RADIONUCLIDE DISTRIBUTIONS AROUND A LOW-LEVEL RADIOACTIVE WASTE DISPOSAL POND AND DITCH SYSTEM AT THE HANFORD SITE

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ABSTRACT

Chemical reprocessing of spent nuclear fuels at the U.S. Department of Energy (DOE) Hanford Site has generated large volumes of low-level radioactive liquid effluents. The majority of these effluents have been used strictly for cooling or other support functions and have been discharged to ditches and ponds. The 216-U-10 (U) Pond and 216-Z-19 (Z-19) Ditch are two such disposal facilities and were selected as representative examples of the surface liquid disposal facilities used at the Hanford Site. These facilities are components of an integrated system of ditches, ponds, and overflow facilities collectively referred to as the U Pond disposal system. The U Pond system has been used since 1943 and has received a large variety of radioisotopes from several sources.

The long-term use of U Pond and the Z-19 Ditch has resulted in the localized accumulation of transuranic and fission product inventories due to sorption and filtration of particulates onto the uppermost sediments. The various radionuclides have different distributions due to their individual discharge sources and behaviors in this type of a disposal system. Cesium-137 (^{137}Cs) is the most widely distributed radionuclide and was used as an index radionuclide to define the maximum extent of contamination. Its 400 pCi/g isopleth indicates surface contamination of approximately 19 hectares (ha) at U Pond and the 216-U-11 Overflow Basin. This contamination is localized in the top ten centimeters (cm) of soil and decreases rapidly with depth. The Z-19 Ditch and its backfilled predecessors, the 216-Z-11 (Z-11) and 216-Z-1 (Z-1) Ditches, received Plutonium-238/239/240 and Americium-241 (^{241}Am) discharges from the 234-5Z and 231-Z facilities and retained more than 90% of the plutonium inventory discharged to the U Pond system.

Based upon the results of this study, the U Pond system has been found to be an effective waste management facility for disposing of large volumes of low-level liquid wastes.

INTRODUCTION

Rockwell Hanford Operations (Rockwell), under contract to DOE, is responsible for nuclear waste management at the DOE Hanford Site. One area of waste management involves disposal of low-level liquid wastes to the unsaturated sediments. Knowledge of the environmental behavior of these disposal sites is essential for evaluating current disposal practices and future waste management alternatives.

A study was conducted from 1979 to 1980 to delineate the distribution of radionuclides beneath and adjacent to the U Pond disposal system. The general approach of this study was to compile and review all previously existing data, identify significant gaps in the existing data base, and characterize those areas by sampling and analysis.

BACKGROUND

The DOE Hanford Site is located in south-central Washington State (Fig. 1). It was constructed and operated for the production and purification of plutonium under the U.S. Government Manhattan Project during World War II.[1] Operation of the Hanford reprocessing and separation facilities has generated large volumes of low-level liquid effluents. These large volumes precluded the practicability of storing the effluents in tanks and the limited amounts of radioactive elements were insufficient for economical recovery.[2] It was determined that the low-level wastes could be disposed of safely in seepage areas if the wastes were diluted with uncontaminated waste water and monitored in concrete retention basins prior to release.[2] These seepage areas were later transformed into ponds.

ENVIRONMENTAL SETTING

Climatology

The Hanford Site is situated in the rain shadow of the Cascade Mountains. The prevailing direction of storm fronts from the Pacific Ocean eastward over these mountains produces year-round mild temperatures and low precipitation. The average annual precipitataion recorded at the Hanford meteorology station is 16 cm; 42% of that amount falls between November and January.[3] The average annual temperature is 11.7°C. Prevailing winds are from the northwest, while prevailing high winds are from the southwest.

Biology

The Hanford Site is referred to as a shrub-steppe grassland. The area surrounding the reprocessing and separations facilities can be further classified as a sagebrush/cheatgrass community, based on its dominant vegetation. Within this community are several riparian habitats (water), consisting of ditches and ponds, created for the disposal of liquid effluents. These riparian habitats provide food, cover, and shelter for many animals, including waterfowl.

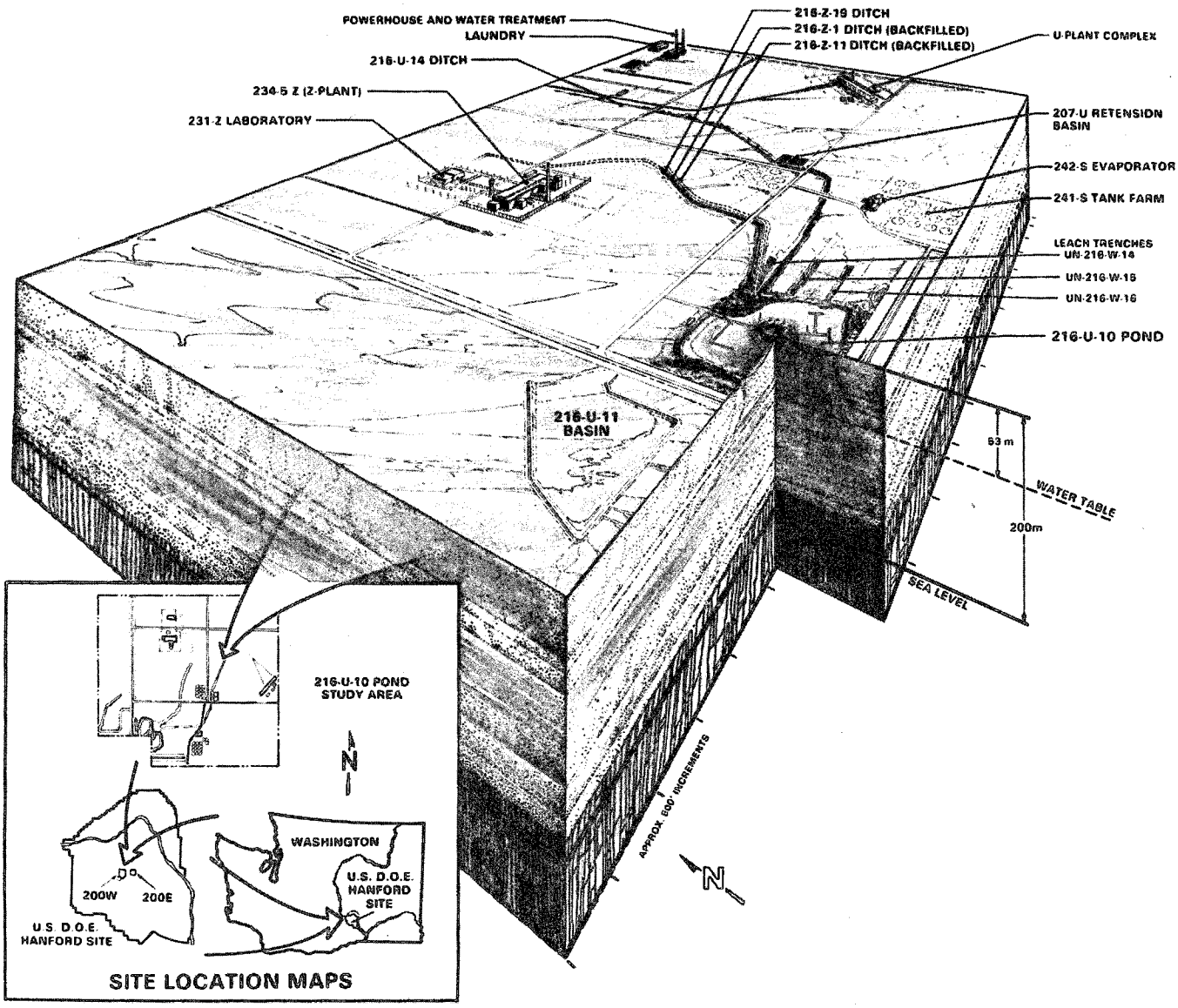

Fig. 1. Location of the U Pond Disposal System and its Various Components.

Geology

The Hanford Site is located near the center of a broad structural and topographic depression, the Pasco Basin, within the intermontane basin of the Columbia Plateau. The major geologic units beneath the Hanford Site are, in general ascending order: basement rocks of undetermined origin, the Columbia River Basalt Group with intercalated sediments of the Ellensburg Formation, the Ringold Formation, early "Palouse" soil, and the Hanford formation. River deposited sediments, landslide debris, and eolian sediments locally veneer the surface.(4)

Radioactive effluents are discharged to the Hanford formation and the surficial eolian deposit immediately overlying it, and thus are the most significant geologic units to the U Pond disposal system (Fig. 2). These sediments, as well as those of the early "Palouse" soil and Ringold Formation effectively isolate and sorb most long-lived radioactive contaminants discharged to the disposal system. Their general horizontal bedding promotes lateral spreading of moisture and retards downward transport of radionuclides.(4)

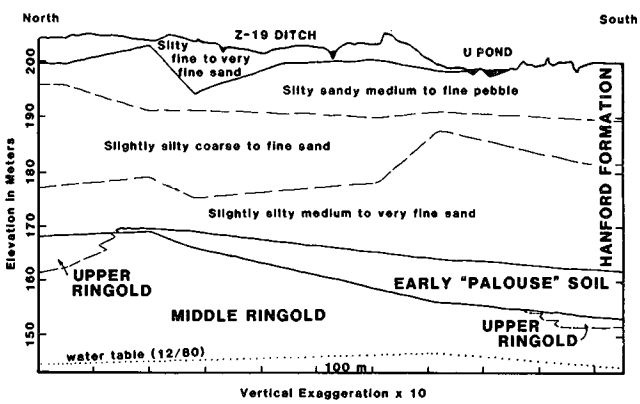

Fig. 2. Geologic Cross Section Beneath the 216-U-10 Pond and 216-Z-19 Ditch.

Hydrology

The Hanford Site lies between two major rivers, the Yakima River to the south and the Columbia River to the north and east. Two ephemeral streams, Cold Creek and Dry Creek, lie along the western margins of the Hanford Site. Other surface waters include man-made waste disposal ditches and ponds, including the U Pond system.

The unconfined aquifer beneath the Hanford Site is contained within sediments of the Hanford and Ringold Formations. Natural recharge to this aquifer occurs from precipitation and runoff along the margins of the Pasco Basin. Artificial recharge occurs from waste disposal operations on the Hanford Site; principally from the ditches and ponds in the Separations Areas. Discharge from the aquifer is primarily to the Columbia River to the east.[5] Infiltration of the liquid effluent discharges to U Pond has created a groundwater mound beneath U Pond and has raised the water table approximately 26 meters (m) over pre-Hanford conditions. Several perched water zones have also developed beneath U Pond as a result of these discharges.

Confined aquifers also occur beneath the Hanford Site. These occur within the sedimentary interbeds and/or interflow zones between dense basalt flows of the Columbia River Basalt Group.[6] These aquifers are not considered in this report.

PREVIOUS STUDIES

The U Pond system has been the subject of numerous published and unpublished studies. Bruns (1975)[7] published results of an aerial radiological survey of the entire U Pond system. From this survey, areal distribution of total gamma, ^{137}Cs, and ^{241}Am activities were determined.

The most complete environmental study of U Pond to date was published in two phases by Emery and Klopfer (1974)[8] and Emery and Garland (1974).[9] The first phase documented the physical and chemical characteristics of U Pond and the distribution of plutonium and americium in the pond bottom sediments. The second phase documented the radiochemical factors of the transuranic elements in the U Pond ecosystem and detailed source terms and actinide ratios discharged to the pond.

Fitzner and Rickard (1975)[10] investigated the use of all Hanford waste ponds by waterfowl and other avian species, Cadwell et al. (1979)[11], Cushing and Watson (1974)[12], and Fix and Blumer (1977)[13] investigated the radionuclide concentrations of the American coot and its role in exporting radionuclides from Hanford ponds.

A comparative study of the Hanford waste ponds and streams was conducted by Emery and McShane (1978)[14] to determine whether radiological conditions affect the occurrence, diversity, and productivity of biological organisms.

Gano (1979)[15] investigated the small mammal populations inhabiting the environs of U Pond. Wheeler and Law (1980)[16] reported the results of air, water, mud, and vegetation samples from the U Pond system taken for routine environmental monitoring purposes.

OPERATIONAL USE AND DISPOSAL HISTORY OF THE U POND SYSTEM

The U Pond disposal system (Fig. 1) was constructed in 1943 to receive large volumes of relatively uncontaminated waste water from 200 West Area facilities. It originally consisted of two drainage ditches, the 216-U-14 and 216-Z-1 Ditches, which diverted waste waters to a slight natural depression. An overflow ditch was also constructed to carry excess waste water out to a larger depression just outside 200 West Area.

Over the last 40 years, the U Pond system has undergone numerous physical modifications. The modifications have included the addition, removal, and modification of the various physical components of the disposal system. The majority of the modifications can be directly correlated with changes in discharge sources and volumes released to the U Pond system. These discharge sources include the Plutonium Processing and Reclamation Facilities (231-Z and 234-5Z), laundry and mask cleaning facilities (2724-W and 2723-W), uranium recovery facilities (221-U and 224-U), a powerhouse and water treatment plant (284-W), and, most recently, an evaporator-crystallizer plant (242-S).

The large volumes of low-level waste water and occasional isolated releases of considerably higher level, non-routine discharges have resulted in the accumulation of transuranic, fission product and activation product inventories. A total of 1.3×10^{11} liters of liquid have been discharged to the system through 1982, with a radionuclide inventory estimated to include 8.2 kilograms (kg) plutonium, 1.5×10^{3} kg uranium, 15.3 curies (Ci) ^{137}Cs, and 22.6 Ci Strontium-90 (^{90}Sr). The large number of discharge sources, their operational service dates, and the operational service dates of the U Pond system components complicate any attempt to derive total inventories for the individual U Pond components.

The discharges of principal interest in this study are to the Z-19 Ditch and its predecessors, the Z-1 and Z-11 Ditches. Of 8.2 kg plutonium released to the U Pond system, all but negligible amounts were released to these ditches. Waste water from plutonium processing activities have been continually discharged to the ditches, but the plutonium releases, usually at low levels, have occurred intermittently.[8] A comparison of the annual plutonium discharges and the service dates of the Z Ditches indicates that the 216-Z-1 Ditch received 138.5 grams (g), the 216-Z-11 Ditch received 8,074.7 g and the 216-Z-19 Ditch received 143.0 grams

PRESENT STUDY

Experimental Design

The first step of this study was to examine the design and use of the disposal system in order to predict what type of contamination might occur in each component of the system. The next step was to compile and review all previous studies at which time the existing data were either accepted, reinterpreted, or discarded. These data were then used to identify specific areas where sample data were lacking and to guide the design of supplementary sampling schemes.

Field Sampling and Analytical Procedures

Two main sampling groups were identified: 1) surface and near-surface sampling, and 2) subsurface sampling. These sampling groups were then subdivided by the component of the disposal system to be sampled.

Surface samples and near-surface core samples were collected throughout the U Pond and U-11 Overflow Basin area. The most extensive sampling was conducted on a 60-m^2 grid established over the entire U Pond and U-11 Basin area, excluding U Pond itself. In situ measurements, surface samples, and near-surface (30 cm deep) core samples were collected at each grid point.

Nine sampling transects, each consisting of seven sampling stations, were established across the Z-19 Ditch. A split-tube sampler was used to obtain 30-cm-deep core samples from all stations but those in the ditch center. In the ditch center, an underwater core sampler (developed to keep water out and to retain the saturated sediment during recovery) was used to obtain undisturbed cores to an average depth of 76 centimeters. A similar sampling scheme was used along the U-14 Ditch, where 12 transects were established with five sampling stations each.

Other surface and near-surface samples were also collected from each component. These were either preliminary samples, taken prior to the main sampling schemes, or were supplementary samples collected after the main sampling efforts in order to provide refinement of the sampling results. A total of 494 surface and near-surface samples were collected from the U pond and U-11 Basin area, 262 samples from the Z-19 Ditch area and 215 samples from the U-14 Ditch area.

Two monitoring dry wells were drilled along Z-19 Ditch to a depth of approximately 25 meters. A third monitoring well was drilled near U Pond to a depth of 75 m for ground-water monitoring purposes. Sediment samples were collected at 0.3 m intervals in the upper portion and at 1.5 m intervals in the lower portions of each well. Seventeen shallow exploration wells were drilled to locate the buried Z-1 and Z-11 Ditches, and one well was drilled in the U Pond delta area. These wells were approximately 4 m deep and samples were collected approximately every 0.3 to 0.6 meters. A total of 322 subsurface samples were collected from these wells.

The field samples were analyzed in the laboratory for gamma emitting radionuclides, plutonium, americium, ^{90}Sr, uranium, moisture content, and texture. Neutron well logging and in situ gamma energy analyses were also conducted.

Data Analysis and Interpretation

A wide variety of radionuclides were detected in the U Pond system. Table I lists the specific radionuclides found in each component of the disposal system. Distributions of the various radionuclides were plotted on a series of maps and cross sections.

Surface concentrations of the most significant radionuclides, ^{137}Cs and Plutonium-239/240 ($^{239/240}Pu$), are delineated in Figures 3 and 4, respectively. Americium-241, ^{90}Sr, Cobalt-60 (^{60}Co), and uranium are also considered significant radionuclides in that they were found in non-releasable concentrations.

TABLE I. Radionuclides Detected in the U Pond Disposal System Components.

Components	Activation and fission products	Uranium and transuranics
216-U-10 Pond and 216-U-11 Basin	^{125}Sb	^{241}Am[a]
	^{144}Ce	$^{238,239,240}Pu$[a]
	$^{134,137}Cs$[a]	$^{234,235,238}U$[a]
	^{60}Co	
	$^{154,155}Eu$	
	^{106}Ru	
	$^{22}Na(?)$	
	$^{85,90}Sr$[a]	
216-Z-19 Ditch	^{137}Cs	$^{238,239,240}Pu$[a]
		^{241}Am[a]
216-U-14 Ditch	$^{141,144}Ce$	$^{239,240}Pu$[a]
	^{137}Cs[a]	$^{234,235,236(?),238}U$
	$^{57,60}Co$[a]	
	$^{152,154,155}Eu$	
	^{59}Fe	
	^{54}Mn	
	^{95}Nb	
	^{106}Ru	
	$^{22}Na(?)$	
	$^{85,90}Sr$[a]	
	^{65}Zn	
	^{95}Zr	

[a]Exceed releasable concentrations.

The cesium distribution with depth is known best around the perimeter of U Pond. In the delta area, near-surface core samples indicated the ^{137}Cs concentration is generally concentrated in the top 18 cm of soil. A potential 47% reduction in the surface area exceeding 400 pCi/g of ^{137}Cs (from 12.6 to 6.7 ha) could be achieved by removing the upper 10 cm of sediment around U Pond.

Subsurface concentrations less than 400 pCi/g ^{137}Cs have penetrated to a depth of 1.5 m with much lower concentrations extending to 30 meters. The ^{90}Sr concentrations were slightly higher in some of these deeper samples, indicating that the ^{90}Sr did not sorb on the sediments as readily as the ^{137}Cs did in this portion of the U Pond system.

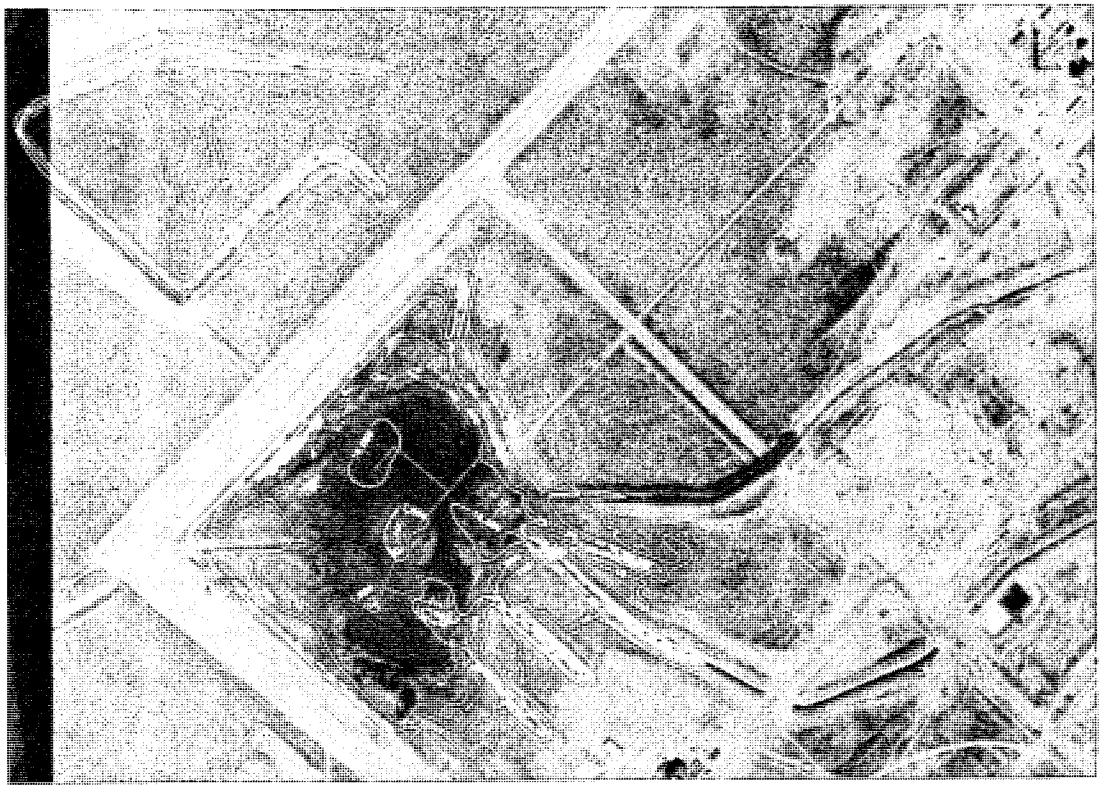

Fig. 3. General Distribution of ^{137}Cs in pCi/g Throughout the 216-U-10 Pond Disposal System.

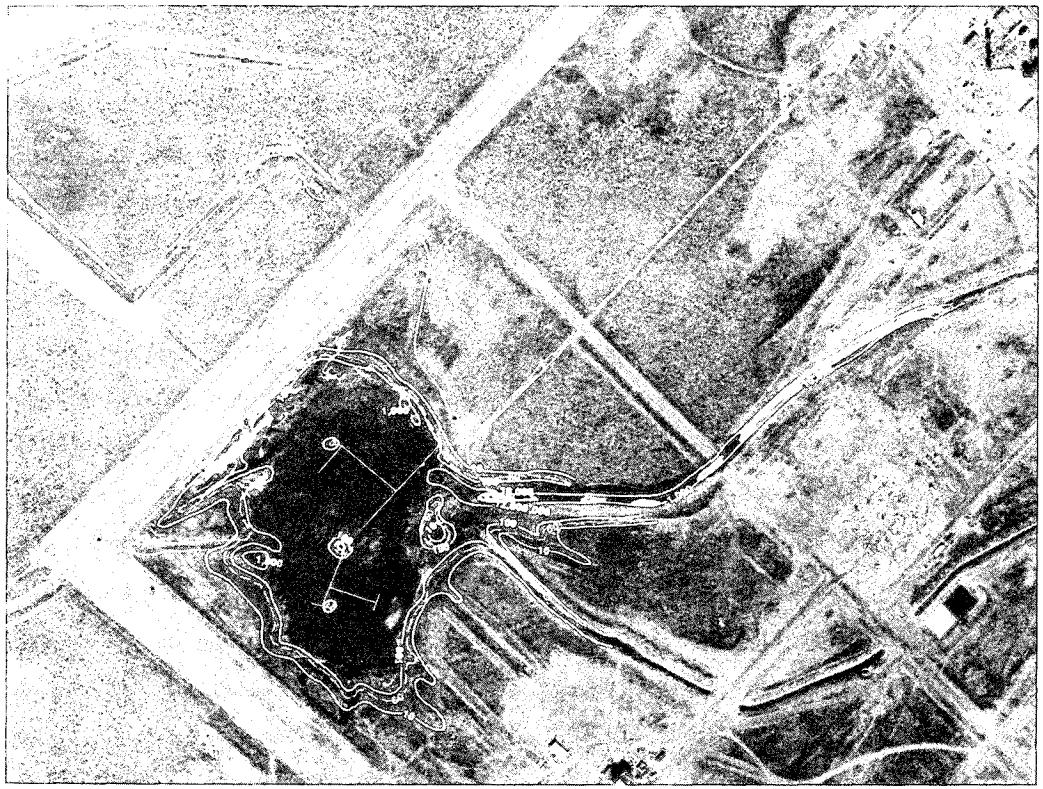

Fig. 4. General Distribution of $^{239/240}Pu$ in pCi/g Throughout the 216-U-10 Pond Disposal System.

Plutonium-238 (^{238}Pu), $^{239/240}Pu$, and ^{241}Am were distributed via 216-Z-19 Ditch and its predecessors, the 216-Z-1 and Z-11 Ditches. These ditches effectively concentrated these contaminants, although non-releasable concentrations are also found throughout U Pond. The primary source of these contaminants was the 234-5Z Building. The distributions of ^{238}Pu, $^{239/240}Pu$, and ^{241}Am were highly variable. This variability is attributed to intermittent releases and the particulate nature of the contaminants. Various isotopic ratios were also found in these samples, indicating that different waste streams contributed to the contamination.

Plutonium-239/240 is considered the index radionuclide for the Z-19 Ditch. The $^{239/240}Pu$ distribution beneath the ditch bottom indicates that plutonium is concentrated in the top 50 cm where concentrations exceed 10,000 pCi/g. Plutonium concentrations in the buried Z-1 and Z-11 Ditches were as high as 100,000 pCi/g and 10,000 pCi/g, respectively. Detectable $^{239/240}Pu$ contamination was found to a depth of 14 m beneath the Z Ditches. Of the reported 8.2 kg of plutonium discharged to the U Pond system, approximately 3 to 10 kg is located in the backfilled Z-1 Ditch. The backfilled Z-11 Ditch and the Z-19 Ditch contain similar concentrations, which are an order of magnitude lower than the Z-1 Ditch. U Pond has an estimated 22 g of plutonium in the first 10 centimeters below the pond bottom. The distribution of ^{241}Am is similar to that of $^{239/240}Pu$, although the concentrations are generally an order of magnitude lower.

SUMMARY AND CONCLUSIONS

This study produced a compilation of the previous environmental studies conducted on the U Pond disposal system and information concerning the operational use of this system. Soil and sediment samples were collected and analyzed to supplement the existing data. Radionuclide concentrations were plotted on maps and cross sections to delineate the distribution of contamination resulting from waste management practices at the U Pond system.

Results of this study indicate that the radionuclides released to the U Pond system have settled out and/or sorbed onto the surficial sediments nearest their discharge sources. The greatest accumulation of contaminants occurs in the topographically low areas of the disposal system. Water levels in the pond have fluctuated exposing surface contamination along the banks of U Pond and the overflow facilities. Cesium-137, ^{90}Sr, ^{60}Co, uranium, $^{239/240}Pu$, and ^{241}Am were all found in non-releasable concentrations. No significant impacts to man are known to have been associated with this disposal system over its 40-year history. In conclusion, this study has shown that the U Pond disposal system has been an effective and flexible waste management tool for the disposal of large volumes of very low-level radioactive liquid wastes.

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