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ACTINIDE-SOIL INTERACTIONS IN WASTE MANAGEMENT AT THE SAVANNAH RIVER PLANT

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DISCLAIMER

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ABSTRACT

Three aspects of the transuranium (TRU) nuclide-soil interaction were studied in connection with Savannah River Plant (SRP) burial ground operations. Results of the studies are reported as three separate parts of this report.

- *Radionuclide Content of an Exhumed Canyon Vessel.* The long-term hazard potential associated with burial of process equipment from radiochemical separations plants is being evaluated. As part of this evaluation, a feed adjustment tank was exhumed eighteen years after burial. The tank had been in service in the fuel reprocessing plant for twenty-nine months before it was retired. Assay of the exhumed tank indicated that 7 mg of ^{239}Pu and 1 mCi of ^{137}Cs remained on its surfaces. Less than 1 μCi of ^{239}Pu was found in the soil under the tank.

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- *Volume Reduction of Plutonium-Contaminated Soil.* A series of laboratory tests was aimed at reducing the volume of plutonium-contaminated soil in the SRP burial ground. The tests showed that the volume of plutonium-contaminated soil could be reduced to one-third by scrubbing and separating a clay silt fraction containing about 95% of the plutonium. Only the plutonium-rich fraction would then require storage in durable containers; the remaining two-thirds (plutonium-depleted fraction) of the soil could be returned to the burial trenches.

- *Movement of Organically Bound Plutonium in Soil.* A safety evaluation of underground storage of spent Purex solvent (tri-n-butyl phosphate, TBP, in hydrocarbon diluent) was made. In this evaluation, laboratory tests showed that small volumes of organic-complexed plutonium are effectively sorbed and immobilized in dry (ground surface) soil. But moist (subsurface) soil would permit extensive migration of postulated large volumes of solvent-complexed plutonium until the plutonium transfers to the water phase with subsequent absorption on the soil.

RADIONUCLIDE CONTENT OF AN EXHUMED CANYON VESSEL — H. P. Holcomb

Summary

To assess the long-term hazard potential associated with the burial of retired, intensely contaminated process equipment, an emplacement of canyon equipment was excavated. During the previous twenty years, failed or obsolete process equipment, amounting to 10^5 cubic feet, from radiochemical separations processes have been placed in earthen trenches at the SRP burial ground. Radionuclides associated with this waste are principally the fission products ^{95}Zr-^{95}Nb, $^{141-144}Ce$, and $^{103-106}Ru$. These species have short to moderate half-lives and present no significant requirements for control and surveillance of the burial site beyond a time span of a few decades. However, this type of waste also includes longer-lived contaminants, such as ^{90}Sr, ^{137}Cs, and $^{238-239}Pu$. These species greatly influence planning for future control and surveillance criteria of the burial site. The TRU nuclide content of this equipment was not measured prior to burial because of the intense beta-gamma radiation associated with the equipment, generally several tens of R/hr at distances of a few feet.

One vessel, a Purex feed adjustment tank from the hot canyon of a separations plant, has been exhumed and studied. This piece of equipment was retired from service and buried in 1957. This part of the study describes the exhumation and assay methods. The assays showed that 7 mg of ^{239}Pu and 1 mCi of ^{137}Cs remain on

the surfaces of the vessel; the amount of radionuclides in the nearby soil is substantially less.

Details

Pre-excavation Work

Before the contaminated vessel was unearthed, the following steps were taken:

- Criteria for selection of buried equipment were set
- Records for available equipment were examined
- A candidate vessel was selected
- The buried vessel was located by drill probing
- A Test Authorization was prepared
- Adjacent soil was sampled
- Laboratory leaching experiments were designed
- A job plan was written and approved

The first choice of a candidate for the exhumation test was a first-cycle Purex feed tank. This tank was an 8-ft-diameter by 8-ft-high vessel that had been buried after it was retired from service in 1957.

The first task was to find the buried process vessel by drill probing (Figure 1) in a high-level waste trench. The location of the feed tank was shown on an old burial ground map with a feed adjustment tank noted as being nearby in the same trench. However, probing the chosen area of the burial trench indicated the presence of only one vessel, an 8-ft-diameter vessel that was buried about 3½ ft beneath the surface.

Soil samples were taken as shown in Figure 2 by vertically coring as close to the vessel as possible. Another series of cores was taken at a distance of one foot from the vessel wall. After the vessel was exhumed, soil that had been beneath the vessel was also sampled.

Trench Excavation and Vessel Exhumation

The remaining steps in the test procedure, beginning with the exhumation of the vessel, are listed below.

- Soil around vessel was excavated
- Vessel was removed and transported to test site
- Soil beneath vessel was backfilled and sampled
- Vessel contents were sampled
- Adhering and contained soil were removed from vessel
- Temporary hut was constructed around vessel
- Radiation surveys and measurements of vessel and surrounding soil were conducted
- Sample coupons were cut from vessel
- Leach tests and soil analyses were performed in laboratory
- Report was written

This was not the first piece of equipment to be exhumed from the SRP burial ground. Previously, five batch evaporators and a process centrifuge were reclaimed, reworked, and returned to service, but this is the first attempt at SRP to recover buried equipment for the purpose of measuring contamination levels.

A clam shell was used to uncover the vessel. Figure 3 shows the first portion of the vessel wall that was uncovered. A dead root was immediately adjacent to the vessel. On this uncovered portion of the vessel wall, the alpha contamination was 10^4 dis/(min)(75 cm^2). Radioactivity in the root was almost exclusively that of ^{90}Sr, about 10^5 pCi/g, with only 6 pCi/g of plutonium.

As excavation and soil removal from around the vessel continued, the serial number, painted on the side, was exposed (Figure 4). On reviewing the records, the vessel being exhumed was found to be the Purex feed adjustment tank instead of the feed tank originally sought. For this test, however, either vessel would suffice because their process histories were very similar. The feed adjustment tank had been in hot canyon service for 29 months, from October 1954 to March 1957. Health Physics records at the time of burial showed a radiation level of 22.5 R/hr at 1 ft. Calculations indicated that the current radiation level would be about 2 mR/hr at 3 in., sufficiently low for extended periods of close work.

When the overburden was removed, it was confirmed that the tank had been buried with the agitator opening uncovered, allowing the tank to be filled with soil and water. Figure 5 shows the mud-filled tank, with clods being supported at the opening. The tank and its contents weighed about 18 tons. A 75-ton crane (Figure 6) lifted the tank from the emplacement and placed it in a transport box on a trailer for moving to the test site.

Cleaning and Assaying Exhumed Tank

At the test site, a platform was constructed to permit working over the tank that was still contained in the transport box. About 350 gal of water was removed and sampled, leaving a mud cake that was core-sampled. The tank was lifted from the box and suspended over the adjacent open trench. The exterior soil was removed by washing as shown in Figure 7, and the interior mud cake was then washed out as shown in Figure 8. When contained soil was removed from the tank, cursory visual inspection revealed that the cooling coils were still intact. A closer view, Figure 9, revealed that the coils and interior of the vessel were bright and shiny, indicating that the vessel was in excellent metallurgical condition, as more thorough visual inspection later indicated.

After the tank was cleaned and visually inspected, radiation measurements began. These included beta-gamma measurements with a Cutie Pie (Figure 10); comprehensive alpha surveys of both exterior and interior as shown in Figure 11; and a gamma pulse height analysis using portable equipment (Figure 12). The beta-gamma activity averaged 3 mrad/hr at 1 ft from the tank. Figure 12 also shows the plastic hut that was used to prevent the spread of contamination from the tank.

Six 2-in.-diameter coupons were cut from the 3/8-in.-thick stainless steel tank wall (Figure 13) and bottom. These coupons have been assayed for alpha and gamma emitters and are undergoing long-term leach testing in the laboratory.

Reburial of the feed adjustment tank in a lysimeter was originally planned, so radionuclidic leaching could be studied under natural conditions. Excavation of the lysimeter pit is shown in Figure 14. The pit is 16 to 18 ft deep with a sloping bottom and is 12 ft long and 13 ft wide. Installation of the 20-mil-thick polyvinyl chloride liner is shown in Figure 15. A standpipe to house a pump was installed, and a base was prepared with sand, gravel, and soil layers to support the vessel and to serve as a sump. However, when the TRU contamination level of the vessel was found to be lower than expected, a decision was made to rebury the vessel in the adjacent trench. Use of the lysimeter is planned for other exhumed equipment with higher contamination levels.

Results

Table 1 summarizes the residual ^{239}Pu contamination found on individual surfaces of the exhumed tank. More than half of the contamination was found on the outside top surface; contamination on the mild steel trunion guides and supports contributed about 20% of the total of 7 mg of ^{239}Pu found. Under ERDA guidelines, waste with a TRU content of greater than 10 nCi/g must be stored retrievably. However, discarded bulky process equipment with a TRU content above 10 nCi/g is presently exempted from retrievable storage. So, although the exhumed tank would be classified as bulky equipment, its low TRU content places it in the nonretrievable storage category. Table 2 shows that the total surface

contamination is only about 1% of the guideline limit (10 nCi/g). Table 3 summarizes the quantities of ^{239}Pu found in the mud cake and water contained in the vessel upon exhumation. The mud, i.e., the soil and interstitial water, contained only 0.08 mg of plutonium, about 1% of the quantity found on the vessel surfaces; the 356 gal of water contained less than 0.01 mg of plutonium. A gamma pulse height analysis showed that ^{137}Cs was the only detectable gamma-emitting fission product on the tank surfaces; a total of 1 mCi of ^{137}Cs was determined to be present on the surfaces of the empty tank.

Conclusion

The primary conclusion so far from this continuing test is that this process vessel, a Purex feed adjustment tank, when buried 18 years ago, contained less plutonium than the 10 nCi/g that ERDA waste management standards currently define as TRU-contaminated, retrievable waste. However, this is only the first bit of information thus far obtained from an overall program to assess the long-term hazards of equipment burials. To provide a better data base for hazard assessment in planning for future surveillance and control of the burial ground site, further exhumations and testing of other equipment, potentially more highly contaminated, is being contemplated. Therefore, this program will not likely conclude with the study of only this one piece of buried, bulky equipment.

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VOLUME REDUCTION OF PLUTONIUM-CONTAMINATED SOIL - J. H. Horton

Summary

A laboratory study was conducted to determine if plutonium in soil at the SRP burial ground is primarily associated with the sand, silt, or clay fractions. Approximately three million cubic feet (maximum) of soil and waste in burial ground trenches may be contaminated with plutonium; this contaminated soil and waste may be retrieved in the future for long-term storage. Separation of the sand, silt, and clay components would reduce the volume of soil requiring further treatment and storage if the plutonium is primarily associated with one of these fractions.

A series of simple laboratory experiments involving water-scrubbing and washing was designed to determine the value of such a step in a conceptual process for volume reduction of soil from plutonium waste trenches in the SRP burial ground. By water washing and scrubbing the soil, the clay-silt fraction containing about 95% of the plutonium, but comprising only one-third of the total soil, was separated from the sand fraction that contained about 5% of the plutonium. The concept of simple water washing or scrubbing was also attractive because wet soil would substantially reduce atmospheric resuspension of plutonium particles during exhumation and because the technology of sand cleaning by water is widely used and relatively inexpensive.

Details

A sample of soil removed from a burial ground trench filled with TRU waste in 1964 was used for these tests. A gamma pulse height analysis showed the soil contained 93 nCi of ^{238}Pu per gram of soil; ^{238}Pu was the only significant alpha emitter found.

The mining industry has developed water-based processes for sorting granular materials. Production of sand meeting ASTM specifications involves scrubbing and washing to remove "fines." Because burial ground soil is about two-thirds sand, this simple operation suggested the possibility to reduce the volume of plutonium-contaminated soil to about one-third of the original volume provided the plutonium is associated with the silt and clay fractions of the soil. This method was tested with the equipment shown in Figure 16. The magnetic stirrer provided scrubbing, and the flow rate of the water could be varied to remove different particle sizes. The plastic pipe was attached to the flask to dampen the stirring action before the particles flowed out of the system and to provide a uniform cross section so that the size of particles removed could be more accurately calculated with Stoke's law. The effluent from the system was collected in 150-ml aliquots. To determine the quantity of plutonium removed in each aliquot, 3 ml was removed while the sample was stirred with a magnetic stirrer. The 3-ml aliquot was used for alpha activity measurements.

The plutonium concentration in the effluent decreased exponentially so that the results could be described by the following equation:

$$\frac{C}{C_o} = e^{-bv}$$

where

C_o = concentration in effluent when flow began

C = concentration in effluent after a flow of volume v

b = elution constant, v^{-1}

v = volume of flow

The data from each test was fitted to a straight line by the least squares method. The results are presented as straight lines calculated with $C_o = 1.0$. Various stirring times before flow began and various flow rates were compared to determine their influence upon the removal of plutonium and the residue of plutonium in the washed sand.

A comparison of ^{238}Pu removal at various flow rates is summarized in Figure 17. In these tests, the soil sample was placed in the flask, and 50 ml of water was added. The total volume of wash water was 1500 ml. Scrubbing time before washing was 10 min. With increasing flow, the rate of plutonium removal increased. As shown in Table 4, the plutonium removed in the clay-silt fraction increased as the flow rate increased. Also, the increased flow rate leaves a smaller amount of washed sand.

The effect of prewash scrubbing times on washing of ^{238}Pu is summarized in Figure 18. The flow rate in these tests was 569 ml/min, and the total flow was 1500 ml. Scrubbing continued throughout the elution of fines. The elution rate of fines increased considerably with scrubbing times of 5 to 20 min before

washing. The test was repeated 4 times with a 10-min scrubbing time to determine the variation between samples. These results are shown by the dashed lines. The variation is so great that little would be gained by continued study in the laboratory because scrubbing times using one type of equipment are not comparable with scrubbing times using another type of equipment. The amount of scrubbing required can best be determined using full-scale equipment because it will be different for each type of experiment. However, these data do indicate that no reasonable amount of scrubbing will remove all of the plutonium from the sand. Other data from these tests are summarized in Table 5 which again shows that in this particular experiment, scrubbing beyond 10 min does not improve the removal of plutonium in the clay-silt fraction.

To determine if additional washing would be worthwhile, two tests were made in which the total flow was 3000 ml, or double the volume used previously. The scrubbing time before washing was 10 min, and the flow rate was 569 ml/min. However, the extended washing had no effect on the elution constant. The washed sand was 60 and 63% of the total soil, and 97.3% of the plutonium was removed in the fines in both tests.

During the course of the scrub tests, there were indications that the ^{238}Pu was present in the soil as tiny particles. This was verified by radioautographs. For the radioautographs, a suspension of fines washed from the burial ground soil during the

scrubbing and washing test was deposited on a steel disk, dried, and coated with collodian. The results of an 8-day exposure to x-ray film is shown in Figure 19. Sample 1 contained 2800 pCi, and Sample 2 contained 950 pCi.

Commercial scrubbers are expected to decontaminate the sand much more effectively than the laboratory apparatus, and commercial classifiers can remove any specified range of particle sizes.

Little water would be needed because it can be recirculated. The clay-silt did not peptize but settled rapidly. After standing overnight, the alpha activity of the wash water was only 0.5 pCi/ml. Eventually the recycled water will become turbid and must then be purified or discarded. Filtration should provide adequate purification. This phase of the study can probably not be evaluated in the laboratory but could be performed with pilot scale or production equipment using clean soil.

The method should be applicable to any soil containing a large fraction of quartz sand regardless of the method of contamination with plutonium.

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MOVEMENT OF ORGANICALLY BOUND PLUTONIUM IN SOIL - E. L. Wilhite

Introduction and Summary

At SRP, irradiated fuel elements are chemically reprocessed by the Purex process. This process uses tri-n-butyl phosphate (TBP) dissolved in a hydrocarbon diluent in the solvent extraction step for separation and purification of plutonium and uranium. During the process, the TBP-hydrocarbon solution is attacked and degraded by reagents used in the process and by radiation from fission products. Degradation products are removed by washing during processing, but eventually some species accumulate that resist removal by washing and adversely affect solvent extraction performance. When the solvent is no longer usable in the process, it is transferred to the burial ground for storage in underground tanks.

The safety of SRP burial ground operations is being reviewed. As a part of the safety analysis, the consequences of a massive leak of stored spent process solvent from the underground tanks at the burial ground were evaluated. A laboratory study was completed to determine the movement of organically bound plutonium in soil as part of an evaluation of the environmental risk of storing contaminated solvent in underground tanks at the burial ground. The maximum credible release of stored solvent was defined as the release of the entire contents of Solvent Storage Tank 2. This tank contains 27 Ci of plutonium (88% ^{238}Pu) in 8025 gal of solvent, the largest amount of plutonium in any tank.

Details

Spent Solvent Storage

Spent solvent has been stored at the burial ground since 1955. The burial ground is situated between the two chemical reprocessing areas (Figure 20). The solvent storage tanks are situated roughly at the center of the burial ground about 0.7 mi from the nearest surface stream (Four Mile Creek). There are currently 22 solvent storage tanks, two of which (Tanks 8 and 17) are no longer in service due to past leaks. Before 1972, the solvent inventory was reduced by burning.[1] Burning resulted in very low emission of airborne radioactivity but did release copious quantities of black smoke. Burning operations ceased in 1972 due to environmental restrictions on smoke emissions. During 16 years of solvent incineration, about 370,000 gal of spent solvent was burned.

The current inventory of solvent is shown in Table 6. The 150,000 gal of solvent contains 45.6 Ci of TRU nuclides and about 46.2 Ci of fission products. ^{238}Pu is the predominant TRU nuclide in the solvent, and the primary fission product is ^{106}Ru.

Solvent-Soil Plutonium Transfer

The characteristics of plutonium transfer from spent solvent to soil and ground water were investigated in a series of laboratory tests. The interaction of solvent-bound plutonium and dry soil is shown in Table 7. In this test, 1.0 ml of solvent from Tank 2 [2.1×10^6 alpha dis/(min)/(ml)] was sorbed on dry soil and placed

at the top of each of two columns of soil. The columns were then eluted by down-flow with ground water. After two months of operation, the columns were dismantled, and the soil was sectioned into 0.1-in. segments for analysis. During the course of the experiment, no plutonium was detected in the effluent from the columns. In each column, little movement of the plutonium was noted (~95% retained in the top 1/2 in.). K_d* is estimated at 6000 for the short column and 3000 for the long column. Earlier studies[2] at SRL have shown that K_d for plutonium is on the order of 1000 to 8000 for a pH range of 5.5 to 7.0.

The sorption of solvent-bound plutonium in moist soil is shown in Figure 21. In this test, Tank 18 solvent was passed through a previously water-saturated soil column (25-ml bed volume). The effluent was analyzed for plutonium. Although there is some scatter in the data, the results clearly show little retention of plutonium on wet soil. Plutonium K_d for this test is estimated to be less than 10.

In other tests (Table 8), ground water was equilibrated with solvent from Tanks 2 and 20 to determine the transfer of plutonium from solvent to water. The distribution coefficients** were 0.001 to 0.01. The degree of absorption by soil of plutonium transferred to water from Tank 2 solvent was found to be moderate (K_d = 150 ±60).

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* K_d = sorbed Pu (per gram soil)/unsorbed Pu (per ml of equilibrated water)

** Distribution coefficient - Pu in water (dis/min/ml)/Pu in equilibrated solvent (dis/min/ml).

The laboratory tests show that solvent released to moist, subsurface soil will not be effectively sorbed, and plutonium will be mobile. Thus, in the event of a leak in one of the underground tanks, solvent may migrate to the water table with little loss of plutonium to the soil. At the water table, the solvent will tend to spread as a thin film over the soil water surface. The rate and extent of this spreading action have not been defined. However, laboratory tests verify that solvent-bound plutonium will transfer to soil water with subsequent transfer of plutonium to soil. Thus, the amount of plutonium remaining in solvent after spreading on water is estimated as outlined in Figure 22.

The calculated distribution of plutonium between solvent and soil is shown in Table 9. The area of solvent spreading was estimated by assuming plutonium interaction with a 2-in. depth of water-saturated soil (bulk density = 1.5 g/cm^3). The fraction of plutonium remaining in the solvent was calculated iteratively to account for plutonium transfer to soil as solvent spreading occurs.

Although solvent released to the subsurface water table may spread to a considerable extent, plutonium will be removed from the solvent and become fixed on the soil as a result of interaction with soil water. In spreading over about three acres of water table, approximately 96% of the plutonium originally in the solvent will have become fixed on the soil; after spreading to

thirty acres, greater than 99% of the plutonium will have been sorbed.

The maximum amount of plutonium that could be released from a leaking tank is the 27 Ci contained in Tank 2. If the entire quantity of solvent in Tank 2 were to leak from the tank, about 30 acres of soil at the water table would be contaminated with plutonium at an average concentration of about 2600 pCi/g. The maximum soil concentration would be approximately 9×10^4 pCi/g over 0.3 acre. A proposed interim standard for plutonium in soil is 400 pCi/g for inhabited areas.[3] The maximum concentration of plutonium in soil water over a 0.3-acre extent would be 6×10^5 pCi/l. Soil water over a 30-acre extent would contain an average plutonium concentration of 17,600 pCi/l. The current ERDA standard for plutonium in water is 5000 pCi/l for an uncontrolled area.[4]

Plutonium sorbed on soil as a result of the postulated solvent tank leak would move slowly through the soil-water system. At least 50,000 years would be required for the plutonium to reach Four Mile Creek. During this time, almost all of the ^{238}Pu will decay, leaving only about 0.8 Ci of ^{239}Pu. Extrapolated concentrations of ^{239}Pu in water would be approximately 500 pCi/l at the ground water outcrop and less than 1 pCi/l after dilution in Four Mile Creek.

Conclusion

In summary, although a postulated massive leak of solvent would result in soil and ground water being contaminated with plutonium, most of the plutonium (~90% ^{238}Pu) will decay within the SRP boundaries. Any transport of plutonium to local surface streams will result in releases below the present operating guides for normal SRP operation.

To minimize the probability of the release of large volumes of waste solvent to the subsurface environment, six new storage tanks with liquid level monitors and leak detectors have recently been installed at SRP. Stored solvent will be transferred to the new tanks early in 1976. After removal of solvent, the old tanks will be abandoned in place. To reduce the solvent inventory, a two-stage solvent incinerator equipped with an exhaust gas scrubber is being designed. The incinerator will process the current inventory in less than two years of operation. With expected waste solvent receipts of less than 5000 gal/year, storage inventory will be minimal after incineration of the present inventory.

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TABLE 1

Contribution of Individual Surfaces to Residual ^{239}Pu[a] in Exhumed Purex Feed Adjustment Tank

Vessel Surface	*Area, ft^2*	*Total ^{239}Pu on Surface, dis/min*	*% of Total ^{239}Pu on Vessel*
Wall, inside	201	7.0×10^7	7.4
Wall, outside	201	4.0×10^7	4.2
Bottom, inside	50	1.1×10^7	1.2
Bottom, outside	50	3.8×10^7	4.0
Top, inside	43	5.4×10^6	0.6
Top, outside	56	5.2×10^8	54.7
Top flange	5.5	9.6×10^6	1.0
Annular opening	7.1	3.3×10^6	0.3
Coils	307	6.1×10^7	6.4
Trunion guides and supports	11	1.9×10^8	20.0

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a. Total = 9.5×10^8 dis/min
Total ^{239}Pu = 7.0 mg
Total ^{239}Pu = 4.3×10^5 nCi

TABLE 2

^{239}Pu Contamination in Exhumed Purex Feed Adjustment Tank, on Weight Basis

Total Empty Weight	7300 lb
Weight of Coils	1820
Total Weight	9120

or 4.14×10^6 g

$$nCi/g = \frac{4.30 \times 10^5 \text{ nCi}}{4.14 \times 10^6 \text{ g}} = 0.1 \text{ nCi/g}$$

TABLE 3

^{239}Pu in Soil and Water Contained in Exhumed Purex Feed Adjustment Tank

SOIL (and interstitial water)

Layer Depth	*^{239}Pu, pCi/g*	*^{239}Pu in Layer, pCi*
0 - 1'	0.529	7.09×10^5
1' - 2'	0.072	9.65×10^4
2' - 3'	0.110	1.47×10^5
3' - 4'	0.094	1.26×10^5
4' - 4'10"	0.229	2.56×10^5
4'10" - 5'9"	0.667	8.20×10^5
5'9" - 5'10"	4.963	2.53×10^6

TOTAL = 4.68×10^6 pCi

= 1.04×10^7 dis/min

= 0.076 mg

WATER

Emptied from vessel = 356 gal or 1.35×10^6 ml

Analysis of composite sample = <1 dis/min/ml ^{239}Pu

Total ^{239}Pu in water = $\leq 1.35 \times 10^6$ dis/min

= <0.01 mg

TABLE 4

Effects of Wash Flow on Soil Classification

Scrubbed 10 min before washing; wash volume 1500 ml

Wash Flow, ml/min	*Washed Sand, % of soil*	*Largest Particle Eluted, μm*	*Plutonium in Clay-Silt Fraction, % of initial*
71	88	38	29.9
217	82	66	88.4
569	76	110	96.3

TABLE 5

Effects of Pre-Wash Scrubbing on Soil Classification

Wash flow 560 ml/min; wash volume 1500 ml

Pre-Wash Scrubbing Time, min	*Washed Sand, % of soil*	*Plutonium in Clay-Silt Fraction, % of initial*
0	81	79.6
5	69	93.3
10	76	96.3
10	64	97.1
20	62	95.6

TABLE 6

Solvent Inventory

Tank	*Solvent Volume, gal*	*TRU Content, Ci*	*Major TRU Nuclide (alpha percent)*	*Fission Product Content, Ci*
1	6,100	0.5	^{244}Cm (66%)	3.5
2	8,025	27.0	^{238}Pu (88%)	5.2
3	8,400	0.02	^{238}Pu (70%)	0.013
4	275	0.006	^{238}Pu (67%)	0.001
5	9,780	17.0	^{244}Cm (93%)	11.0
6	19,350	0.06	^{244}Cm (80%)	0.26
7	2,075	0.01	^{238}Pu (77%)	0.014
8[a]	Contains no liquid			
9	4,135	0.006	^{239}Pu (30%)	2.0
10	1,365	0.003	^{238}Pu (50%)	0.05
11	6,190	0.2	^{244}Cm (56%)	0.6
12	5,025	0.15	^{238}Pu (63%)	0.5
13	11,500	0.08	^{238}Pu (97%)	0.2
14	22,700	0.15	^{238}Pu (98%)	0.15
15	7,550	0.18	^{244}Cm (63%)	1.4
16	2,000	0.003	-	0.0007
17[a]	100	0.013	^{239}Pu (60%)	0.29
18	965	0.007	^{239}Pu (30%)	3.5
19	19,500	0.1	^{244}Cm (65%)	2.6
20	7,900	0.06	^{238}Pu (60%)	15.0
21	3,100	0.001	-	0.013
22	2,900	0.0008	^{244}Cm (70%)	0.004
Total	148,935	45.6	^{238}Pu (54%)	46.2

a. Tank no longer in service due to past leak.

TABLE 7

Columns Treated with 1.0 ml Tank 2 Solvent
(2.1×10^6 dis/min/ml)
Sorbed on Dry Soil

Column Length, in.	*Effluent Collected*	
	Liters	*Bed Volumes*
2.6	48.5	1450
5.8	24.5	330

Movement Down Column, in.	*Gross Alpha in 0.1 in. soil, dis/min*	
	2.6 in. Column	*5.8 in. Column*
0.1	6.2×10^5	-
0.2	2.4×10^5	4.1×10^5
0.4	1.1×10^5	2.1×10^5
0.5	1.7×10^5	2.8×10^5
0.6	2.1×10^4	1.3×10^4
0.8	5.2×10^3	8.4×10^3
0.9	2.6×10^3	1.1×10^4
1.0	3.0×10^3	3.4×10^3
1.1	-	1.2×10^3
1.2	-	<10
1.4	-	<10
1.5	-	<10
1.6	-	<10

TABLE 8

Transfer of Plutonium from Solvent to Water

Solvent Sample	*Distribution Coefficient*
Tank 2	0.001 ±0.0005
Tank 20	0.01 ±0.01

Retention of Plutonium (transferred from Solvent to Water) by Soil

Solvent Sample	K_d
Tank 2	150 ±60

TABLE 9

Calculated Distribution of Plutonium Between Solvent and Soil[a]

Soil Mass, g	*Area, acres*	*Fraction of Plutonium Remaining in Solvent*	*Fraction of Plutonium Remaining in Soil*
1×10^5	0.0003	0.9975	0.0025
1×10^7	0.03	0.802	0.198
1×10^9	3.0	0.039	0.961
1×10^{10}	30.0	0.004	0.996

a. See Figure 22.

TABLE 10

Consequences of Postulated Leaking Tank
(Release of 27 Ci of plutonium in 8025 gal of solvent)

Distribution of Plutonium Released to the Environment

Average soil concentration:	2600 pCi/g over 30 acres
Maximum soil concentration:	9×10^4 pCi/g over 0.3 acre
Average water concentration:	17,600 pCi/ℓ
Maximum water concentration:	6×10^5 pCi/ℓ
Long-term release of ^{239}Pu:	500 pCi/ℓ at ground water outcrop <1 pCi/ℓ in Four Mile Creek

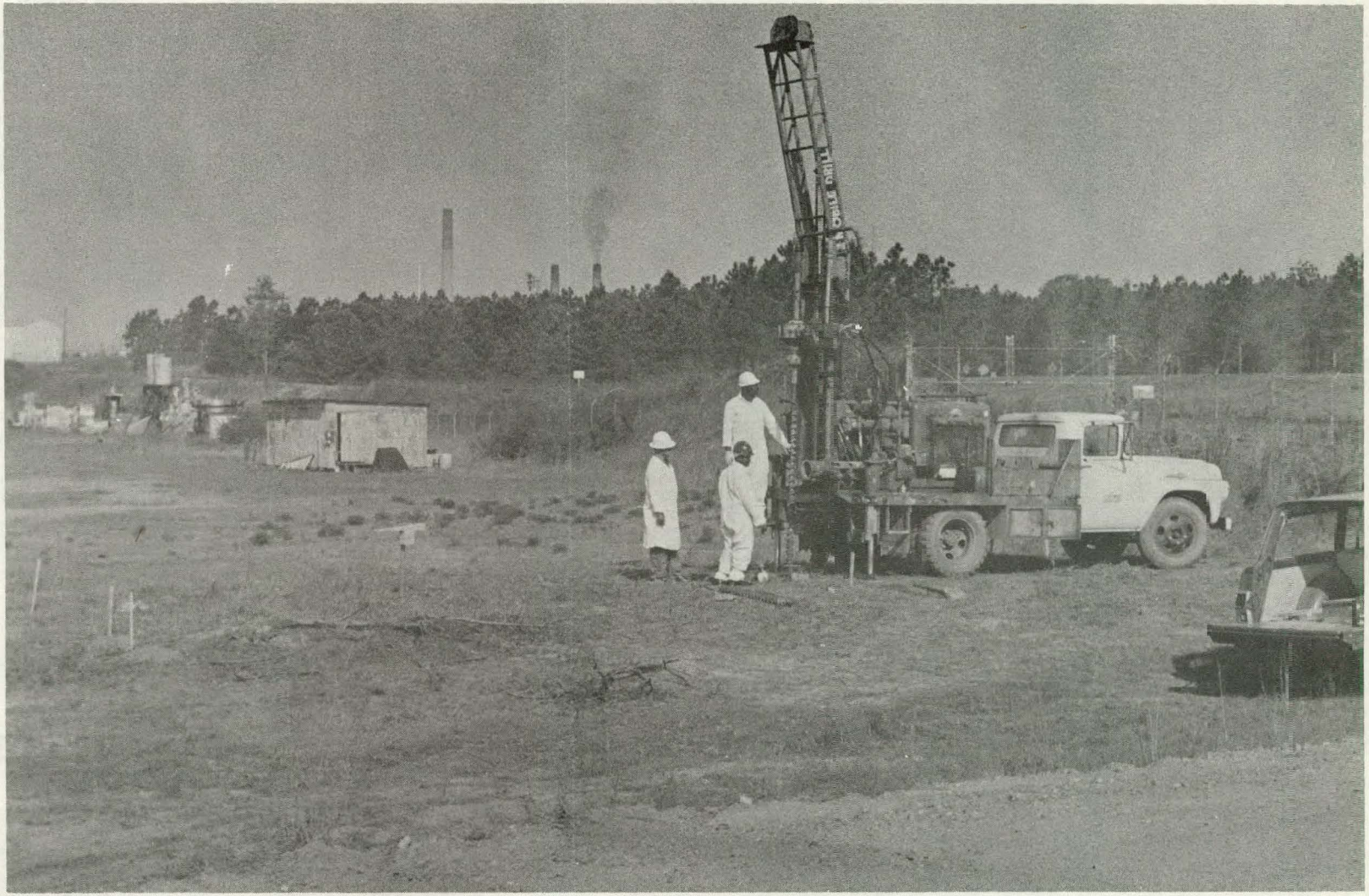


FIGURE 1. Drill Probing for Buried Process Vessel

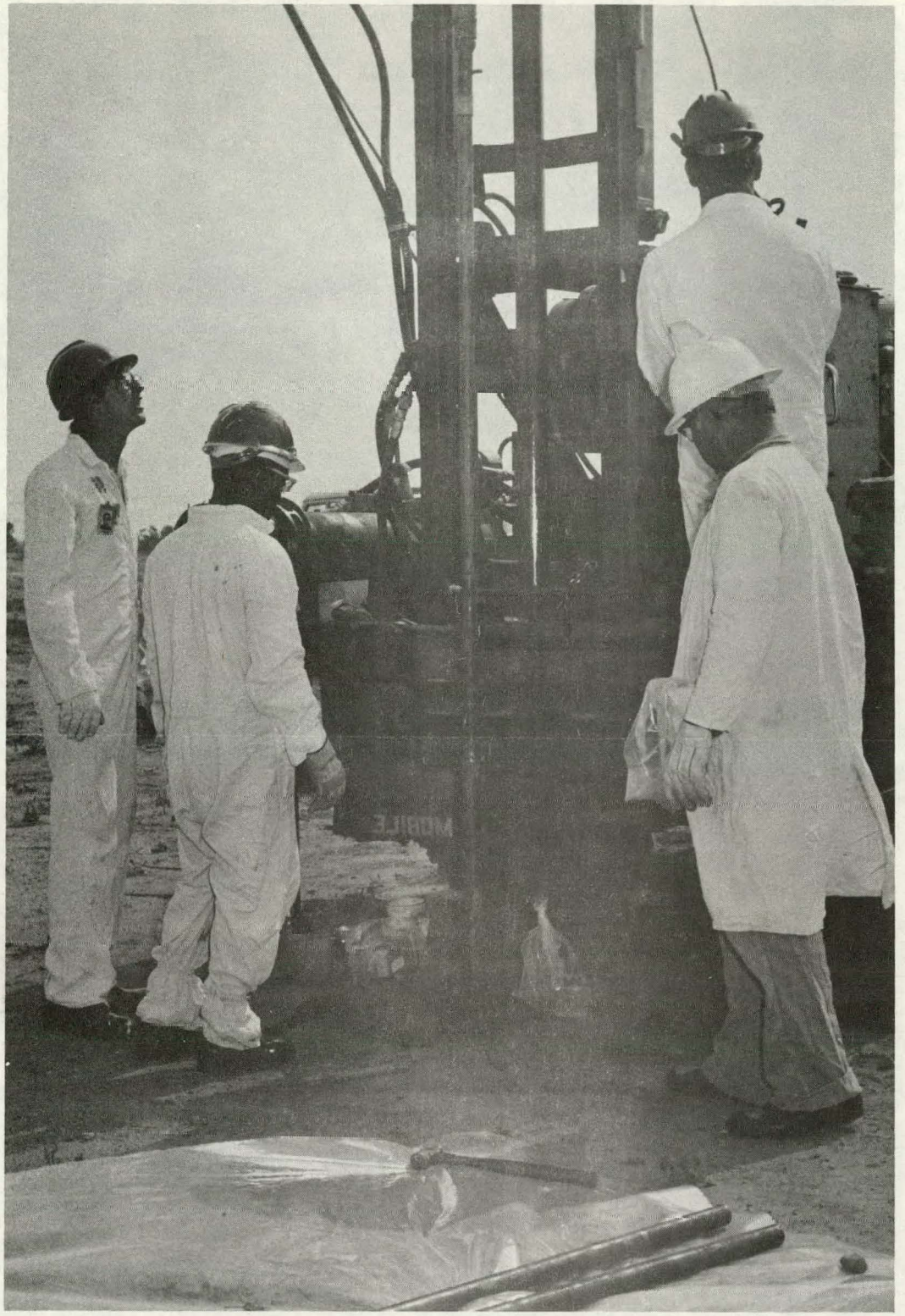


FIGURE 2. Core Sampling Soil Surrounding Buried Process Vessel

FIGURE 3. First Portion of Buried Vessel to be Uncovered. Dead Root Immediately Adjacent to Vessel.

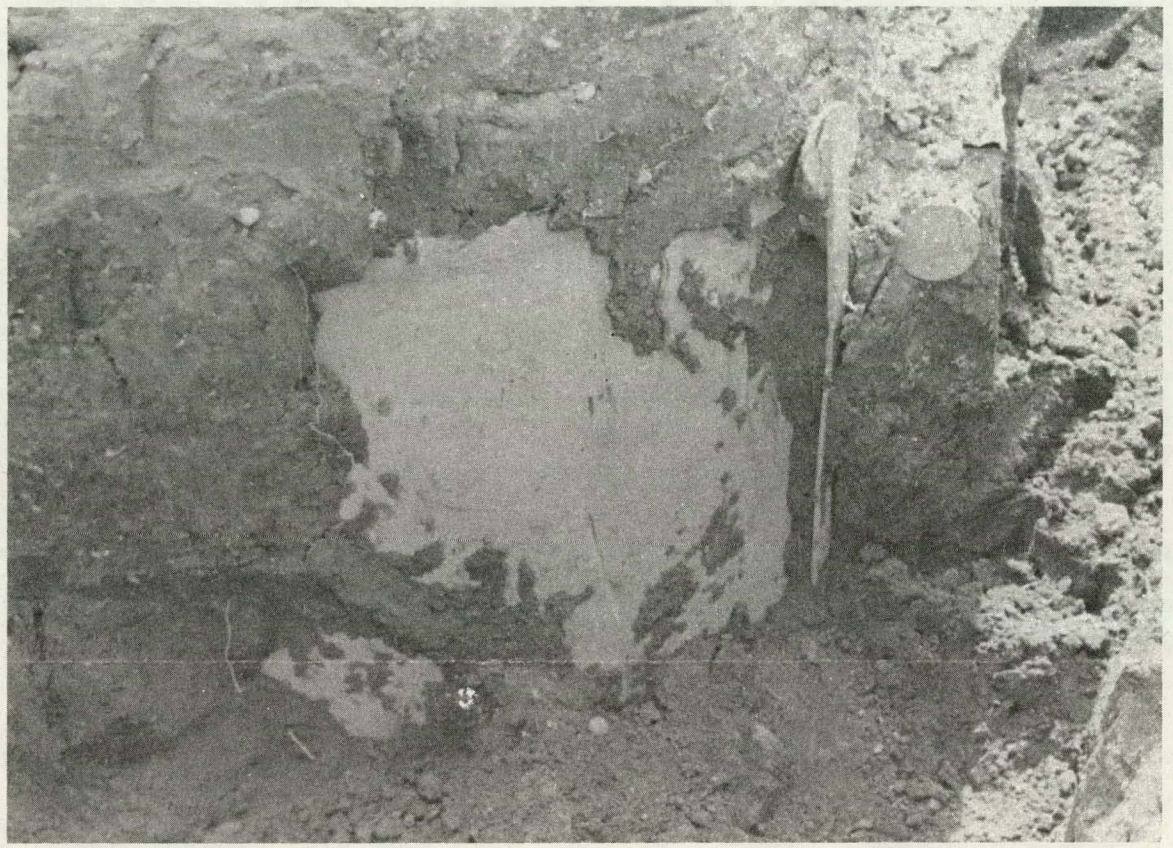


FIGURE 4. Wall of Exhumed Purex Feed Adjustment Tank Showing Serial Number

FIGURE 5. Buried Purex Feed Adjustment Tank Filled With Soil and Water

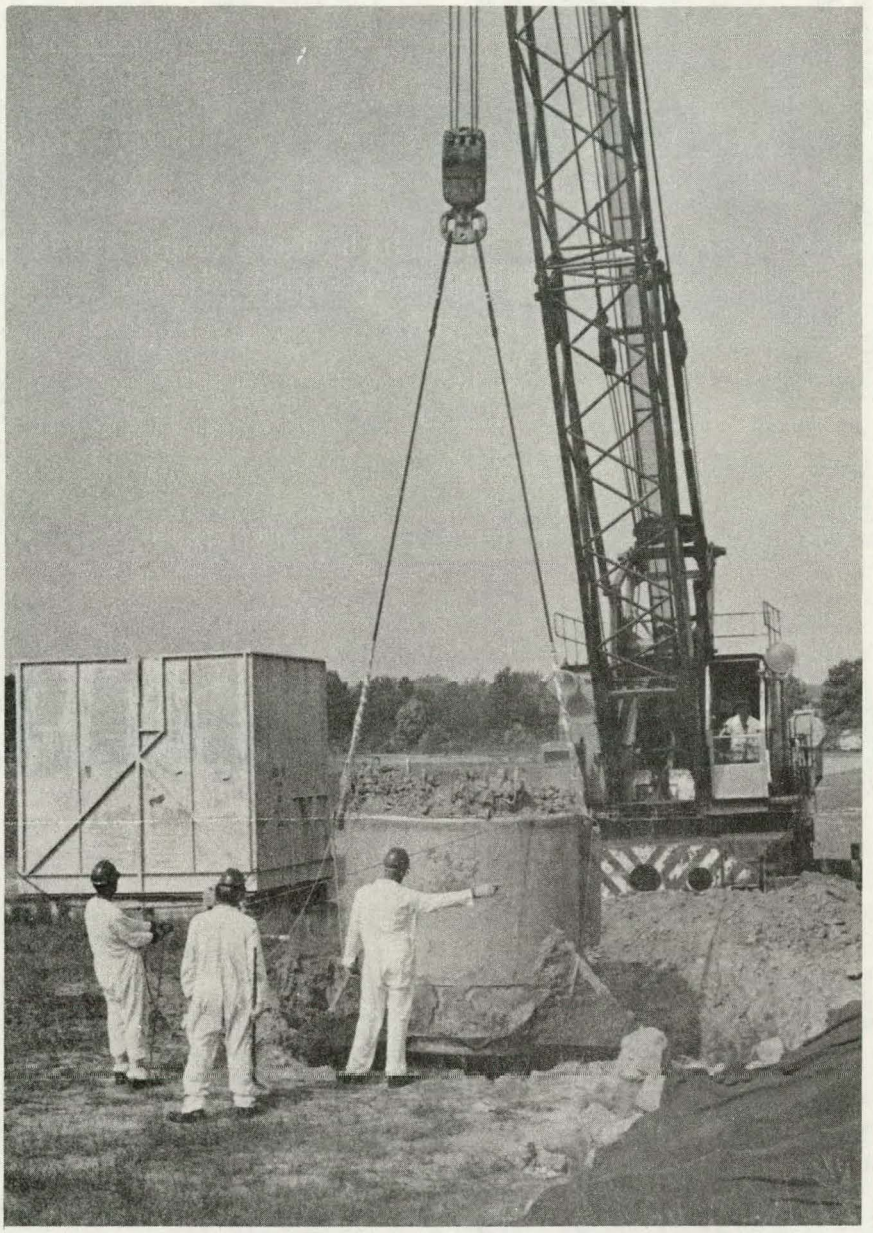


FIGURE 6. Purex Feed Adjustment Tank Being Lifted from Emplacement and Placed in Transport Box

FIGURE 7. Washing Exterior of Exhumed Purex Feed Adjustment Tank

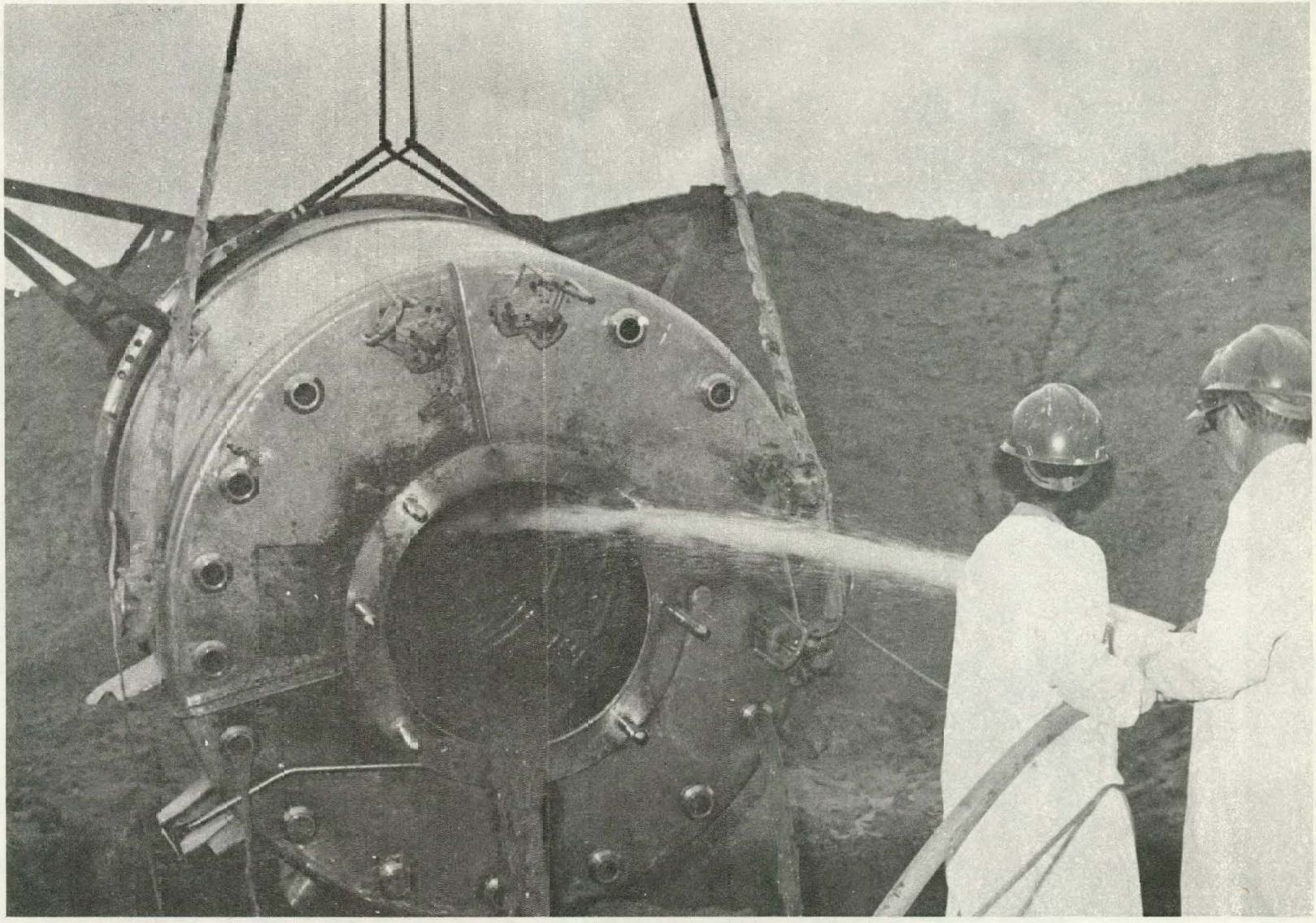


FIGURE 8. Washing Interior of Exhumed Purex Feed Adjustment Tank

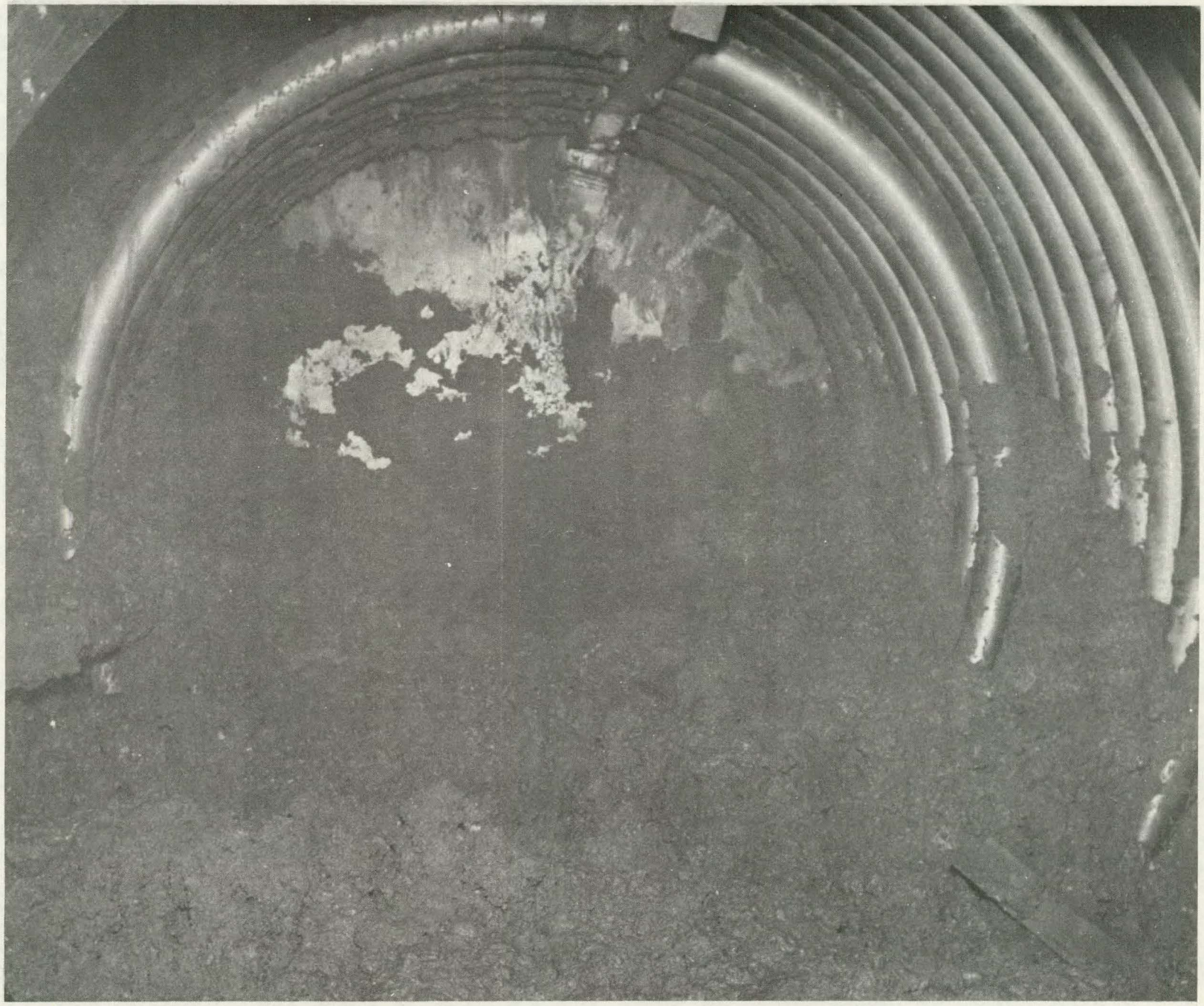


FIGURE 9. Interior of Exhumed Purex Feed Adjustment Tank

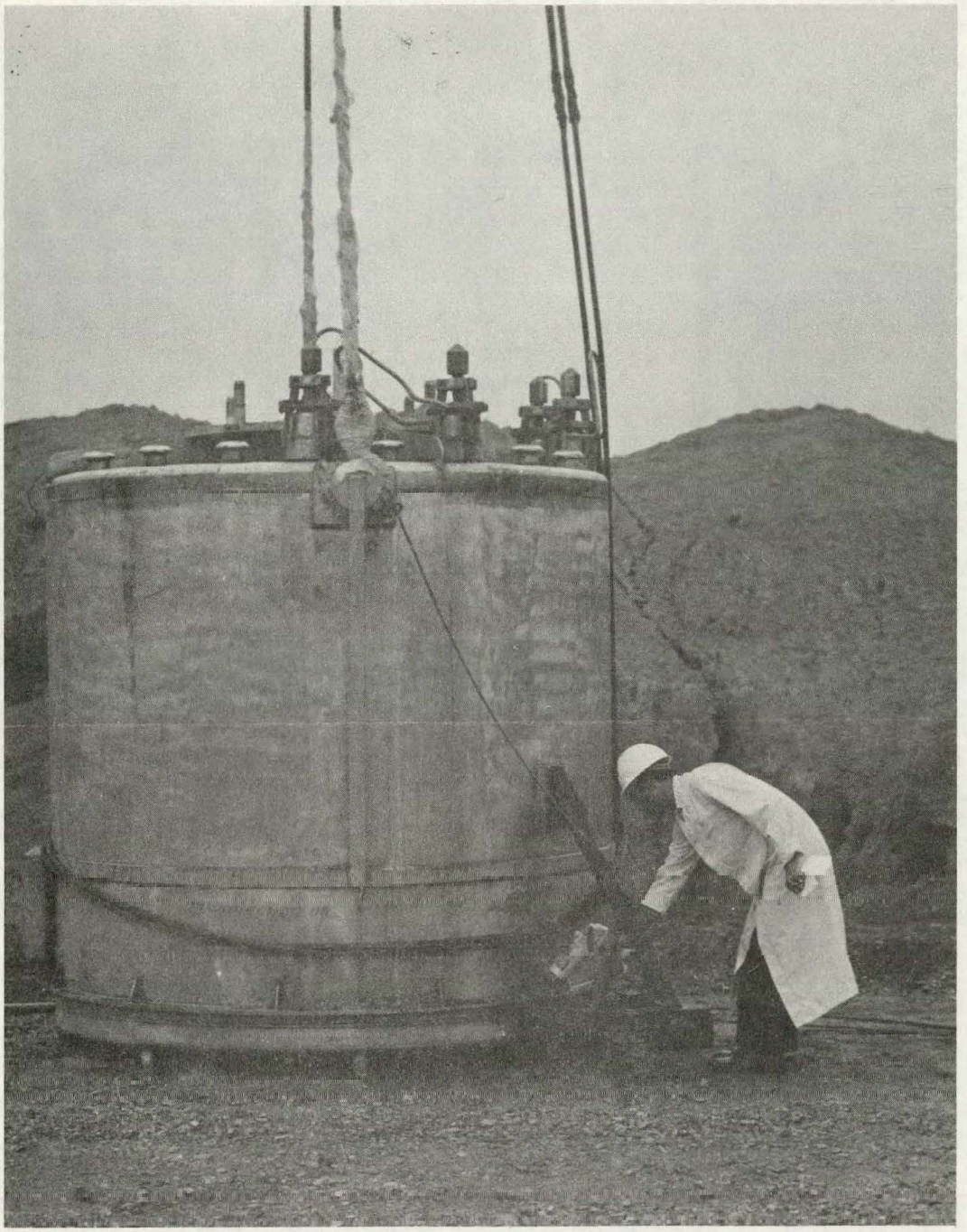


FIGURE 10. Beta-Gamma (Cutie Pie) Survey of Exhumed Purex Feed Adjustment Tank After Tank Was Washed

FIGURE 11. Alpha Activity Survey of Interior of Exhumed Purex Feed Adjustment Tank After Mud Removal

FIGURE 12. Gamma Pulse Height Analysis of Exhumed, Cleaned Purex Feed Adjustment Tank

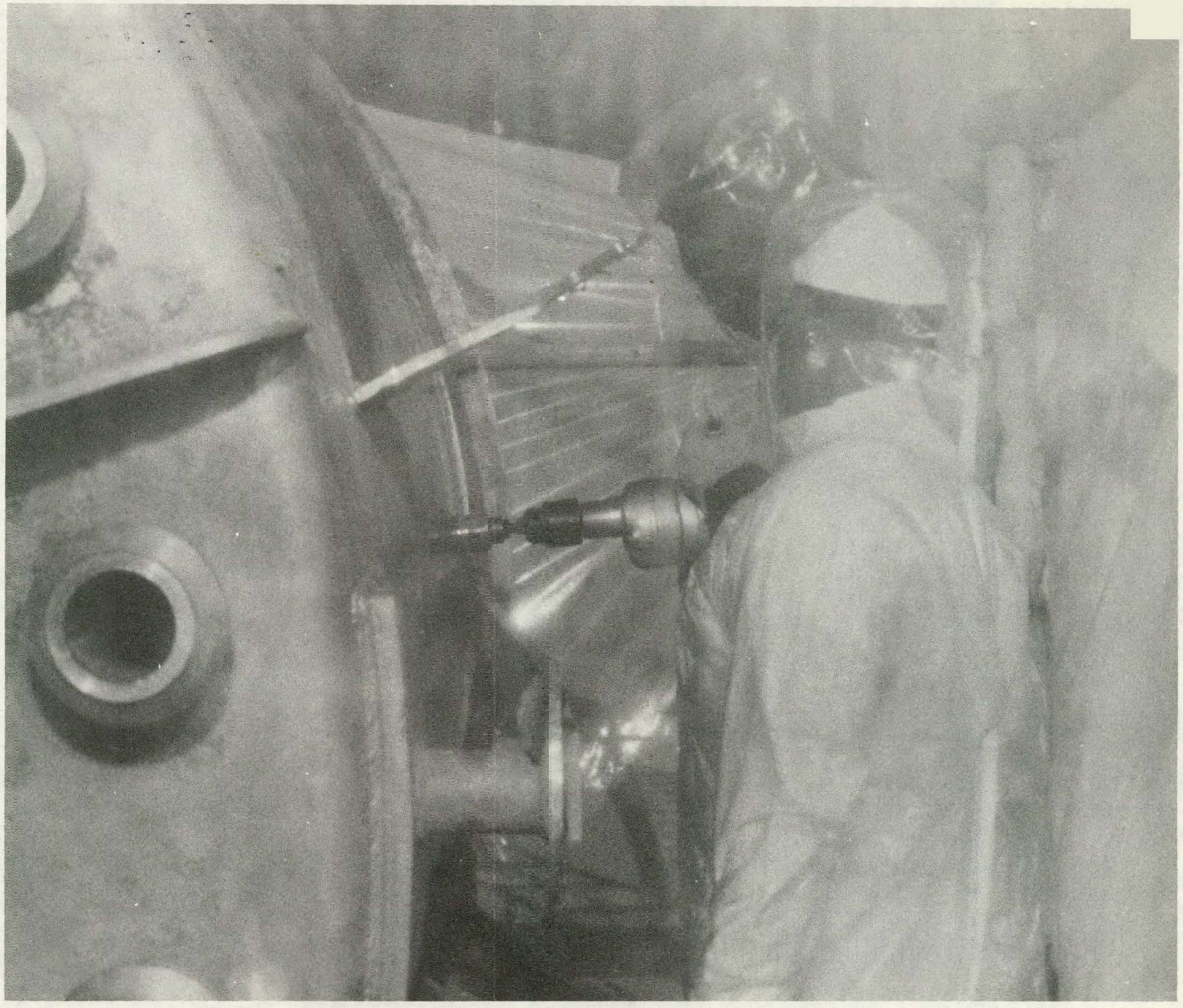


FIGURE 13. Cutting Sample Coupons from Exhumed Purex Feed Adjustment Tank

FIGURE 14. Excavation cf Lysimeter Pit

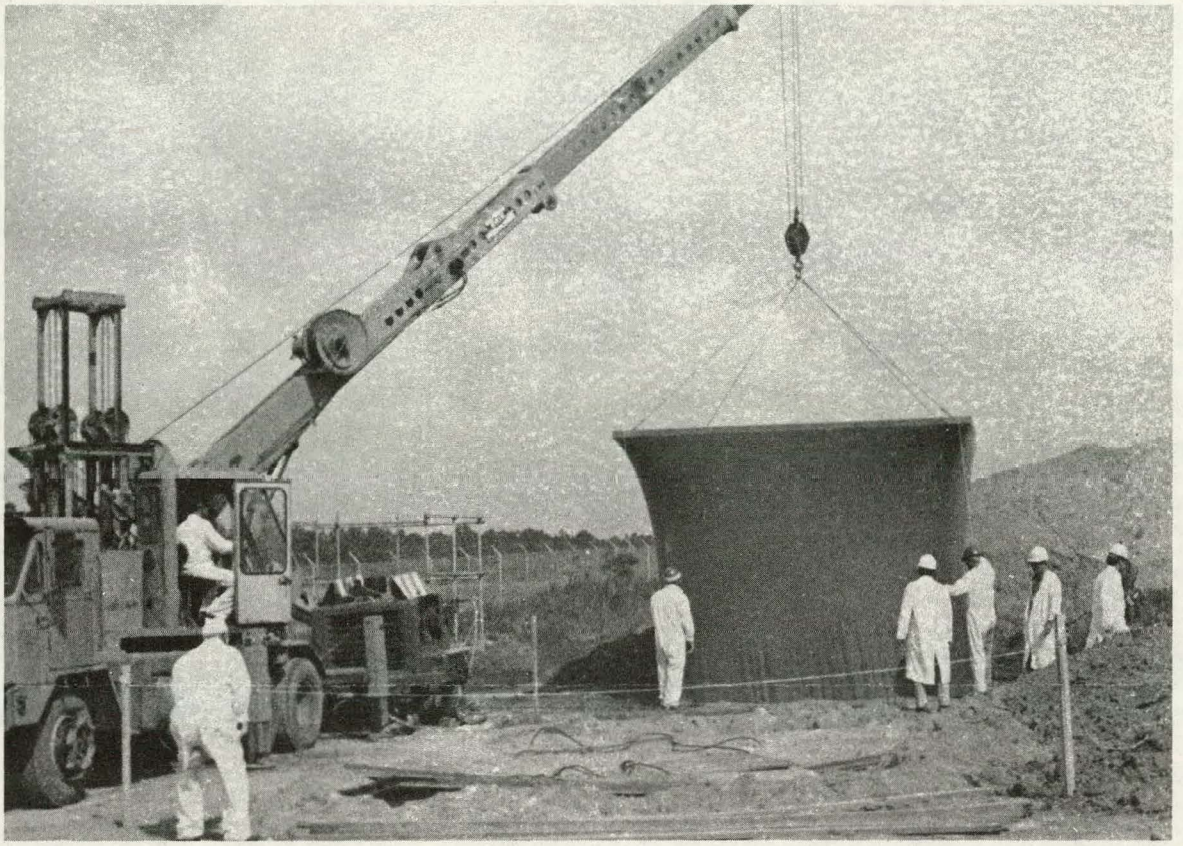


FIGURE 15. Installing Lysimeter Liner
(20-mil-thick polyvinyl chloride)

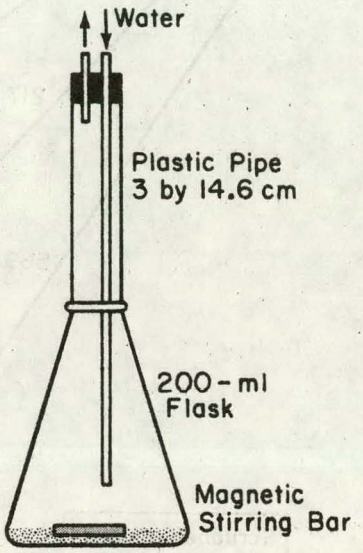


FIGURE 16. Laboratory Equipment for Scrubbing and Washing Soil

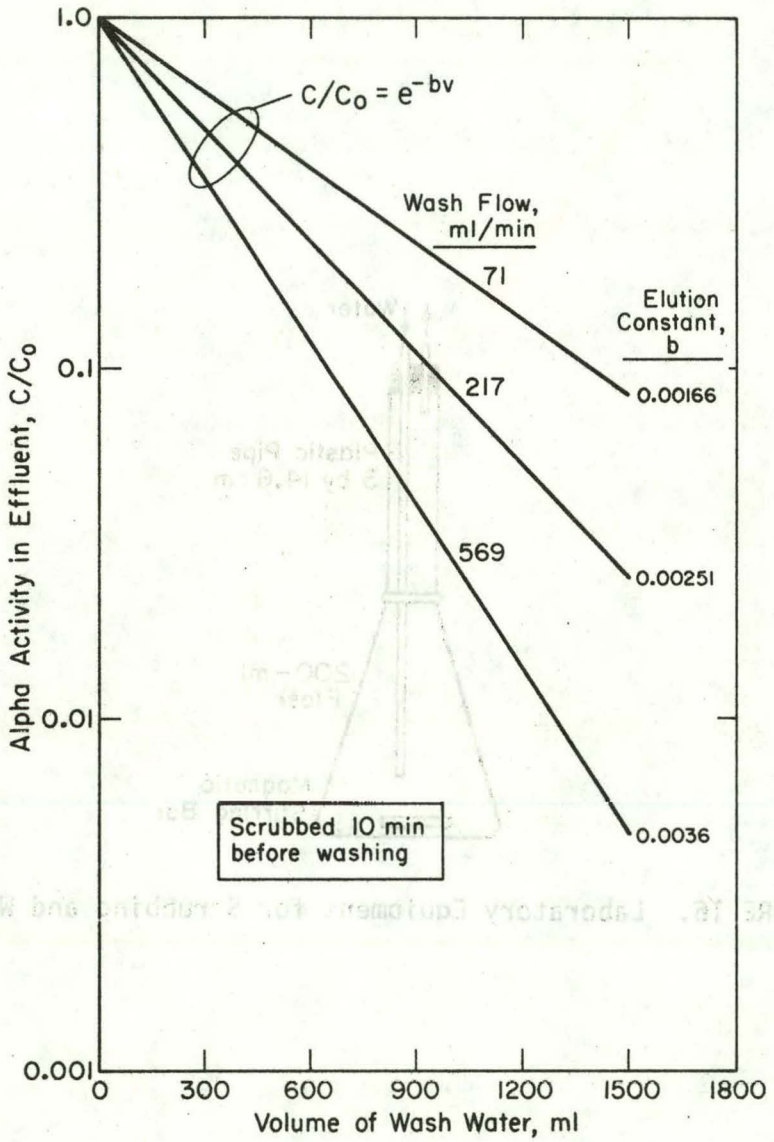


FIGURE 17. Removal of ^{238}Pu from Burial Ground Soil by Scrubbing and Washing at Various Flows

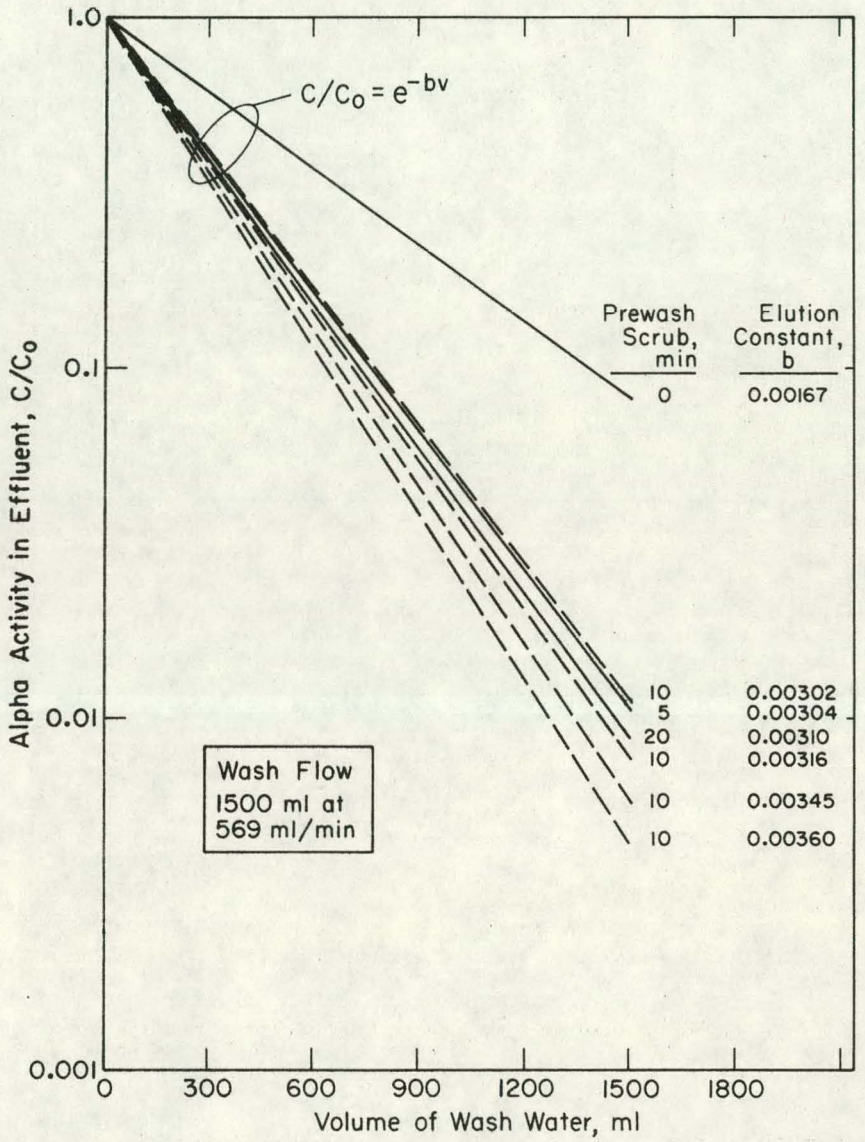


FIGURE 18. Effect of Prewash Scrubbing Time on Washing of ^{238}Pu from Burial Ground Soil

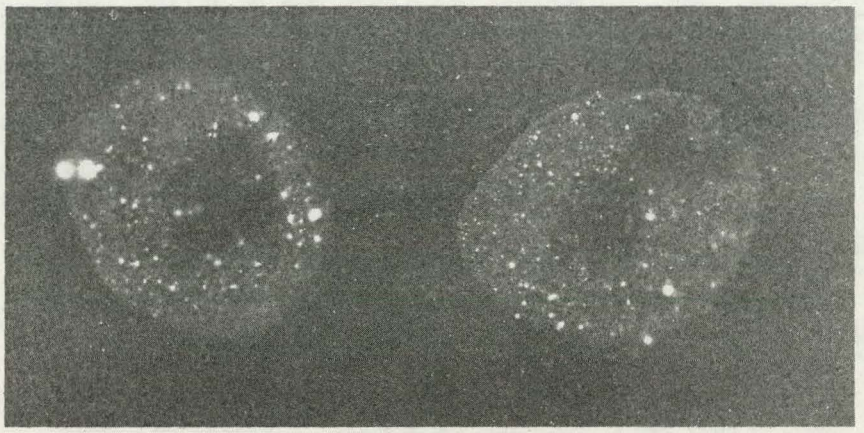


FIGURE 19. Autoradiograph of Clay-Silt from Burial Ground Soil

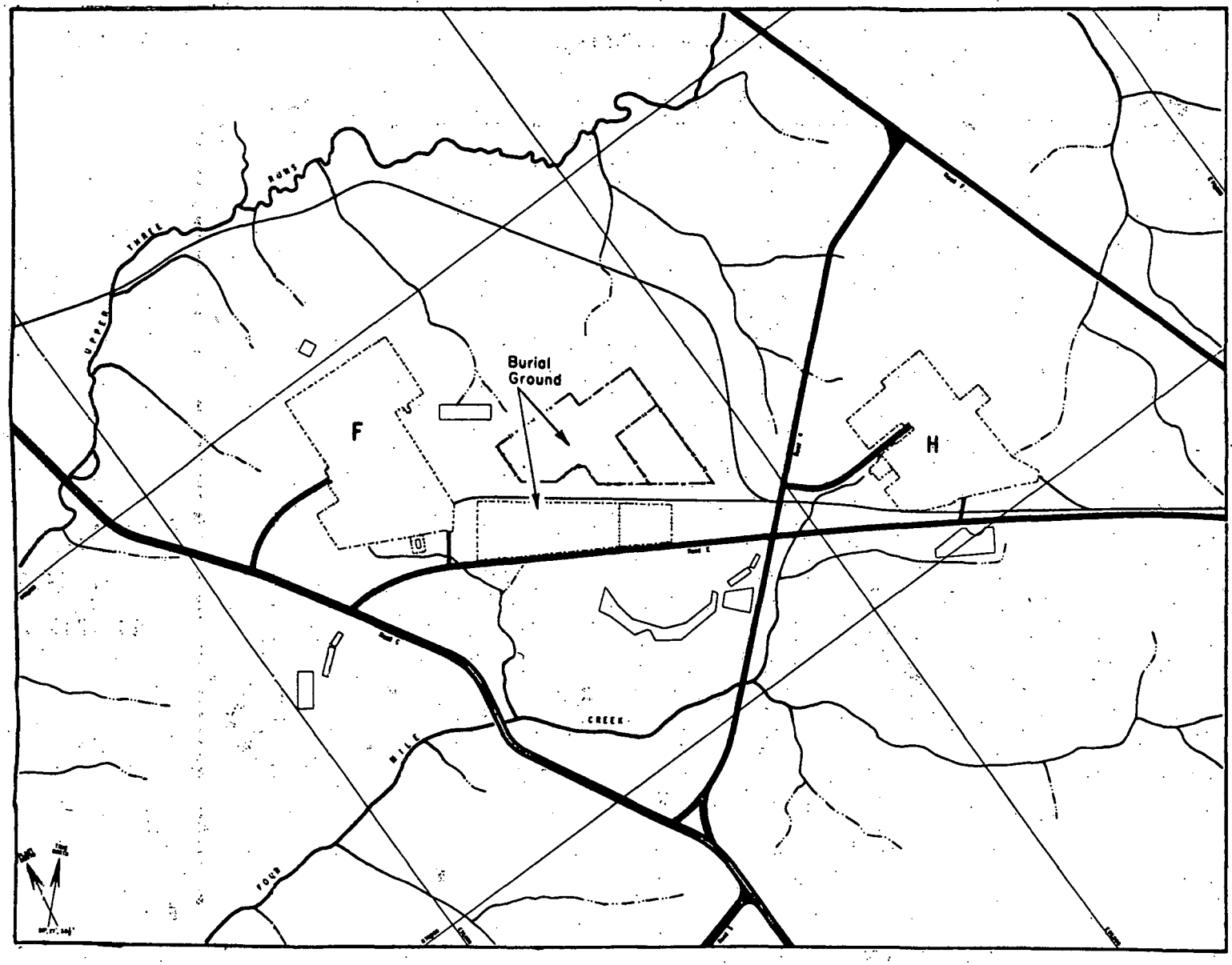


FIGURE 20. Chemical Separations Areas - Savannah River Plant

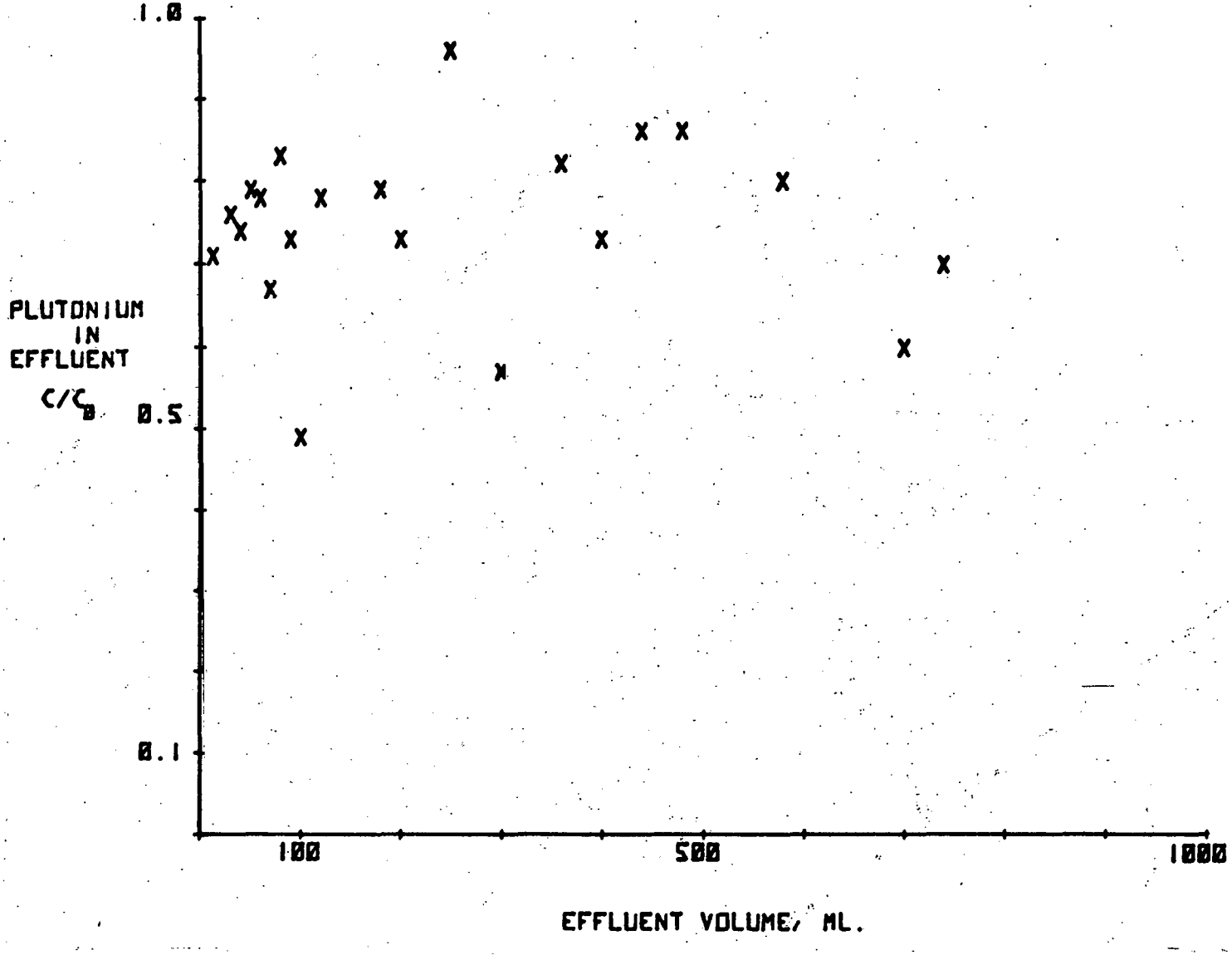
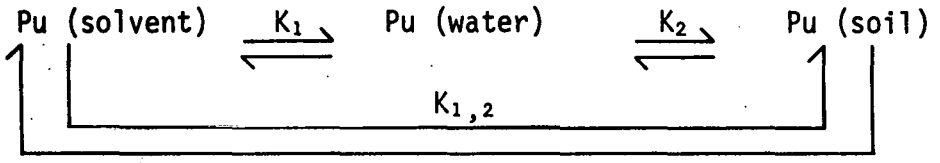


FIGURE 21. Column Test with Tank 18 Solvent and Water-Saturated Soil



K_1 = distribution coefficient

K_2 = K_d

$K_{1,2} = K_1 \cdot K_2$

$$K_{1,2} = \frac{\text{Pu on soil, pCi/g}}{\text{Pu in solvent, pCi/ml}}$$

$$K_{1,2} = \frac{f_{soil}}{f_{solvent}} \cdot \frac{V_{solvent}}{M_{soil}}$$

where: f_{soil} = fraction of plutonium sorbed on soil

$f_{solvent}$ = fraction of plutonium remaining in solvent

$V_{solvent}$ = volume of solvent, ml

M_{soil} = mass of soil, g

FIGURE 22. Plutonium Transfer from Solvent to Soil