatant layers were calculated assuming a cylinder with inside radius of 6 ft and length of 61.5 ft capped at each end with convex bulk heads (see Fig. 2.3).

[b] Total volume of sludge and supernatant obtained from "May 1996 Concentrate Report" for Melton Valley Storage Tanks (Maddox 1996).

[c] Sludge volume obtained from Table 4.1.3 of Sears et al. (1990).

[d] Supernatant volume calculated as total volume minus sludge volume.

Table 6.8. Calculated exposure rates at selected locations near sides and ends of storage tanks

Contact tank	Location	Calculated exposure rate (R/h)[a]					Measured exposure rate (R/h)[c]	
		Contact tank		Adjacent tank[b]		Total		
		Sludge	Supernatant	Sludge	Supernatant		TLD	Ion chamber
W-24	End of tank, 1 ft (0.3 m) from floor	1	<0.1	Not applicable	Not applicable	1	2	≈2[d]
W-25	Side of tank, 5 ft (1.5 m) from floor	3	6	7	6	22	6	≈12
W-26	Side of tank, contact with floor	11	<0.1	1	1	13	4	5
W-27	Side of tank, 3.3 ft (1 m) from floor	16	<0.1	Not applicable	Not applicable	16	1	≈2
W-28	Side of tank, 6.6 ft (2 m) from floor.	<0.1	5	Not applicable	Not applicable	5	2	4

[a] Values obtained using MicroShield computer code, analytical data for supernatant and sludge samples from Tables 6.5 and 6.6, and slab dimensions for supernatant and sludge layers in Table 6.7.

[b] If calculations were made for comparison with measurements between two adjacent tanks, but near contact with one tank, individual contributions and total from both tanks are given. "Not applicable" means that there was no adjacent tank that contributed to measured value for contact tank.

[c] Values taken from thermoluminescent dosimeter (TLD) and ion chamber measurements reported by Yong et al. (1996a).

[d] Approximately equal sign (≈) with value means that there was no measured value for exact location for calculation, but one was obtained by linear interpolation between measured values near this location.

Table 6.9. Calculated exposure rates at selected locations near top of storage tanks

Tank	Location[a]	Calculated exposure rate (R/h)[b]			Measured exposure rate (R/h)[c]
		Tank	Adjacent tanks	Total	
W-24	Top of manhole cover to tank	6	1	7	4
W-24	Bottom of vault plug opening	3	1	4	2
W-25	Top of manhole cover to tank	9	3	12	5
W-25	Bottom of vault plug opening	5	3	8	2
W-26	Top of manhole cover to tank	9	2	11	5
W-26	Bottom of vault plug opening	5	1	6	2
W-27	Top of manhole cover to tank	2	2	4	3
W-27	Bottom of vault plug opening	1	2	3	1

[a] Top of manhole cover to tank corresponds to Location A in Fig. 2.3, and bottom of vault plug opening corresponds to Location B in Fig. 2.3.

[b] Values obtained using MicroShield computer code, analytical data for supernatant samples from Table 6.5, and slab dimensions for supernatant layer from Table 6.7. Calculations account for exposure rate contributions from tank in first column plus any adjacent tanks. Exposure rates from sludge layers were not considered because they are reduced to insignificant levels by supernatant shielding.

[c] Values from ion chamber measurements reported by Anderson (1996a) and summarized in Table 3.3.

Table 6.10. Calculated exposure rates with and without supernatant liquid above sludge layer in storage tanks

Tank	Exposure rate (R/h) at top of manhole cover to tank[a,b]			Exposure rate (R/h) at bottom of vault plug opening[a,c]		
	Current	Bare sludge	Change	Current	Bare sludge	Change
W-24	6.0	1.8	-70%	3.4	1.0	-70%
W-25	8.5	2.7	-70%	4.7	1.7	-60%
W-26	8.9	9.7	+10%	5.0	5.5	+10%
W-27	2.0	1.7	-15%	1.2	1.1	-10%
W-28	4.4	4.8	+10%	2.2	2.9	+30%
W-31	4.1	0.7	-80%	2.1	0.4	-80%

[a] Values obtained from MicroShield computer code, analytical data for supernatant and sludge samples in Tables 6.5 and 6.6, and slab dimensions in Table 6.7. Current values represent exposure rate due to supernatant and sludge content in tanks as of June 1996, and bare sludge values indicate exposure rate at same location assuming supernatant liquids are removed from tanks. Exposure rates are due to indicated tank only, because exposure contributions from adjacent tanks were not included.

[b] Top of manhole cover to tank corresponds to Location A in Fig. 2.3.

[c] Bottom of vault plug opening corresponds to Location B in Fig. 2.3.

Table 6.11. Calculated exposure rates before and after treatment to remove ^{137}Cs from supernatant liquids in storage tanks

Tank	Exposure rate (R/h) at top of manhole cover to tank[a,b]			Exposure rate (R/h) at bottom of vault plug opening[a,c]		
	Untreated supernatant	Treated supernatant	Ratio (U/T)	Untreated supernatant	Treated supernatant	Ratio (U/T)
W-24	6.0	1.0	6	3.4	0.54	6
W-25	8.5	1.4	6	4.7	0.75	6
W-26	8.9	0.67	13	5.0	0.38	13
W-27	2.0	0.08	25	1.2	0.04	30
W-28	4.4	0.22	20	2.2	0.11	20
W-31	4.1	0.35	12	2.1	0.18	12

[a] Values obtained from MicroShield computer code, analytical data for supernatant samples in Table 6.5, and slab dimensions for supernatant layer in Table 6.7. Untreated supernatant values (U) represent exposure rate due to supernatant content in tanks as of June 1996, and treated supernatant values (T) indicate exposure rate at same location assuming supernatant liquids have treated to remove ^{137}Cs. Exposure rates are due to indicated tank only, because exposure contributions from adjacent tanks were not considered.

[b] Top of manhole cover to tank corresponds to Location A in Fig. 2.3.

[c] Bottom of vault plug opening corresponds to Location B in Fig. 2.3.

Table 6.12. Calculated exposure rates from contaminated sluicer-mixer system[a]

Location	Exposure rate (mR/h) at various radial distances		
	Contact	50 cm	1 m
Centrifugal pump at bottom of 6-in. ID feed line	220	20	7
Booster pump and grinder unit at top of both 3-in. ID return and 6-in. ID feed lines	280	30	10
Single-sluicer nozzle at bottom of 3-in. ID return line and near middle of 6-in. ID feed line	130	20	9

[a] Values obtained from MicroShield computer code by assuming that 6-in. ID feed line has length of 16 ft and wall thickness of ¼ in. of stainless steel, 3-in. ID return line has length of 8 ft and wall thickness of ¼ in. of stainless steel, and pumps and grinder have wall thicknesses of ¾ in. of stainless steel and chamber volumes of 1 gal (4 L). It is further assumed that inside and outside of pipes and outside of centrifugal pump are contaminated with 100-µm layer of sludge from tank W-26 and that inside surfaces of centrifugal pump, booster pump, and grinder unit are contaminated uniformly with 0.05 gal (0.2 L) of sludge, also from tank W-26.

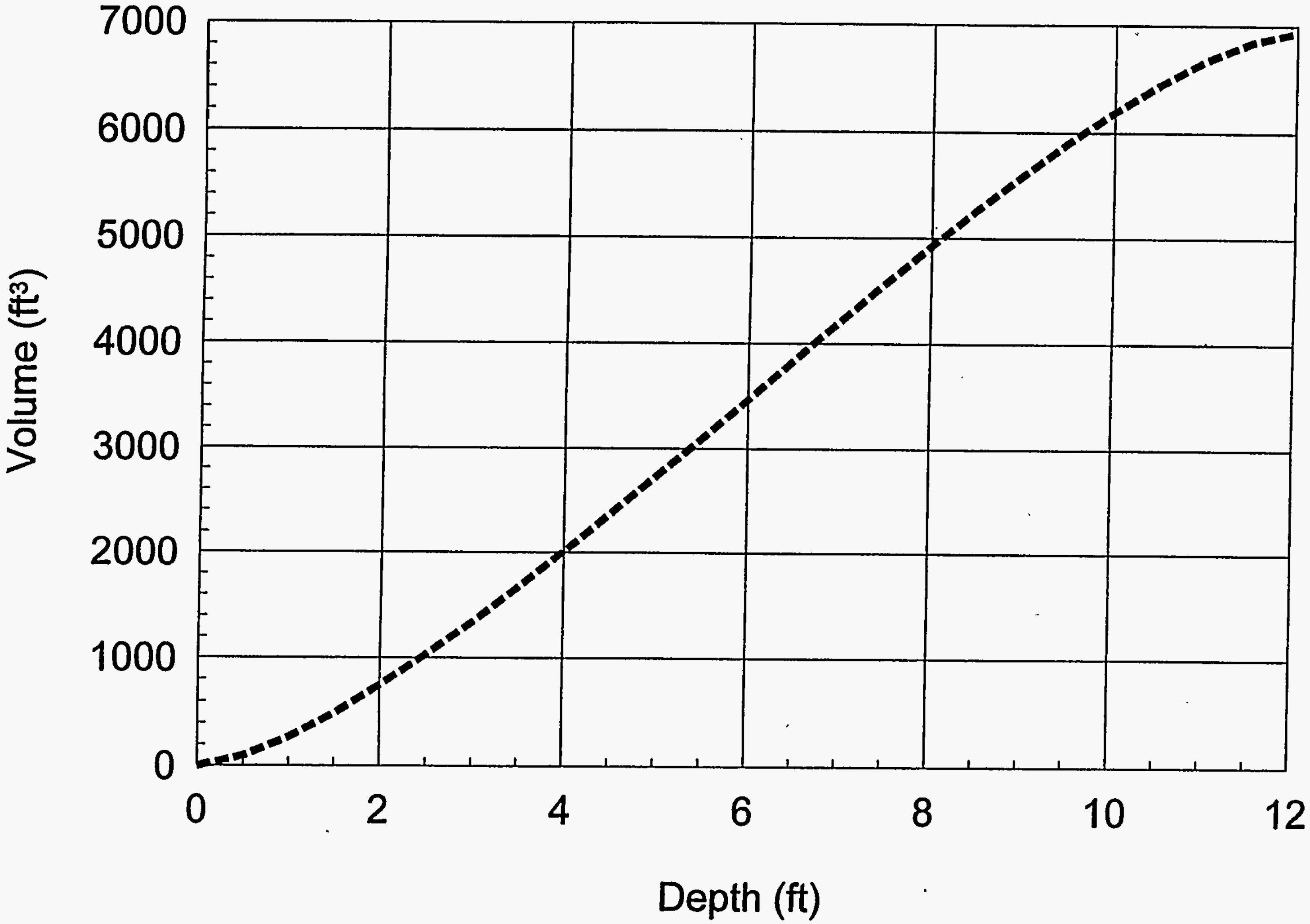

Fig. 6.1. Volume of contents of storage tank vs. depth of contents in tank. Calculations used to generate this curve assumed that ends of tanks are convex (see Fig. 2.3).

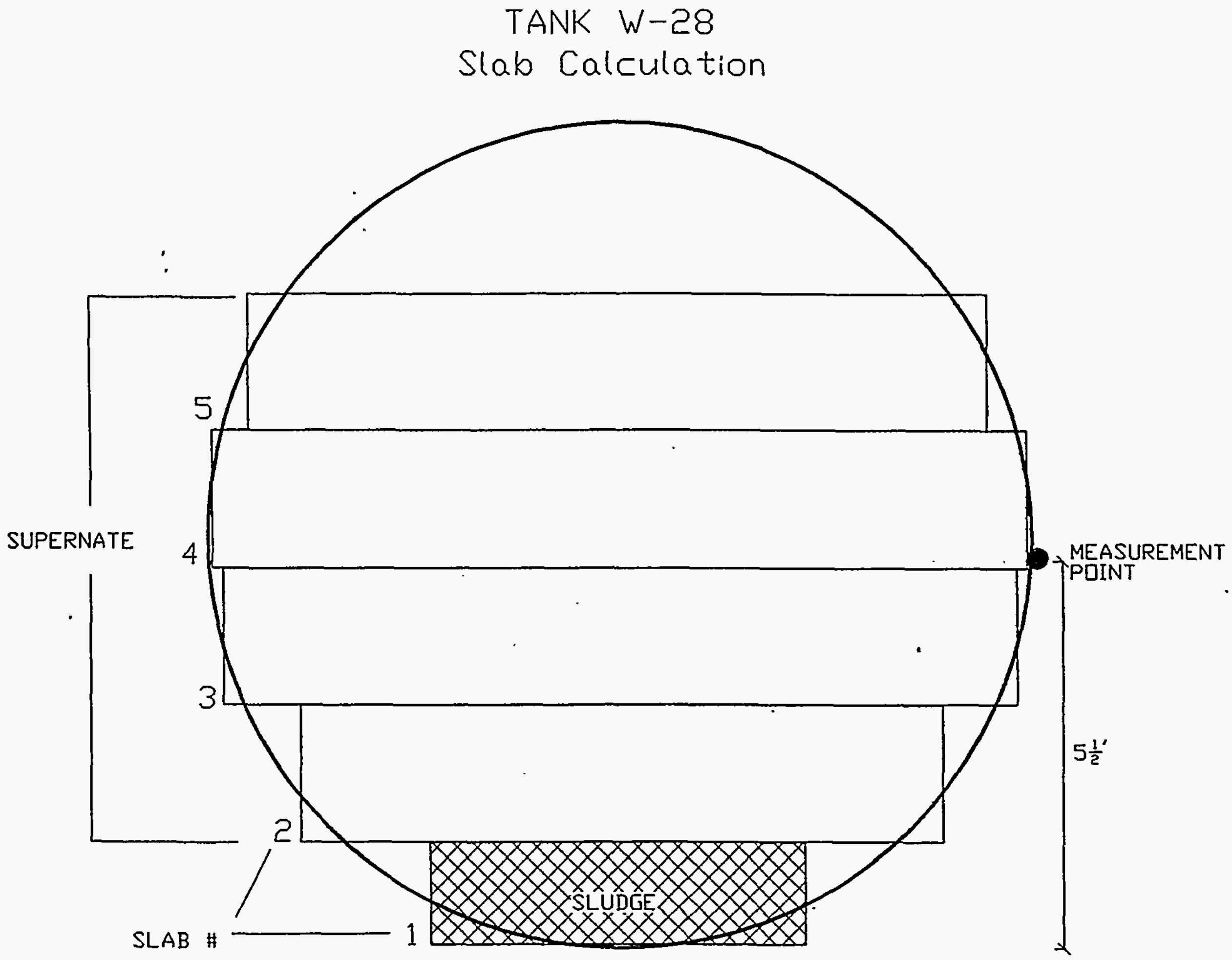

Fig. 6.2. End view of Melton Valley Storage Tank W-28 showing supernatant liquid and sludge layers used in multi-slab calculation for tank W-28. Thickness of slab #1 is 1.5 ft and thicknesses of slabs #2–5 are 2.0 ft. Measurement location is 5½ ft (1.7 m) from bottom of tank or 6½ ft (2.0 m) from floor of vault (see Yong et al. 1996a).

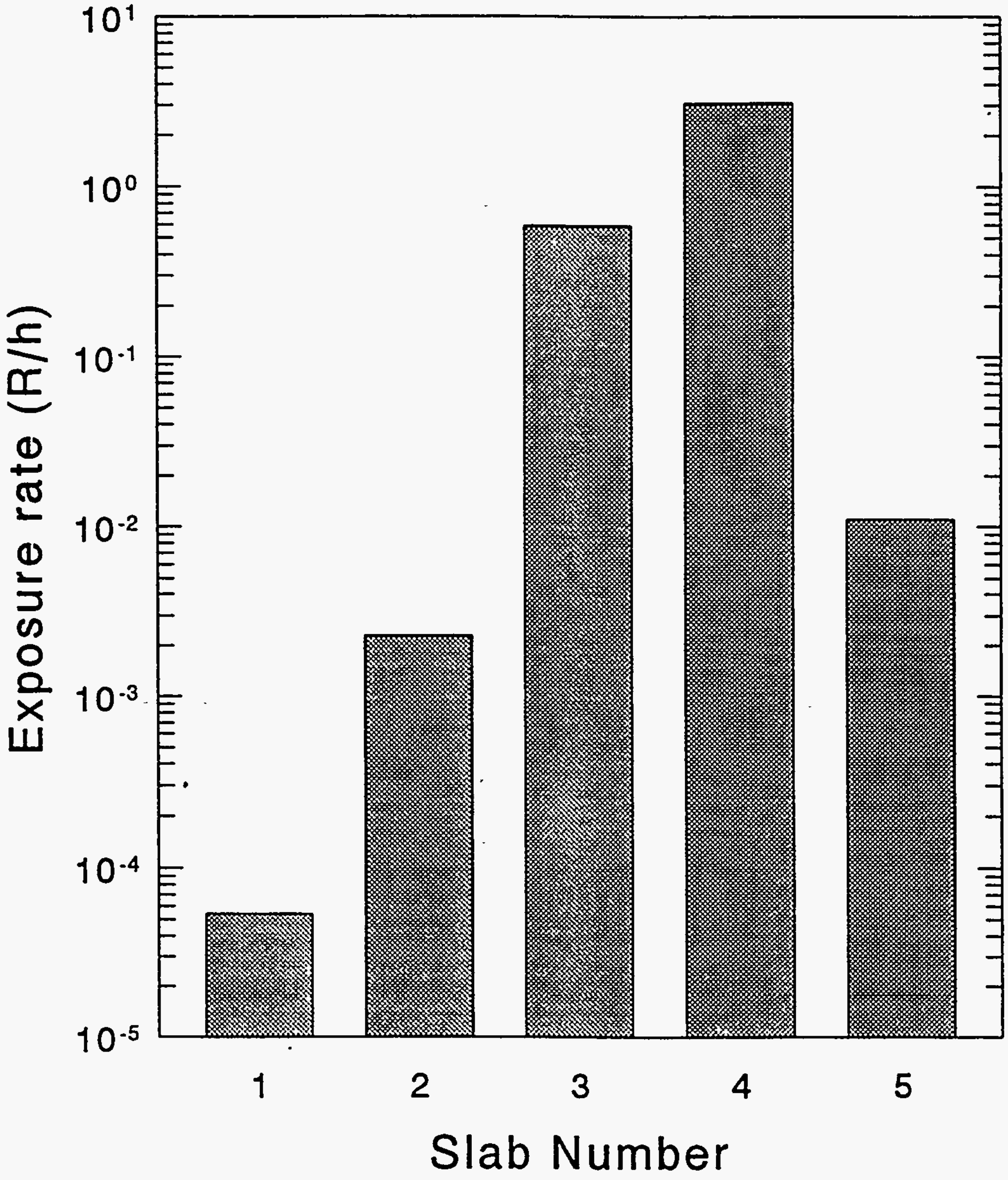

Fig. 6.3. Contributions of various slabs shown in Fig. 6.2 to calculated gamma exposure rate at location of contact exposure-rate measurement on side of Melton Valley Storage Tank W-28.

7. WORKER DOSE ASSESSMENTS

In this section, collective doses to workers from external exposure are estimated based on the radiation measurements described in Section 3, the exposure scenarios described in Sections 4 and 5, and the calculations described in Section 6. Measured exposures are converted to dose equivalents by assuming that 1 R from a broad energy spectrum of gamma rays is equal to 1 rem (10 mSv). In the calculations with the MicroShield code, both exposure rate in air and dose-equivalent rate to an individual are provided. The calculated dose-equivalent rates of interest here are those for an anterior-posterior geometry (i.e., an individual is facing the radiation source and the body is irradiated primarily from the front) and a rotational irradiation geometry (i.e., an individual is irradiated from all directions).

7.1 Sludge Manifold Hookup in Pump and Valve Vault

Sections 3.2 and 4.1 discuss potential worker exposures during sludge manifold hookup in the pump and valve vault (P&VV). The total time for all such activities is estimated to be about 3400 person-hours, with 50% of the workers' time spent in the radiation zone of the P&VV and 50% of the time spent in an area above the vault just outside the P&VV. The gamma dose-equivalent rate in the P&VV is assumed to average about 0.2 rem/h (2 mSv/h) in the areas where most of the work will be performed (see Sections 3.2 and 4.1), and the gamma dose rates in the areas above the vault just outside the P&VV are assumed to be negligible (see Section 3.5).

Because the exposure rates on top of the roof of the MVST vaults are low (see Section 3.5) and the vault roof and P&VV have similar shielding against radiation from the tanks (see Figs. 2.2 and 2.3), it can be assumed that the exposure rates in the P&VV result almost entirely from internal contamination of the existing piping in the P&VV (see Section 3.2). It may be possible to reduce the high gamma-exposure levels in the P&VV by rinsing the existing pipes with clear supernatant and process water. However, the potential reduction in the gamma radiation levels in the P&VV by rinsing of the pipes has yet to be determined, and no credit for decontamination of the existing piping was applied in our estimates of collective doses to workers.

The various work activities during sludge manifold hookup in the P&VV and the number of occurrences of each activity are discussed in Section 4.1, and the collective doses for each activity are summarized in Table 7.1. For one occurrence of Activity 1 (see Section 4.1.1), for example, the collective dose is (320 person-hours) × (50%) × (0.2 rem/h) or 32 person-rem (0.32 person-Sv). The total collective doses thus are estimated to be 80 person-rem (0.80 person-Sv) for startup (i.e., one occurrence of each activity) and 340 person-rem (3.4 person-Sv) for the total project (i.e., all occurrences of each activity). These doses are sufficiently high to indicate the need for careful planning, including the possible use of temporary shielding, to minimize worker exposures during these activities.

7.2 Removal of Manhole Cover and Installation of Secondary Confinement and Spool Piece

Sections 3.4, 4.2, and 6.2.2 discuss potential worker exposures during removal of the manhole covers from the waste storage tanks and installation of the secondary confinement and spool pieces to extend the manholes to the roof of the tank vaults. The total time for eight occurrences of these activities is estimated to be 3800 person-hours, or about 480 person-hours for each occurrence, with 25% of a worker's time spent in the radiation zone near the vault plug openings on the vault roof and the other 75% of the time spent either on top of the vault roof away from the openings or in non-radiation areas away from the vault roof (see Section 4.2). The work away from the radiation zone near the vault plug openings will be done in areas where the gamma dose rates are negligible (see Section 3.5).

There is considerable uncertainty in estimating doses for these activities. A worker's exact movements in the radiation zone near the vault plug openings are not well defined, and the gamma exposure rates vary rapidly with radial distance from the openings. In addition, the remotely operated tooling used in this work may provide shielding of the workers in some instances, or it may cause radiation to be scattered from the vault plug openings toward the workers in other instances. Given these uncertainties, it is assumed conservatively that a worker is exposed above the edge of the vault plug openings while working in the radiation zone near the openings.

Based on the radiation measurements near the vault plug openings to tanks W-24 and W-25 (see Section 3.4), the gamma exposure rate at a distance of 18 in. (42 cm) or more above the edge of a vault plug opening is assumed to be one-fifth of the exposure rate at the top of the vault roof, center of the vault plug opening (i.e., at Location C in Fig. 2.3). Thus, based on the measurements at Location C given in Table 3.3, the dose-equivalent rate above the vault plug openings where a worker might stand is estimated to be 0.2 rem/h (2 mSv/h) for tanks W-24, W-25, and W-26, and 0.1 rem/h (1 mSv/h) for the other five tanks, W-27 through W-31.

Collective doses based on the assumptions described above are presented in Table 7.2, and are designated as untreated supernatant values. For tank W-24, for example, the collective dose is estimated to be (480 person-hours) × (25%) × (0.2 rem/h) or 24 person-rem (0.24 person-Sv). If the supernatant liquid is treated to remove the ^{137}Cs, then the dose rates near the vault plug openings to all tanks are assumed to be reduced by a factor of 10 (see Section 6.4), and the collective dose from the treated supernatant in tank W-24 is estimated to be 2 person-rem (0.02 person-Sv). Thus, the collective doses for these activities at all eight tanks are estimated to be 130 person-rem (1.3 person-Sv) for the untreated supernatant and 11 person-rem (0.11 person-Sv) for the treated supernatant.

7.3 Sluicer-Mixer Installation and Removal

Sections 4.3 and 6.5 discuss potential worker exposures during sluicer-mixer installation and removal from the waste storage tanks. The total time for eight occurrences of these activities is estimated to be 1900 person-hours, or about 240 person-hours for each occurrence, with about 25% of a worker's time spent in the radiation zone near the manhole extension openings or in the radiation zone of the contaminated sluicer-mixer system. Thus, the time spent by workers in the radiation zones is estimated to be (240 person-hours) × (25%) or 60 person-hours for each occurrence of these activities. The 60 person-hours per occurrence are assumed to be allocated as 15 person-hours to each of the following four activities: removal of the lid on the manhole extension and installation of the wash-down system in the manhole extension, installation of the sluicer-mixer system in a waste storage tank, removal and wash-down of the sluicer-mixer system, and removal of the wash-down system from the manhole extension and replacement of the lid on the manhole extension. The other 75% of workers' time will be spent in areas where the dose rates are negligible (i.e., in areas of the vault roof away from the open manhole extensions or in non-radiation areas near the vault roof).

It is assumed conservatively that a worker is exposed above the edge of the manhole extension opening while working at that location or is exposed at a distance of 50 cm (20 in.) from the contaminated sluicer-mixer system. The dose-equivalent rates near the open manhole extensions to the various tanks are estimated to be the same as those near the edge of the open vault plugs (see Section 7.2); i.e., the dose-equivalent rate above the manholes is estimated to be 0.2 rem/h (2 mSv/h) for tanks W-24, W-25, and W-26 and 0.1 rem/h (1 mSv/h) for the other five tanks, W-27 through W-31. The dose-equivalent rate at a distance of 50 cm (20 in.) from the sluicer-mixer system is estimated to be 0.02 rem/h (0.2 mSv/h) during its removal from tank W-26 and during its installation and removal from the other seven tanks (see Section 6.5 and Table 6.12).

Collective doses based on the assumptions described above are presented in Table 7.3, and are designated as untreated supernatant values. For tank W-24, for example, the collective dose is estimated to be (30 person-hours) × (0.2 rem/h) or 6 person-rem (0.06 person-Sv) from all activities near the open manhole extensions and (30 person-hours) × (0.02 rem/h) or 1 person-rem (0.01 person-Sv) from all activities near the contaminated sluicer-mixer, for a total of 7 person-rem (0.07 person-Sv) from all activities during installation and removal of the sluicer-mixer from this tank. If the supernatant liquid is treated to remove the ^{137}Cs, the total collective dose is estimated to be only 2 person-rem (0.02 person-Sv) for tank W-24. The collective dose for these activities at all eight storage tanks is estimated to be 41 person-rem (0.41 person-Sv) for the untreated supernatant and 10 person-rem (0.10 person-Sv) for the treated supernatant. In estimating collective doses for tank W-26, it was assumed that the sluicer-mixer was clean during its initial installation and that exposures would occur only during the 15 person-hours of the workers' time spent in the radiation zone of the contaminated sluicer-mixer during its removal from this tank.

7.4 Maintenance Activities on Roof of Tank Vaults

Section 4.5 discusses worker exposures during various maintenance activities on the roof of the storage tank vaults. Ten maintenance activities are defined: eight related to contaminated items on the submerged portion of the sluicer-mixer system, one related to replacement of the TV camera used to monitor sludge removal activities in the tanks, and one related to replacement of the HEPA filters in the off-gas ventilation system for the tanks. The worker exposures are specified in terms of times spent in contact with an item and in the radiation field at a distance of 50 cm (20 in.) from the contaminated item. Each of the defined maintenance activities is expected to occur once or twice per year over a period of approximately two years. It is assumed conservatively that each of the maintenance activities will occur four times during a two-year period.

Prior to maintenance on the sluicer-mixer system, internal surfaces of the pumps and pipes will be cleansed by back-flushing with clean water, and external surfaces will be washed down using clean water during its removal from the waste storage tanks (see Section 4.7). Thus, all of the supernatant should be removed from the sluicer-mixer system, and the differences in radioactivity between untreated supernatants and treated supernatants with the ^{137}Cs removed are assumed to have little effect on the dose from residual radioactivity in the sluicer-mixer system. However, it is assumed that a 100-μm layer of sludge remains on the interior and exterior surfaces of the sluicer-mixer system and, based on the calculations described in Section 6.5 and summarized in Table 6.12, that the dose-equivalent rates due to this sludge layer will be about 0.2 rem/h (2 mSv/h) on contact and 0.02 rem/h (0.2 mSv/h) at a distance of 50 cm (20 in.). These dose rates also are assumed to apply to the TV camera following its wash-down and removal through the G-3 nozzle to the waste storage tanks (ORNL 1995). For the HEPA filters, it is assumed conservatively that the dose-equivalent rate is 1 rem/h (10 mSv/h) on contact (see Section 4.5) and 0.1 rem/h (1 mSv/h) at a distance of 50 cm (20 in.) (see Section 3.5). The latter value is based on the largest past measurement made near the HEPA filter banks serving the off-gas ventilation system for the waste storage tanks (Yong 1996b).

Collective doses based on the assumptions described above are presented in Table 7.4. During replacement of a worn pump rotor on the sluicer-mixer, for example, a two-person crew is assumed to spend 8 hours each, or a total of 16 person-hours, with 25% of the time spent at a distance of 50 cm (20 in.) from the sluicer-mixer and 10% of the time in closer contact with the sluicer-mixer and pump. Thus, the collective dose is estimated to be (16 person-hours) × (10%) × (0.2 rem/h) or 0.3 person-rem (0.003 person-Sv) from close contact with the sluicer-mixer and pump and (16 person-hours) × (25%) × (0.02 rem/h) or 0.1 person-rem (0.001 person-Sv) during the time spent at a distance of 50 cm (20 in.) from the sluicer-mixer, for a total of 0.4 person-rem (0.004 person-Sv) per occurrence or 1.6 person-rem (0.016 person-Sv) for all four occurrences of this activity. The total collective dose for all maintenance activities on the roof of the tank vaults thus is estimated to be 11 person-rem (0.11 person-Sv).

7.5 Maintenance Activities in Pump and Valve Vault

Section 4.6 discusses worker exposures during maintenance activities in the P&VV. Three maintenance activities are defined: replacement of a flange seal, replacement of a valve operator, and replacement of a pressure transducer. The worker exposures are specified in terms of times spent in close contact with an item and in the radiation fields in the open work areas in the P&VV. Each of the three defined maintenance activities is expected to occur once or twice per year over a period of approximately two years. It is assumed conservatively that each of the maintenance activities will occur four times during a two-year period.

Gamma radiation levels have been measured on contact with the existing pipes at three locations in the P&VV and in open work areas at six locations along the length of the P&VV (see Section 3.2 and Table 3.2). Based on these measurements, the dose-equivalent rates are assumed to be 1 rem/h (10 mSv/h) in close contact with a pipe flange or pressure transducer (see Section 4.6) and 0.2 rem/h (2 mSv/h) in an open area of the P&VV where most of the work is performed (see Section 7.1). The dose-equivalent rate at a valve operator is assumed to be intermediate between these two values, or 0.6 rem/h (6 mSv/h).

Collective doses based on the assumptions described above are presented in Table 7.5. For replacement of a flange seal on a pipe, for example, a two-person crew is assumed to spend 8 hours each, or a total of 16 person-hours, with 25% of the time spent in open work areas of the P&VV and 10% of the time in close contact with the pipe flange. Thus, the collective dose is estimated to be (16 person-hours) × (10%) × (1 rem/h) or 2 person-rem (0.02 person-Sv) from close contact with the pipe flange and (16 person-hours) × (25%) × (0.2 rem/h) or 1 person-rem (0.01 person-Sv) from work in open areas of the P&VV, for a total 3 person-rem (0.03 person-Sv) per occurrence and 12 person-rem (0.12 person-Sv) for all four occurrences of this activity. The total collective dose for all maintenance activities in the P&VV is estimated to be 24 person-rem (0.24 person-Sv).

7.6 Summary of Doses from Normal Work Activities

Potential doses to workers from the normal work activities considered in this assessment are discussed in Sections 7.1–7.5 and are summarized in Tables 7.1–7.5. The collective dose to workers during installation of equipment in the P&VV could exceed 300 person-rem (3 person-Sv) if the existing gamma dose rates in the vault, which are due primarily to existing contamination of piping in the vault, are not reduced (see Table 7.1). The collective dose during installation of equipment on the roof of the MVST vaults could be about 200 person-rem (2 person-Sv) (see Tables 7.2 and 7.3), and the collective dose during all other activities considered should be less than 40 person-rem (0.4 person-Sv) (see Tables 7.4 and 7.5).

Collective doses from installation of equipment on the roof of the MVST vaults can be reduced substantially if the supernatant in the tanks is first treated to remove the ^{137}Cs. The total collective dose for the treated supernatant is estimated to be about an order of magnitude less than that from the untreated supernatant, or about 20 person-rem (0.2 person-Sv) (see Tables 7.2 and 7.3). The collective doses for the treated supernatant are presented as an example of how the dose-equivalent rates to workers can be reduced.

It may be possible to achieve similar reductions by using temporary shielding near the open manholes to the tank vaults during removal of the current manhole covers on the tanks and installation of the new spool pieces (see Section 7.2) and during installation and removal of the sluicer-mixer system during sludge removal from the tanks (see Section 7.3).

Collective doses from installation of equipment in the P&VV are sufficiently high to indicate the need for further planning to reduce the current gamma dose rates in the vault (see Table 7.1). There is a need for better radiation surveys in the P&VV before and after the existing pipes have been rinsed with clean water to remove as much of the internal contamination as possible (see Section 3.2). In addition, the feasibility of using temporary shielding to reduce doses during normal work activities in the P&VV should be investigated (see Sections 7.1 and 7.5).

The exposure scenarios for workers assumed in this assessment are somewhat subjective, particularly in regard to the working times associated with the defined activities. However, if exposure times different from those used in this assessment were assumed for purposes of planning for sludge mobilization and removal, the estimates of collective dose can be scaled in proportion to the exposure time.

7.7 Doses from Credible Accident in Pump and Valve Vault

Doses to workers from a credible accident in the P&VV are discussed in Sections 5.2 and 6.6. Following the accident, it is assumed that a two-person crew will need to enter the partially decontaminated east or west sections of the P&VV to repair a leaking seal on the sludge manifold. It is further assumed that the workers will be in the P&VV for approximately 0.5 h during the repairs. The dose-equivalent rate in the vault's east or west sections could be 0.7 rem/h (7 mSv/h) from the accidental contamination of the vault (see Section 6.6) and 0.2 rem/h (2 mSv/h) from the normal internal contamination of the piping in the vault (see Section 3.2). Thus, the total dose-equivalent rate could be 0.9 rem/h (9 mSv/h), and the collective dose from repair of the leaking seal following the accident could be (0.9 rem/h) × (0.5 h) × (2 persons) or about 1 person-rem (0.01 person-Sv).

Collective doses while working near open manholes on the roof of the P&VV during initial spray decontamination of the vaults following an accident (see Section 5.2) have not been estimated in this assessment. The calculated dose rates near the ceiling of the P&VV presented in Section 6.6.1 in conjunction with the measured exposure rates near the pipes in the vault suggest that the dose rates above open manholes could be quite high. However, a reliable estimate of the dose rates at these locations cannot be obtained based on the available information. On the other hand, workers should spend only small amounts of time in these areas.

Collective doses to workers from decontamination of the vault following the accident also have not been estimated. It is assumed that the high dose rates in the vault would require the use of robotic equipment, and that workers would be in the vault only for very short periods of time during decontamination operations. The long-term concern would be the incremental increase in the dose rate in the P&VV due to incomplete removal of the contamination on the floor and walls and its impact on collective doses from other activities in the P&VV (see Sections 4.1 and 4.6). It would seem that plans should be developed to limit accidental leakage into the P&VV (e.g., by the use of secondary containment and/or rapid leak-detection devices).

Table 7.1. Collective worker doses for sludge manifold hookup in pump and valve vault

Activity[a]	Number of occurrences[a]	Person-hours per occurrence[b]	Collective worker doses (person-rem)[c]	
			Each occurrence	All occurrences
1	8	320	32	260
2	2	160	16	32
3	1	160	16	16
4	2	160	16	32
Total			80	340

[a] See Section 4.1 for discussion of these activities and number of occurrences.

[b] Assumes workers spend 50% of their time in radiation zone of vault and 50% of their time in area above vault. Work outside vault will be done in areas where dose-equivalent rates are negligible.

[c] Assumes that dose-equivalent rate to workers in radiation zone of vault where most of work will be performed will average about 0.2 rem/h (see Section 3.2). No credit is taken for any reduction in gamma radiation levels in vault due to rinsing of existing contaminated pipes with clear supernatant and process water.

Table 7.2. Collective worker doses for removal of manhole cover and installation of secondary confinement and spool piece

Tank	Number of occurrences[a]	Person-hours per occurrence[b]	Collective worker doses (person-rem)	
			Untreated supernatant[c]	Treated supernatant[d]
W-24	1	480	24	2
W-25	1	480	24	2
W-26	1	480	24	2
W-27	1	480	12	1
W-28	1	480	12	1
W-29	1	480	12	1
W-30	1	480	12	1
W-31	1	480	12	1
Total			132	11

[a] See Section 4.2 for discussion of activities related to preparation of tanks for sludge removal.

[b] Assumes workers spend 25% of their total working time in radiation zone near vault plug openings and 75% of the time either on top of vault roof away from vault plug openings or in non-radiation areas away from vault roof. Work away from radiation zone near vault plug openings will be done in areas where dose rates are negligible.

[c] Assumes that dose-equivalent rate is 0.2 rem/h above edge of vault plug openings for tanks W-24, W-25, and W-26, and 0.1 rem/h above edge of vault plug openings for the other five tanks, W-27 through W-31.

[d] Assumes that supernatant liquid is treated to remove ^{137}Cs prior to work activities. Treatment of supernatants is estimated to reduce dose-equivalent rates near vault plug openings of tanks by factor of about 10 (see Section 6.4 and Table 6.11).

Table 7.3. Collective worker doses for sluicer-mixer system installation and removal

Tank	Number of occurrences[a]	Person-hours per occurrence[b]	Collective worker doses (person-rem)	
			Untreated supernatant[c]	Treated supernatant[d]
W-24	1	240	7	2
W-25	1	240	7	2
W-26	1	240	7	1
W-27	1	240	4	1
W-28	1	240	4	1
W-29	1	240	4	1
W-30	1	240	4	1
W-31	1	240	4	1
Total			41	10

[a] See Section 4.3 for discussion of activities related to sluicer-mixer system installation and removal.

[b] Assumes that workers spend 25% of their time in radiation zone near manhole extension openings and in radiation zone near contaminated sluicer-mixer system, or 60 person-hours per occurrence of these activities. Allocation of these 60 person-hours to different work activities is described in Section 7.3.

[c] Assumes that dose-equivalent rate is 0.2 rem/h above edge of open manholes for tanks W-24, W-25, and W-26 and 0.1 rem/h above edge of open manholes for other tanks, W-27 through W-31. Dose-equivalent rate at radial distance of 50 cm (20 in.) from sluicer-mixer system is assumed to be 0.02 rem/h during removal from tank W-26 and during installation and removal for all other tanks (see Section 6.5 and Table 6.12).

[d] Assumes that supernatant liquids are treated to remove ^{137}Cs. Treatment of supernatants is estimated to reduce dose-equivalent rate above open manholes to tanks by factor of 10 (see Section 6.4 and Table 6.11).

Table 7.4. Collective worker doses during maintenance activities on roof of tank vaults

Activity[a]	Number of occurrences[a]	Person-hours per occurrence[b]	Collective worker doses (person-rem)	
			Each occurrence	All occurrences
Replace worn pump rotor	4	16[c]	0.4	1.6
Replace pump seal	4	16[c]	0.4	1.6
Replace motor bearing	4	16[c]	0.08	0.3
Replace hydraulic hose to motor	4	8[c]	0.04	0.2
Replace valve	4	16[c]	0.9	3.6
Replace valve operator	4	8[c]	0.04	0.2
Replace pressure transducer	4	4[c]	0.2	0.8
Replace camera light	4	4[c]	0.2	0.8
Replace video camera	4	4[d]	0.02	0.1
Replace HEPA filters	4	4[e]	0.5	2.0
Total				11

[a] See Section 4.5 for discussion of activities related to maintenance on roof of tank vaults.

[b] Assumed time spent by workers in contact with an item and in radiation field at distance of 50 cm (20 in.) from item are discussed in Section 4.5.

[c] Dose-equivalent rates at contact with items and at distance of 50 cm (20 in.) are estimated to be 0.2 and 0.02 rem/h, respectively.

[d] Dose-equivalent rates at contact with video camera and at distance of 50 cm (20 in.) are assumed to be 0.2 and 0.02 rem/h, respectively.

[e] Dose-equivalent rates at contact with HEPA filters and at distance of 50 cm (20 in.) are assumed to be 1 and 0.1 rem/h, respectively.

Table 7.5. Collective worker doses during maintenance activities in pump and valve vault

Activity[a]	Number of occurrences[a]	Person-hours per occurrence[b]	Collective worker doses (person-rem)	
			Each occurrence	All occurrences
Replace flange seal	4	16[c,d]	3	12
Replace valve operator	4	16[c,e]	2	8
Replace pressure transducer	4	4[c,d]	1	4
Total				24

[a] See Section 4.6 for discussion of activities related to maintenance in pump and valve vault.

[b] Assumed time spent by workers in contact with an item and in radiation fields in open work areas in pump and valve vault.

[c] Dose-equivalent rate in open work areas in pump and valve vault is assumed to be 0.2 rem/h.

[d] Dose-equivalent rate in close contact with pipe flange or pressure transducer is assumed to be 1 rem/h.

[e] Dose-equivalent rate in close contact with valve operator is assumed to be 0.6 rem/h.

8. DISCUSSION AND CONCLUSIONS

The estimates of external radiation doses to workers provided in this report are intended for use in planning of work activities during sludge mobilization and removal from the Melton Valley Storage Tanks to insure that the workers are adequately protected in accordance with radiation protection requirements established by the U.S. Department of Energy or the U.S. Nuclear Regulatory Commission. It must be recognized, however, that the dose estimates in this report are subject to considerable uncertainty. Some important sources of uncertainty include the limited information on the concentrations of important radionuclides in the sludges and the subjective nature of the various worker exposure scenarios assumed in the dose assessments. Thus, the dose estimates serve only as indicators of the potential magnitude of external doses that might be experienced and the considerable care that will be required in protecting workers during sludge mobilization and removal activities. In addition, internal exposures of workers in contaminated areas would need to be considered but were not evaluated in this assessment.

In spite of the considerable uncertainty in the dose estimates, two potential concerns in controlling external doses to workers have been identified. One of these involves installation of the sludge manifold in the pump and valve vault (P&VV), and the other involves an accidental spillage of sludge and supernatant on the floor of the P&VV. The estimated collective doses during sludge manifold hookup in the P&VV are sufficiently high to indicate the need for further planning to minimize worker exposures during these activities. There is a need for better radiation surveys in the P&VV before and after the existing pipes have been rinsed with clean water to remove internal contamination. In addition, the feasibility of using temporary shielding to minimize worker exposures during sludge manifold hookup activities should be investigated. For an accidental spillage of sludge and supernatant liquid in the P&VV, incomplete decontamination following the spillage could add a substantial incremental dose rate to the already high dose rates in the P&VV, resulting in further increases in collective doses from other activities in the P&VV. Thus, it would seem that plans should be developed to limit accidental spillage in the P&VV (e.g., by the use of secondary containment or rapid leak-detection devices).

External doses to workers during installation of equipment on top of the roof of the storage tank vaults also could be substantial. In this case, the analysis indicated that the collective dose could be reduced by about an order of magnitude by first treating the supernatant liquid in the tanks to remove the ^{137}Cs. Similar reductions in dose may be obtained by using temporary shielding near open manholes on the roof during installation of equipment.

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