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Nuclear Reactivity Evaluations of 216-Z-9 Enclosed Trench

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A. E. Smith

December 1973

Research Department

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NUCLEAR REACTIVITY EVALUATIONS OF 216-Z-9 ENCLOSED TRENCH

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A. E. Smith

Research Department
Research and Engineering

December 1973

ATLANTIC RICHFIELD HANFORD COMPANY
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ABSTRACT

Plutonium accumulation and the nuclear criticality implications were evaluated for a subsurface liquid waste disposal site at Hanford, Washington. Remote plutonium detection by infrared, gamma, and neutron surveys are described. Geological drilling and soil sampling techniques were developed and described. Nuclear criticality safety was evaluated by computer model calculations and by neutron pulsing techniques. This study discusses technologies used to evaluate a waste disposal site for a plutonium recovery operation.

NUCLEAR REACTIVITY EVALUATIONS OF 216-Z-9 ENCLOSED TRENCH

INTRODUCTION

The 216-Z-9 (Z-9) Enclosed Trench, a ground disposal facility, was used to receive waste from the Plutonium Finishing Plant between July 1955 and June 1962. The plutonium-bearing wastes discharged to Z-9 originated in the plutonium recovery facility. Waste solutions were partially neutralized salt wastes which at times contained organic materials and undissolved solids that accumulated during operations. The accountability records show that 27.4 kilograms of plutonium were discharged to Z-9. The possibility of sampling error due to very fine particulate matter was identified after Z-9 was taken out of service. Possible presence of unsampled particulates gave credence to the possibility that the accountability value for plutonium was biased low. Based on chemical analysis of soil samples taken from Z-9 in 1963, the quantity of plutonium in the facility was estimated to be 100 ±50 kilograms. The major concentration of plutonium was identified as being near the top of the soil column. The Atomic Energy Commission budget for fiscal year 1973 authorized funds for constructing a mining facility to remove the top 30 centimeters of the Z-9 soil column. An environmental statement for the mining facility was issued by the AEC in April 1972.[1] The environmental statement provides the complete background of the facility.

A part of the soil removed by the mining operation is scheduled for processing to recover a major part of the plutonium. Representative soil samples were required for developing a chemical processing flowsheet for extracting

the plutonium from the mined soil. The distribution of the plutonium was needed to support the mining program. New samples were obtained by developing special sampling techniques using split-barrel drive-samplers. Special precautions were taken to avoid cross-contamination of the deeper samples with material from near the surface that contained higher concentrations of plutonium.

A preliminary comparison of the 1963 and 1973 plutonium analyses indicated that the plutonium concentration was less in the new samples and that plutonium relocation may have taken place. This possibility was investigated by making new neutron pulsing measurements. The neutron pulsing measurement technique measures the neutron flux (number of neutrons in a given time period per unit area) as a function of time following the injection of a burst of neutrons into the system being tested. If k_{eff} , the neutron multiplication factor, is less than one, then the neutron flux diminishes (decays) to the level that existed before injecting the neutrons. The rate at which the neutron flux decays to background is related to the proximity of the system to a critical condition.

The 1973 neutron pulsing measurement gave a higher k_{eff} than previous measurements made in 1963 and 1969. This higher k_{eff} value indicated that the reactivity of the system was increasing. The first neutron pulsing measurements were reported in 1963. The k_{eff} was reported to be 0.86 at that time. An improved pulsed neutron source and more sophisticated analytical techniques became available in 1969. The system was tested using these, and k_{eff} was reported to be 0.91 ±0.01. The difference between the two values was not considered to be significant since the analysis of the experimental data differed for the two determinations.

The first analysis used a calculated neutron lifetime and was thought to be a more meaningful analysis. The values obtained using the neutron pulsing measurement technique in a more critical system in the critical mass laboratory predict a k_{eff} value higher[2] than the actual reactivity that exists. The initial values obtained from measurements made in March 1973 were in the range 0.95 to 0.98.[3] Primary concern was focused on the apparent change that was taking place with time. The 1969 and 1973 values were determined using the same equipment placed at the same location in the Z-9 system. When the 1973 values indicated a continuing increase, the trend was recognized as indicating an undesirable change.

Neither the early nor the recent k_{eff} measurements could be supported by reliable k_{eff} computation techniques. Therefore a more detailed understanding of the plutonium distribution in the Z-9 system and the neutron pulsing determination techniques was required. This document records the actions and analyses executed to define the plutonium distribution and to improve the understanding of the neutron pulsing measurement technique.

SUMMARY

A two-phase investigation to define the plutonium distribution and the consequent neutron multiplication factor in the Z-9 Enclosed Trench (system) and to improve the understanding of the neutron pulsing measurement techniques was carried out between April 9, 1973, and October 1, 1973. In addition, a neutron absorber, in the form of cadmium nitrate solution, was placed in the plutonium-rich area of Z-9.

The plutonium distribution investigations included (1) infrared (temperature) survey of the trench floor, (2) gamma radioactivity survey of the trench floor surface, (3) neutron survey of the trench floor, (4) sampling and chemical analyses of the plutonium-rich areas identified by the surveys, (5) modeling of the system based on the information developed by the surveys and analyses, and (6) computation of system reactivity based on the models developed.

The more complete system definition gave improved estimates of the plutonium content of the Z-9 system. It is now estimated that the system contains between 25 and 70 kilograms of plutonium. The best estimate is that the plutonium content in the top 30 centimeters is about 40 kilograms. The maximum calculated effective neutron multiplication factor, k_{eff}, for the system was obtained using a model containing 169 kilograms of plutonium, almost 100 kilograms more than the maximum predicted to be present. The k_{eff} for this system calculated to be about 0.8. A model based on 71 kilograms of plutonium gave a calculated k_{eff} of about 0.5.

The k_{eff} reported from the neutron pulsing measurement technique was reported as less than 0.98 in April 1973. Analysis of the data by the Savannah River Laboratory and the Los Alamos Scientific Laboratory identified a possible equipment deficiency. Replacement of the 256 channel analyzer with a 4096 channel analyzer provided the data needed for more definitive analysis. This resulted in establishing that k_{eff} was less than 0.8 and probably less than 0.5 before the neutron absorber was placed in the system and less than 0.3 after the neutron absorber was placed in the system.

DISCUSSION

The reactivity investigations of the 216-Z-9 Enclosed Trench (Z-9) were carried out in two simultaneous phases. One phase investigated the plutonium distribution and the consequent neutron multiplication factor in the Z-9 system and the other phase investigated the neutron pulsing measurement technique.

The plutonium distribution investigations of the Z-9 system consisted of the following elements:

1. An infrared temperature survey to locate thermal hot spots associated with radioactive decay.
2. A gamma radiation survey to locate areas of highest radioactivity at the surface.
3. A neutron survey to locate areas of highest plutonium concentration.
4. Additional sampling from areas identified by the surveys.
5. Critical mass computations based on the identified plutonium distribution. Critical mass calculations were also made using assumed plutonium distributions in order to define the conditions that would be required to produce k_{eff} values as high as indicated by the neutron pulsing measurement technique.

The results of the infrared, gamma, and neutron survey all showed the plutonium concentration to be highest in the same general area. They also showed that the low elevation region of the Z-9 Trench floor contained most of the plutonium. The sample results verified these observations. The highest plutonium content was found in the clay-like

material on top of the soil column in the same area shown to have high plutonium concentration by thermal, neutron, and gamma survey.

The results from samples taken in the areas identified as containing most of the plutonium were used to develop a plutonium distribution model which was used as a basis for calculating the reactivity of the system. The calculated values for a system identified from the sampling program and for a system having more than twice as much plutonium were significantly lower than the 1969 and 1973 neutron pulsing measurements, ≈0.5 and ≈0.8 as compared with 0.91 and less than 0.98.

The Atomic Energy Commission invited knowledgeable criticality prevention and plutonium chemistry personnel from the Los Alamos Scientific Laboratory and the Savannah River Laboratory to review and comment on the program being carried out, and the information available at that time. On May 2 and 3, 1973, the program for characterizing Z-9, the neutron pulsing measurement technique, and the analytical data available from 1963 and 1973 samplings were presented to these individuals as background. At the time of this meeting the 1963 plutonium values were recognized as being biased high. The plutonium analyses were reported in terms of grams of plutonium per gram of soil. In order to convert the analyses to volumes of soil, the density or weight per unit volume was required. The overstated quantities of plutonium resulted from using the density of the soil grains containing the plutonium, 2.3 grams per cubic centimeter, whereas the actual bulk density measurements were 1.7 g/cm^3 for the sand and as low as 0.8 g/cm^3 for the clay-like material at the top of the soil column. The clay-like material has been clearly shown to contain the majority

of the plutonium.

Several suggestions resulted from the meeting with SRL and LASL personnel. These included: (1) additional neutron pulsing measurements with the neutron detector located at different levels with respect to the trench floor. All prior measurements were made with both the pulser and the detector located at the top of the soil column; and (2) additional calculation of the effect of thin layers of cadmium nitration solution on top of a system having an 0.98 k_{eff}. This was considered to be an extra precautionary effort to assure complete safety, should events require the addition of cadmium nitrate solution to the system.

The consensus at this meeting was that a large inconsistency existed between the identified conditions in the trench (including calculated k_{eff} values) and the neutron pulsing measurements. The plan to further reduce the reactivity of the Z-9 system by the addition of an appropriate neutron absorber was endorsed by the personnel from SRL and LASL. However they also strongly suggested that a more thorough understanding of the system should be assigned an importance. A better knowledge of the plutonium content, the distribution of plutonium, and the quantity of water moderator present was consistent with the survey, sampling, and calculation program described heretofore.

A modification of the neutron pulse equipment was recommended by the SRL and LASL consultants. This approach was the product of careful and thorough evaluation of the data obtained with the neutron detector located on the surface of the trench as well as in a sample hole at a level below the surface. There was evidence to indicate an error in the delayed neutron value that would bias the k_{eff} on the high side. The equipment modification consisted of substituting

a 4096 channel analyzer for the 256 channel analyzer used originally. More channels allowed the collection of neutron data for a longer period whereby the delayed neutron value could be determined with greater assurance that the equilibrium value was obtained.

The equipment change and subsequent neutron pulsing measurements were deemed to be the extent of the experimental work that should be carried out in the facility before the addition of a neutron absorber.

The action to render the Z-9 Trench further subcritical by the addition of a neutron absorber was initiated prior to the determination of the reactivity from the data obtained using the 4096 analyzer. The action plan was based on k_{eff} being 0.98 rather than the reported value of less than 0.98. The reflector thickness of a solution on the trench surface was limited to two-thirds that calculated to cause an 0.01 increase in k_{eff}. The addition system was designed and tested to provide a uniform spray over a 3-2/3 x 3-2/3 meters area. The liquid volume was controlled by measuring the specified volume, 7-1/2 liters initially, placing it in a container, and then pressurizing to 3.5 kg/cm^2 with air. The area containing the greatest concentration of plutonium, as identified by the survey studies, was selected for the neutron absorber treatment. Four spray nozzles were mounted in access holes in the concrete slab covering the trench. The addition was made through one spray nozzle at a time, providing further assurance that the reactivity would not be increased by the presence of a neutron reflector. A television camera mounted in a fifth access hole was directed to provide visual observation of the trench floor before, during, and after the addition of the neutron absorber. The television output was also video-taped for record purposes

and to allow multiple observations of the additions. When the reactivity value calculated from the data obtained using the 4096 channel analyzer was found to be lower, the liquid addition rate was increased; the lower k_{eff} provided a basis for permitting a much thicker neutron reflector. The addition rate was increased to 57 liters based on video feedback that showed a slight puddling in a small area when 38 liters of solution were added to one area. Buildup of liquid on the surface was avoided to assure partially saturated flow conditions rather than saturated flow conditions. Partially saturated flow provided more time for diffusion of the neutron absorber into the wetted soil and assured more uniform diffusion of the absorber in the system.

Cadmium was selected as the neutron absorber based on the cross-section of the material and the acceptability of cadmium in the plutonium recovery process. Cadmium nitrate solution was selected at a concentration of 10 grams cadmium per liter for chemical compatability and to provide sufficient liquid volume to percolate to a 15-centimeter depth of penetration. A total of 1100 ±30 liters of cadmium nitrate was introduced into the system, 11 ±0.3 kilograms of cadmium.

After the cadmium was in place, the reactivity was measured using the neutron pulsing measurement technique employing the 4096 channel analyzer. The addition of the cadmium reduced the indicated reactivity of the system to a more subcritical condition of $k_{eff} \leq 0.3$.

Further investigation of the neutron pulsing reactivity measurement technique was carried out simultaneously with the survey, sample, modeling, calculational, and neutron absorber program. The neutron pulsing data obtained with the neutron detector located in the trench soil and the 4096 channel analyzer replacing the 256 channel analyzer were

analyzed by three laboratories. Battelle Pacific Northwest Laboratories made the measurements and analyzed the data. The data were sent to the Savannah River Laboratory of E. I. du Pont de Nemours and Company and to the University of California Los Alamos Scientific Laboratory. The analyses of the data by these three laboratories disclosed that, depending on the assumptions and data interpretations made, a wide range of nuclear reactivity values was possible. In the final analysis, all three laboratories agreed that the k_{eff} before the addition of cadmium never exceeded 0.8 and most probably did not exceed 0.5.

Furthermore, the consensus of these three laboratories was that the k_{eff} of the Z-9 system with the 11 ±0.3 kilograms of cadmium in place is less than 0.3. The real value may be less, but agreement on a smaller value requires additional investigation.

The plutonium content of the Z-9 system was reevaluated during these studies. The new data indicate that the plutonium content is in the range of 26 to 69 kilograms. The best estimate is that the upper 30 centimeters of soil contains 38 kilograms of plutonium. The value of 38 kg is in reasonable agreement with the original accountability value of 27.4 kg and lower than the 100 ±50 kg given in Reference 3. The difference is still ascribable to sampling error caused by unmeasured particulates containing plutonium.

INVESTIGATIONS AND ACTIONS

SURVEYS AND CORE SAMPLE ANALYSES

Radioisotope concentrations and distribution patterns in Z-9 were determined by infrared survey, gamma survey, neutron survey, and core drilling with subsequent analyses of core

samples. The surveys were useful in revealing the distribution of plutonium on the floor of the trench and in particular they indicated the location of maximum plutonium accumulation. All surveys showed that the vast majority of surface plutonium was in the region of lowest floor elevation. This region was in the south half of the trench. Core sample data from this area showed that the maximum plutonium accumulation was about 20 grams of plutonium per liter of soil. Most surface plutonium values for this area were between 0.5 and 15 grams of plutonium per liter of soil.

Heat from radioisotopes on the surface was measured with an AGA thermovision infrared scanner.[4] Maximum heat flux values of from 30 to 40 watts per square meter were observed in small areas, all located in the south half of the trench. Several large areas in the south half had values of 10 to 30 watts per square meter. Values in the north half did not exceed 5 to 10 watts per square meter (see Appendix K).

The gamma survey of the trench surface was obtained using an NaI(Tl) detector[5] (see Appendix I). This survey revealed the distribution pattern of radioactivity and showed that the probable maximum plutonium concentration was located in the south half of the trench. Large areas of less than maximum plutonium concentration were located in the south half of the trench while the lowest concentrations were in the north half.

A neutron survey of the top 13 centimeters of the soil was obtained with a specially constructed directional neutron counter using a ^{3}He tube to count thermal neutrons and neutrons above thermal energies, and a BF_3 tube to count essentially only thermal neutrons.[6] The neutron survey yielded a relative distribution pattern for plutonium which supported the gamma and infrared surveys (see Appendix J).

Core samples were taken with split-tube core samplers driven by a cathead-actuated drive hammer enclosed in a glovebox (see Appendices A and B). All core samples were analyzed for plutonium and americium. A few select samples were analyzed for pH, moisture, cation exchange capacity, percent volatiles, elemental composition, percent TBP, cadmium, chloride, and nitrate. The contents of two samplers were subjected to microscopic analysis, autoradiographic analysis, and electron microprobe analysis.

Plutonium and americium concentrations in the core samples were determined nondestructively with lithium-drifted germanium detectors[7] and gamma energy analysis techniques. Plutonium values were expressed as milligrams plutonium per liter of soil to facilitate critical mass calculations. Americium concentrations were expressed as microcuries of ^{241}Am per liter of soil to facilitate radiation dose calculations (see Appendix B).

Most soil taken from the south half of the trench contained 0.5 to 15 grams of plutonium per liter in the top 15 centimeters and 0.1 to 0.5 gram of plutonium per liter of soil at the 18- to 30-centimeter depth. Deeper samples taken near 2.4 meters yielded 0.03 to 0.1 gram of plutonium per liter of soil. Americium values were 2,000 to 19,000 microcuries of ^{241}Am per liter of soil in the top 15 centimeters compared with the range of 600 to 5,000 microcuries of ^{241}Am per liter of soil in the 18- to 30-centimeter depth. Deeper samples near 2.4 meters contained 200 to 550 microcuries ^{241}Am per liter of soil. The data specifically for the area containing the maximum accumulation of plutonium are:

Depth Centimeters	Grams ^{239}Pu per Liter of Soil	Microcuries ^{241}Am Per Liter of Soil
0- 2	13 -20	90,000-143,000
2- 8	1 - 9	8,000- 60,000
8-15	0.1- 3	700- 18,000
15-23	0.1- 0.8	500- 5,000
23-30	0.1- 0.3	400- 2,000

The pH of the soil varied from three to four over the soil column down to three meters. Moisture in soil varied from 5 to 15% by weight depending on location. The sludge layer contained up to 45% volatiles, which was assumed to be water for purposes of calculations. Cation exchange capacity was very high in the upper few centimeters, *ca.* 20 milliequivalents per 100 grams of soil, compared with values obtained at depths below 15 centimeters; *ca.* 2 to 5 milliequivalents/gram of soil. Only trace levels of tributyl phosphate (TBP), cadmium, chloride, and nitrate were found (see Appendix J). A typical elemental analyses was as follows:

SiO_2	63.7
Al_2O_3	12.9
FeO	7.0
MgO	2.8
CaO	2.9
Na_2O	2.8
K_2O	1.3
TiO_2	2.0
Others	4.6

Mineralogical studies included microscopic analyses, electron microprobe analyses, and autoradiographic analyses for locating alpha emitters. Optical photos with 50X enlargement showed that individual soil fragments of sand-size or smaller had been subjected to chemical attack as evidenced by deterioration of fragment edges with channel holes cut into the interior. Electron microprobe analyses indicated

loss of alkaline earth metal cations from feldspars and pyroxenes while quartz and metallic minerals such as ilmenite and magnetite were not affected. Autoradiographic and electron microprobe analyses of plutonium showed that essentially all of the plutonium existed as discrete particles as large as 10 micrometers in diameter mostly in the sludge layer. The trace amounts of plutonium throughout the trench soil was associated with silicon and iron crystals in the ground mass.

CALCULATED REACTIVITY*

Criticality calculations for Z-9 have been made several times since the 1969 neutron pulsing measurements. Sphere and infinite homogeneous slab and cylinder calculations have been made with the DTF-IV transport theory computer code based on cross-sections generated by the GAMTEC-II code. Three-dimensional calculations were performed following the initial pulsed neutron measurements in 1973 using the GEM4 and KENO-II Monte Carlo codes.

The limited analyses performed in 1963 did not permit exact calculation of the criticality status of Z-9. Instead, infinite slab calculations assuming plutonium compositions equal to the highest densities found were used to find the effect of varying water content and reflectors. These calculations were considered to be theoretical studies only and are not considered to have described the actual Z-9 reactivity.

In 1970 a parameter study was performed for spheres, infinite slabs, and infinite cylinders with soil containing plutonium over a very large range of densities to provide data for safety parameters for soil removal. Again, these

*Details may be found in Appendix N.

homogeneous calculations did not attempt to define the reactivity status of Z-9.

The initial 1973 pulsed neutron reactivity measurements were followed by neutron, gamma, and infrared surveys and analyses of soil samples which were used to characterize the plutonium distribution in Z-9. With these data, a series of three-dimensional calculations were started. The first plutonium distribution used in the calculations was based on the best estimate obtained from the initial raw data. The assumed composition of the material in Z-9 included the soil composition itself (based on 1963 analysis), the plutonium density, and the water fraction. The k_{eff} was calculated to be about 0.45. A recalculation using refined data gave a k_{eff} of about 0.35. Since the k_{eff} must be 1.0 for a chain reaction to occur, the system appeared to be far from critical. This appeared to contradict the initial 1973 pulsed neutron determination of less than 0.98. To determine if some unmeasured but conceivable variation existed that could account for this high value, well over 20 additional cases and 30 separate computer runs were made to examine changes in dimensions, plutonium densities, reflectors, and water content. The worst case calculated did not exceed a k_{eff} of 0.80. [This value would be consistent with about one-half of a critical slab thickness.]

Based on these calculations, it is considered very unlikely that a higher k_{eff} could have existed. The actual k_{eff} of Z-9 without cadmium (*i.e.*, unpoisoned) is now considered to have been in the neighborhood of 0.5.

REACTIVITY MEASUREMENTS

A number of reactivity measurements using the neutron pulsing source technique have been performed on Z-9. The

most recent measurements, utilizing improved data accumulation instrumentation, show the value of k_{eff} to be no greater than 0.8 prior to the addition of neutron poison in the form of cadmium nitrate to the trench. This value for k_{eff} decreased to less than 0.3 following the addition of the neutron poison.

The data from these neutron pulsing measurements can be interpreted in such fashion as to give lower values of k_{eff}. Such interpretation has merit on the basis that room-return neutrons can distort the time decay in the region where the delayed neutrons would be expected to reach equilibrium--there is some evidence that this is the case (see Appendix P). However, it would not be considered prudent to place such merit on the presence of the room-return neutrons, which, in any event, cannot be fully substantiated in the trench itself. Where nuclear criticality and safety are a matter of concern, any bias in the data, and interpretation thereof, must always be on the safe side, or maximum value, unless the numbers (and the assumptions on which these numbers were deduced) can be established with absolute certainty. This is especially so in the case of this particular underground waste trench (cavern), which constitutes the only system of its kind ever pulsed--and a system that is not feasible to mock up in the laboratory. Laboratory-type systems (critical and subcritical systems) have been investigated extensively in the Plutonium Critical Mass laboratory, and the reactivity measurements from neutron pulsing source experiments are well verified. A detailed discussion, together with associated analyses, is presented in Appendix O.

In a neutron pulsing source experiment, bursts of neutrons are repetitively injected into the system for which knowledge of the reactivity is desired. The time behavior

between bursts of neutrons and their progeny is measured by means of a suitable detector properly positioned in or near the system and a series of scalers. The accumulated data can be divided, basically, into two components. The neutron count rate just preceding a new burst is due entirely to background plus the slowly decaying delayed neutron contribution (the delayed neutrons are emitted from certain of the fission fragments following beta decay). The neutron count rate following the burst at time zero is due to the relatively fast decaying prompt neutrons (those emitted promptly at the instant of fission) created by the burst, plus the background and delayed neutrons. It should be borne in mind that, in the case of plutonium, about 99.8% of the neutrons from fission are emitted promptly and only about 2 out of every 1000 are delayed. By making a background measurement preceding the pulsed neutron experiment, the delayed and prompt neutron components can be segregated.

After a period of time the prompt neutron portion of the total population that is due to the neutron burst will approach the background level preceding the burst, and only the delayed neutrons will remain. The neutron decay rates and the ratios of prompt to delayed neutrons can be used to determine reactivity or to obtain an effective neutron multiplication constant for the system as discussed in Appendix O.

Three methods have been developed whereby the reactivity of a system can be determined from the data. All three methods are similar in that, in each case, the reactivity of the system is related to the area under the curve of neutron counts plotted by time as generated by the neutron pulsing source measurements. Briefly, there are the Sjöstrand method, the Gozani method, and the Garelis-Russell method.

The first measurements made in Z-9 (1963) utilized a technique that was dependent on a calculated neutron lifetime of 33 microseconds, and a measured decay rate of 4350 sec^{-1}. At the time of these measurements the theory had not been developed to the point where a direct measurement could be made of the reactivity. As a result, the value of k_{eff} (0.86) was dependent on a calculated neutron lifetime (ℓ), which, in turn, depended on a knowledge of the plutonium concentration and distribution in the soil. This was the first time the pulsed neutron source technique had been applied to this type system.

Neutron pulsing source measurements were repeated in 1969, after the analytical techniques of Garelis-Russell and Gozani had been developed. These techniques required the measurement of the delayed neutrons resulting from the fissions caused by pulsing. In order to apply the new techniques to Z-9, a neutron source of larger yield was required. In the intervening period from 1963, a special neutron source had been obtained which would meet the requirements and permit the measurements on the above basis. These measurements showed the reactivity, by the Garelis-Russell method, to be at least \$43 subcritical (a k_{eff} of 0.92, maximum, for a β_{eff} value of 0.0021). The 1969 measurements were considered of better quality than those of 1963, as the results were not subject to the uncertainty of a calculated lifetime--and no knowledge of plutonium distribution in the soil was required.

Neutron pulsing source measurements were repeated in Z-9 during April 1973 with the same source and detector used in the 1969 measurements. These measurements, which were made in the same region of the trench as in 1969, showed the reactivity to possibly be within \$7 of critical ($k_{eff} \leq 0.98$). The pulsed neutron source and BF_3 tube were moved to the

central region of Z-9, where neutron and gamma surveys made in May had indicated the highest concentrations of plutonium to be located, and the measurements were repeated. However, after reviewing the measurement data, an independent AEC consultant suggested that the data accumulation period of 0.00512 second that was being used between pulses of neutrons was not sufficiently long to fully establish the decay pattern in the time domain where the delayed neutrons (essential for the reactivity determination) were expected to dominate. Due to limitations on the 256 channel analyzer, it was not practical to cover a greater time span, and at the same time obtain sufficient definition on the prompt neutron portion of the decay. The 256 channel analyzer was then replaced by a new 4096 channel analyzer which had the capability of good data resolution over a greatly extended time period. The measurements at this location, with the more sophisticated data accumulation system, yielded a maximum value of 0.8 for k_{eff}. This value was determined from data taken in the region indicated to have the highest plutonium concentration; k_{eff}, for the surface layers of the trench floor, was calculated to be no more than 0.8 at that time. [It should be remembered that it was only after the more sophisticated instrumentation was procured and placed in operation that there was any real basis for a reduction in the value of k_{eff} based on neutron pulsing measurement techniques.]

The measurements were repeated following the addition of some 1100 liters of aqueous cadmium nitrate solution containing 11 ±0.3 kg cadmium to Z-9 soil in August; the reactivity was observed to decrease to a k_{eff} of less than 0.3.

NEUTRON POISONING

Neutron absorbers (poisons) considered included: boric

acid, sodium borate, gadolinium nitrate, gadolinium chloride, cadmium nitrate, and cadmium sulfate. Availability, cross-sections, solubility, and previous experience in plutonium recovery and processing narrowed the selection of a neutron absorber to cadmium and boron. Use of cadmium nitrate solutions in the Recuplex pilot-plant plutonium scrap recovery process had caused no problems in either processing of the dissolved scrap or in final plutonium product decontamination. Work with boron additions had given occasional impurity problems in the final product. Since plans include the recovery of plutonium from the Z-9 soil, cadmium nitrate was selected as the poison.

The concentration of 10 grams of cadmium per liter was based on hydrogen-to-plutonium atomic ratios (H/Pu). Each H/Pu ratio requires a corresponding cadmium-to-plutonium atomic ratio (Cd/Pu) to assure that the multiplication factor for an infinitely large system (k-infinity or k_∞) will remain less than 1.0. The top 2.5 centimeters of soil required 4.5 grams of cadmium per liter of soil and the next 15 centimeters of soil required 3.0 grams of cadmium per liter of soil. A 10-gram per liter cadmium solution provided these values since the top 2.5 centimeters had a 45% void volume (45% water) and the second layer had a 30% void volume in the soil.

The cadmium addition to Z-9 was based on a k_{eff} of 0.98. Since a layer of cadmium nitrate solution will reflect neutrons, the method of addition and the quantity added had to be such that the neutron reflection would not exceed safe levels. Calculations showed that if the layer was kept to 0.16 centimeters the increase in k_{eff} would be less than 1%.

By actual measurement of the spray nozzles that were used, 7 1/2-liter additions were shown to give a uniform

layer less than 0.16 centimeters thick (0.06 cm average) over a 3 2/3 meters by 3 2/3 meters area. This gave the necessary safety factor.

Holes B, C, 11, and 12 on the south half of the trench (Figure 1, Appendix B) were selected as the addition points. With a 3 2/3 meters by 3 2/3 meters coverage in each hole, the major portion of the high-activity area would be poisoned (see gamma and neutron maps)(Appendices I and J, respectively).

The equipment was designed to give a uniform spray over a 3 2/3 meters by 3 2/3 meters area. A 9 1/2-liters fire extinguisher was used as the addition tank. Seven and one-half liters of 10-grams per liter cadmium solution were placed into the extinguisher tank and pressurized to 3.5 kilograms per square centimeter. The extinguisher system was connected to a solenoid valve and a spray nozzle for addition to Z-9. Personnel were evacuated from the area, and the solenoid was remotely actuated. About one minute was required for a 7 1/2-liter addition.

A television system was installed in Z-9 to assist in evaluating the cadmium poisoning operation. The picture was tape-recorded for review if needed. By directing the camera to key areas, puddling, if any, and spray efficiency could be monitored. A neutron counter was placed five meters above the Z-9 floor to note change in flux. A gross gamma instrument was operating to record changes in gamma activity. The gamma activity was predominantly 60 KeV from ^{241}Am. Since water readily attenuates this energy level, the gamma monitor also served as a water layer detector.

Seven and one-half liters of a 10-gram per liter cadmium nitrate solution were added to each of the four selected holes. No change was noted in the neutron and gamma monitors

and no puddling was observed. The time required to add 7 1/2 liters was one minute.

The first evaluation of the pulsed neutron measurements using the 4096 channel analyzer showed that k_{eff} was no more than 0.92. On the basis of this value, 58-liter additions could be made safely. Based on criticality prevention calculations, a layer of solution 1.27 centimeters thick would increase k_{eff} to a safe value of 0.97. The 58 liters corresponded to an equivalent layer of 0.46 centimeter.

The equipment for adding 58-liter batches consisted of a head tank, a positive displacement pump with variable speed motor, a spray nozzle and associated equipment mounted on a movable pallet. The motor speed and nozzle were varied until the desired spray pattern was obtained. Adding 58 liters required six minutes. Tests using air only showed that this equipment did not pressurize Z-9.

The first addition was limited to 38 liters and was sprayed into Z-9 through the "B" hole. Slight puddling was observed in one small area of about 0.1 square meter. The other 20 liters were then added with no increase in puddling. After this, 58 liters were added to each hole rotationally until 1100 ±30 liters had been added. The "B" hole was observed to puddle in one small area for each addition, and it was believed to be due to a piece of tile embedded in the top soil layer. The neutron counter positioned five meters above the floor showed no significant change. The neutron counter in the soil showed a 30% drop.

Separate tests by the Atlantic Richfield Hanford Company Chemical Technology Laboratory and the Battelle Pacific Northwest Laboratories showed the bulk of the 10-gram per liter cadmium solution to stay in the top 30 centimeters of soil. Chemical Technology Laboratory found 24% to be held

in the top 2.5 centimeters of actual Z-9 top soil, including the sludge layer. Battelle Pacific Northwest Laboratories found the following cadmium distribution:

Depth Centimeters	Cadmium Sorption Percent by Weight
0 - 2.5	32
2.5- 7.5	34
7.5-15	18
15 -23	3
23 -30	3
30 -38	7
38 -46	3
46 -53	5

Penetration into the Z-9 soil from the cadmium addition appeared to follow this pattern since k_{eff} dropped significantly. A neutron counter inserted 20 centimeters into the Z-9 soil showed a 30% drop in neutron count rate.

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GLOSSARY

Cadmium: A naturally occurring chemical element capable of controlling a nuclear chain reaction because it readily absorbs neutrons (see "Neutron Absorber").

Covered Trench (sometimes called a "crib"): An underground area that acts as a seepage pit for filtering out radioactive material from radioactive waste water.

Dollars ($): see "Reactivity."

Fissile: Capable of being split; used to describe atoms that split when hit by neutrons.

Gamma Ray: A short-wave radiation emitted by radioactive materials. The gamma ray differs from visible light and manufactured X-rays in that it comes from the nucleus of the atom rather than from the electrons outside the nucleus which are the source of light and X-rays.

Heat Generation: Energy in the form of heat given off during spontaneous disintegration or transformation of fissile material such as plutonium.

k_{eff}, k-effective: A numerical value relating to the ratio of neutrons produced by fission collisions to neutrons consumed in a fissile system. It is influenced by many conditions; *i.e.*, shape, fissile concentrations (density), associate chemicals, location, etc. This value is used in criticality prevention to determine safe conditions. If k_{eff} is equal to or greater than 1.0, a self-sustaining nuclear chain reaction will occur.

Monitoring: The continuous or periodic determination of the amount of radiation or radioactive material present.

Neutron Absorber: A material that absorbs or captures neutrons. In this report, this kind of material in a system reduces the potential for a nuclear reaction occurring by reducing the neutrons available for fission collisions (see "Cadmium").

Neutron Pulsing Technique: A method of evaluating a system containing fissile material by introducing a burst of neutrons into the system and then measuring the change with time in the number of neutrons in the system (see "k ").

Nuclear Chain Reaction: A process produced by the splitting of a fissile atom (fission) which then releases two or more neutrons which will cause other fissions. The chain reaction will continue, provided that at least one of the emitted neutrons collides with another fissile atom, causing another fission.

Percolate: To pass through a porous substance; trickle; ooze.

Plutonium: A radioactive element produced artificially when neutrons are captured by uranium.

Poison: Any nonfissionable element that readily absorbs or captures neutrons (see "Cadmium", "Neutron Absorber").

Radioactivity: The spontaneous emission of radiation, either directly from unstable atomic nuclei or as a consequence of a nuclear reaction.

Reactivity: A numerical measure $\left(\text{equal to } \frac{k_{eff} \text{ minus } 1}{k_{eff}}\right)$ of how far a system is from being critical. The units of the value are expressed in $'s.

Surveillance: Keeping close watch on systems involving radioactivity for the sake of safety to workers and the environment (see "Monitoring").

Common Metric Equivalents

	Approximate Equivalents	Accurate Conversions
1 inch	=25 millimeters	25.4 millimeters
1 foot	=0.3 meter	0.3048 meters
1 yard	=0.9 meter	0.9144 meters
1 mile	=1.6 kilometers	1.609 34 kilometers
1 square inch	=6.5 sq. centimeters	6.4516 sq. centimeters
1 square foot	=0.09 square meter	0.092 903 sq. meters
1 square yard	=0.8 square meter	0.836 127 sq. meters
1 acre	=0.4 hectare	0.404 686 hectares
1 cubic inch	=16 cu. centimeters	16.3871 cu. centimeters
1 cubic foot	=0.03 cubic meter	0.028 316 cu. meters
1 cubic yard	=0.8 cubic meter	0.764 555 cu. meters
1 quart (lq)	=1 liter	0.946 353 liters
1 gallon	=0.004 cubic meter	0.003 785 41 cu. meters
1 ounce (avdp)	=28 grams	28.349 grams
1 pound (avdp)	=0.45 kilograms	0.453 592 kilograms
1 horsepower	=0.75 kilowatt	0.745 700 kilowatts
1 millimeter	=0.04 inch	0.039 370 1 inches
1 meter	=3.3 feet	3.280 84 feet
1 meter	=1.1 yards	1.093 61 yards
1 kilometer	=0.6 mile	0.621 371 miles
1 sq. centimeter	=0.16 square inch	0.155 sq. inches
1 square meter	=11 square feet	10.7639 sq. feet
1 square meter	=1.2 square yards	1.195 99 sq. yards
1 hectare	=2.5 acres	2.471 05 acres
1 cu. centimeter	=0.06 cubic inch	0.061 023 cu. inches
1 cubic meter	=35 cubic feet	35.3147 cu. feet
1 cubic meter	=1.3 cubic yards	1.307 95 cu. yards
1 liter	=1 quart (lq)	1.056 69 quarts (lq)
1 cubic meter	=250 gallons	264. 172 gallons
1 gram	=0.035 ounces (avdp)	0.035 274 ounces (avdp)
1 kilogram	=2.2 pounds (avdp)	2.204 62 pounds (avdp)
1 kilowatt	=1.3 horsepower	1.341 02 horsepower

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APPENDIX A

SAMPLING EQUIPMENT AND PROCEDURES[1]

M. C. Metz
V. L. Schuelein

INTRODUCTION

In October 1972 the Plutonium Process Engineering Section requested that the Advanced Technology Section procure samples from the floor of 216-Z-9 (Z-9). Samples representative of the plutonium-contaminated sediments were needed to design the plutonium reclamation process for the Z-9 mining facility. This paper reports the sampling method and procedure which were selected, tested, and field-proven.

EQUIPMENT

Samples were taken with split-tube drive core samplers driven by a cathead activated drive hammer. Contamination was controlled by enclosing sampling operations in a portable glove box. The basic sampling equipment is composed of a hoisting tripod (Figure 1a), sampling glove box (Figure 1b), and blower assembly (Figure 1c). The hoisting tripod supplied the needed overhead pulley system for driving samplers and hoisting various pieces of equipment including the glove box. The sampling glove box controlled contamination and contained all of the needed sampling tools. A slight negative pressure was maintained on the cavern, and thus the

[1]W. H. Zimmer, V. L. Schuelein, and M. C. Metz, "Interim Report: Sampling Techniques and Analyses of the 216-Z-9 Covered Trench," ARH-2752, August 1973, Atlantic Richfield Hanford Company, Richland, Washington.

sampling glove box, with an absolute filter blower assembly hooked to a 20-centimeter access hole.

Samples were taken with 10-, 8-, 6.4-, and 5-centimeter diameter split-tube drive core samplers. Disassembly of sampler is shown in Figure 2. Samplers were disassembled in a laboratory glove box in order to control contamination.

The drive rod used within the glove box was of a nonscrew-type to avoid unnecessary twisting of plastic. For this reason drive rods with J-slot connectors were selected for use (Figure 3). The drive rods were connected to the outside of the hood by a Kelly which had a flexible accordion bag.

SAFETY

The following safety rules were used during sampling:

All personnel involved in the core sampling operation shall follow the "Master Safety Rules," the "Radiation Protection Standards and Controls" (ARH-220), and the "Emergency Procedures" (ARH-222).

The Plutonium Finishing Section "General Safety Rules" and the Plutonium Processing "General Safety Rules" also apply wherever pertinent except that in those cases where differing characteristics of the site or the greater exposure of the operation to natural hazards warrant more definitive or appropriate procedures. The specific procedures included herein shall be followed at all times.

Aside from the normal mechanical hazards associated with the core sampling operation, additional hazards will be encountered due to the contaminated soil in which the wells will be drilled.

The primary hazard is contamination spread. Careful surveying during all glove box operations shall be observed. The hood gloves should be pulled clear of the driving mechanism when not in use to avoid possible cuts in the gloves. No one shall be within the bounds of the tripod legs while a sampler is being driven.

After driving and before a sampler is pulled from the hole, the Kelly and drill rods must be turned clockwise until tight to insure that all connectors are locked. Care must be exercised while raising and lowering drill rod to insure that the connectors are locked and that the rod is locked to the staging platform before the hoist is disconnected.

A criticality incident alarm shall be in operation during the period in which personnel are present at the site. In addition, neutron and gamma monitoring systems shall be recording the relative neutron and gamma levels in Z-9.

The systems shall be checked out to assure that they are operating each day prior to entry of the Z-9 concrete slab.

Two alpha survey instruments shall be available for self-monitoring and, in addition, a radiation monitor shall be on duty for the direction of such matters pertaining to radiation protection.

PROCEDURE

Sampling was done with a crew composed of four operators, one radiation monitor, and one project engineer. The following step-by-step procedure was used:

PREPARATION

1. Obtain an excavation permit.

2. Obtain a Radiation Work Permit (RWP) for work at site.
3. Install the blower assembly by bolting the filter-flange unit over an existing 20-centimeter hole in the trench top.
4. Provide and install needed radiation detection equipment, constant alpha air monitor, and criticality incident alarm.
5. Establish change room facilities.
6. Provide a radio or other communications link with plant facilities.
7. Provide containers for storage or disposal of materials and equipment used in the sampling operation.
8. Arrange for daily progress sheet.

GLOVE BOX PLACEMENT

1. Center the tripod over the existing 20- or 10-centimeter sample hole (Figure 4a).
2. Tape two layers of plastic around the 20- or 10-centimeter hole out to the edge of the tripod.
3. Turn on the blower. Check negative pressure; if below 0.25 centimeter water, change filters.
4. Don a mask and remove the cover cap from the 20-centimeter hole. Bag the cover and save for reuse.
5. Lay rubber seal over hole and insert the adapter.
6. Roll the glove box over the hole, attach hoisting harness, raise it with the hoist, remove the dolly, and lower the box onto the adapter (Figure 4b).
7. Survey the area for contamination and with assurance that control has been maintained, remove masks.

GUIDE TUBE PLACEMENT

1. Measure the distance from the trench top to the trench bottom.

2. Bag an appropriately sized aluminum guide tube into the glove box and sampling hole (Figure 4c). Position the tube on the bottom of the trench at the location to be sampled.

3. The first guide tube in each sample hole can be positioned before the glove box is sealed over the hole.

SAMPLER INSERTION

1. Bag the proper sized sampler into the hood (Figure 4d).

2. Clip the hoisting plug onto the sampler and lower it into the guide tube.

3. Insert the special wrench into the slots on the sampler and lock the sampler in place on the staging platform.

   CAUTION: Be certain the sampler (or drive rod) is locked before unhooking the hoisting plug.

4. Unclip the hoist from the hoist plug and clip it into the Kelly. Unrack a section of drill rod, couple the Kelly onto the top of the drive rod, lower the rod with the hoist, and couple the bottom of the rod onto the sampler.

5. Raise the rod-sampler-Kelly unit with the hoist, remove the locking wrench, and lower the unit into the hole (Figure 4e). Lock the drill rod in place with the special wrench when the slots at the top of the drill rod are even with the staging platform.

6. After the drill rod has been locked, unhook the Kelly

from the rod and repeat Steps 4 and 5 until the sampler rests on the bottom of the crib. Note the depth at which the sampler reached bottom.

7. Remove the hoist and hoist ring from the Kelly.

8. Mark on drive rods, with tape, the depth sampler is to be driven.

SAMPLE DRIVING

1. Attach a 2.5-centimeter diameter rope to the drive hammer.

2. Use the hoist to raise the drive hammer into position and attach it to the Kelly.

3. Clip guide ring to drive hammer (Figure 4f).

4. Start the cathead and use the 2.5-centimeter diameter rope to raise the hammer (Figure 4g).

   CAUTION: No one shall be within the bounds of the tripod legs during driving. Do not allow the rope to cross on the cathead drums. Always hold the rope so that it cannot cross over itself.

5. When the hammer has been raised to the desired travel, release the rope on the cathead and allow the manner to drop and pound the sampler into the crib. Keep track of the hammer travel and number of strokes required to drive sampler.

6. Repeat Steps 3 and 4 until the sampler has been driven 27 centimeters into the crib.

7. Shut off the cathead.

8. Unhook the hammer from the Kelly and use the hoist to lower it back to the ground.

SAMPLER RETRIEVAL

1. Using a special wrench on the top of the Kelly, rotate the drill string clockwise until tight to insure that the connections are locked.

2. Insert the rod puller into the slots in the drill rod above the stage platform.

3. Attach the hoist and lifting plug to the Kelly. Using the hydraulic jacks on the rod puller and the hoist, break the sampler loose.

4. Remove the rod puller from the drill rod and raise the first section of drill rod out of the hole with the hoist. Lock the second drill rod with the special wrench through the slots just above the stage platform.

5. After securing the second drill rod with the special wrench, disconnect the first rod and rack it.

6. Repeat Steps 4 and 5 until all the drill rods have been removed from the hole and the sampler is secured on the stage platform by a special wrench through its slots.

7. Set the Kelly aside and unclip the hoist. Clip the hoist onto the lifting plug and raise the sampler out of the hole.

8. As soon as the sampler clears the hole, cap the end with tape and a plastic plug. Bag the sampler out of the hood (Figure 4h).

FURTHER OPERATION

1. Repeat the sample operation as required to reach the desired depth. The guide tubes may be relocated to

different positions in the same hole as required by partially pulling them out of the hole, canting them off to an angle, and then relowering them.

2. When the required sampling depth exceeds a depth of 3 meters below the trench floor, threaded steel casing will be substituted for the aluminum guide tubes. The steel casing will be added in 1-meter sections during sampling operations until the desired depth is reached.

HOOD MOVEMENT AND/OR CLEANUP

1. When all sampling operations at a hole have been completed, pull the guide tubes out of the hole, section them in lengths appropriate for burial (depending on the availability of a burial box or drums), and bag them out of the hood (Figure 4i).

   NOTE: It may be desirable to leave a guide tube in place for future work.

2. After the guide tube and all other equipment have been removed from the hole, don an assault mask, attach hoisting harness, raise the sampling hood with hoist, and tape a plastic cover over the adapter hole in the bottom of the hood. Cap the adapter with a similar plastic cover (Figure 4j).

3. Lower the hood onto the dolly, survey the area, and remove the hood.

4. Remove the adapter from the hole, cap both ends, and bag the adapter for further use. Survey the area; then cap the hole with the original steel plate (Figure 4k). Paint area to prevent corrosion of steel plate (Figure 4ℓ).

NOTE: If a guide tube is left in the access hole for future use, cover the tube end with two layers of plastic and seal to floor with tape.

5. Remove the plastic from the trench top.

6. The drilling rig and hood may be moved to other 20- or 10-centimeter sampling holes on the trench top as required. Repeat Steps "Glove Box Placement" through "Hood Movement and/or Cleanup" of this procedure as required for each sampling hole.

SAMPLE BREAKDOWN[2]

Each sampling was bagged into Glove Box 10, examined for external damage, and dismantled. Before the cores were disturbed, the following observations were made:

1. The exact fullness of the sample.
2. Condition of the brass tubes.
3. Degree of soil compaction.
4. Obvious obstacles to sampling, such as large rocks.
5. A CP reading over each 15-centimeter section.

Each 15-centimeter section was then capped and set aside for further treatment.

Each 60-centimeter sampler was divided into four 15-centimeter sections. The following analyses on an aliquot from these 15-centimeter sections were made in the following order of priority. Soil for plutonium analysis was obtained by taking a 2.5-centimeter diameter core sample 8 centimeters

[2] Letter, V. L. Schuelein and M. H. Campbell to R. E. Isaacson, "Sampling of Z-9 Trench," May 24, 1973, Atlantic Richfield Hanford Company.

deep on the end of every 15-centimeter section. By taking the 2.5-centimeter diameter core sample from the center of the 15-centimeter diameter core sample, the plutonium contamination smeared downward on the outside of the 15-centimeter cores was avoided.

SAMPLE ANALYSES

1. Plutonium: A tared, 2.5-ml vial was filled and compacted for plutonium analysis by gamma counting. If enough sample existed, two samples were prepared.

2. Tap Density: Determined using the weight of the soil in the samples compacted to a known volume.

3. Water: (Volatiles to 150 °C) 10 to 15 grams of soil were heated at 150 °C to drive off all free water and volatiles to that temperature.

4. Cd, Cl^-, and NO_3^-: 15 to 20 grams of soil were contacted with 20 ml of distilled water for three minutes and centrifuged; Cd, Cl^-, and NO^{3-} were determined on the extract.

5. CCl_4: 10 to 15 grams of soil were contacted with 10-ml dichloromethane and 10-ml distilled water for three minutes. The sample was then filtered and the dichloromethane analyzed for CCl_4.

6. TBP: A 10- to 15-gram sample was contacted with 10-ml CCl_4 and 10-ml H_2O for three minutes, filtered, and the CCl_4 taken for analysis of TBP.

7. Total Volatiles: The sample which was used for H_2O determination was heated to 750 °C and the weight loss between 150 and 750 °C measured.

ALIQUOTS FOR DETAILED BREAKDOWN OF SECTIONS

SECTION A

Sample 1 — Top 2.5 centimeters of sludge. If the layer of sludge was more than 2.5 centimeters thick, it was noted and the excess over the 2.5 centimeters went into Sample 2.

Sample 2 — Five-centimeter soil sample from 2.5 to 7.5 centimeters from top.

Sample 3 — Bottom 7.5 centimeters of soil.

SECTION B

Sample 4 — Top 7.5 centimeters of soil.

Sample 5 — Bottom 7.5 centimeters of soil.

SECTION C

Sample 6 — All of "C" was treated as one sample.

SECTION D

Sample 7 — All of "D" was treated as one sample.

Each sample aliquot was photographed after its removal from the sampler.

It should be noted that when for some reason the sample was not full, the increment of sampling will start at the top of the soil sample received.

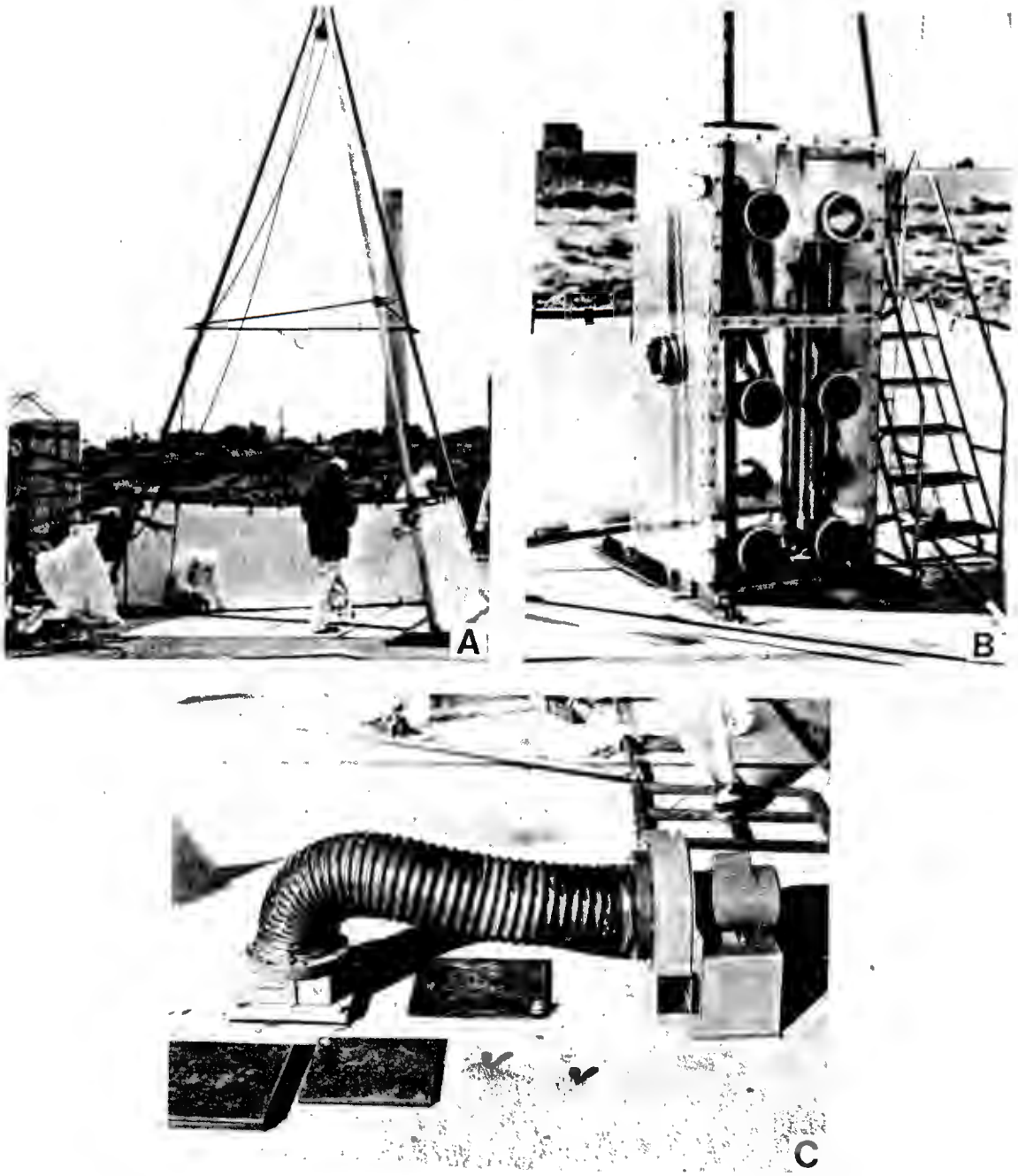

FIGURE 1

A. HOISTING TRIPOD. B. PORTABLE SAMPLING GLOVE BOX CONTAINING SAMPLING TOOLS. C. ABSOLUTE FILTER BLOWER ASSEMBLY FOR MAINTAINING NEGATIVE PRESSURE ON CAVERN

V7312-10.1

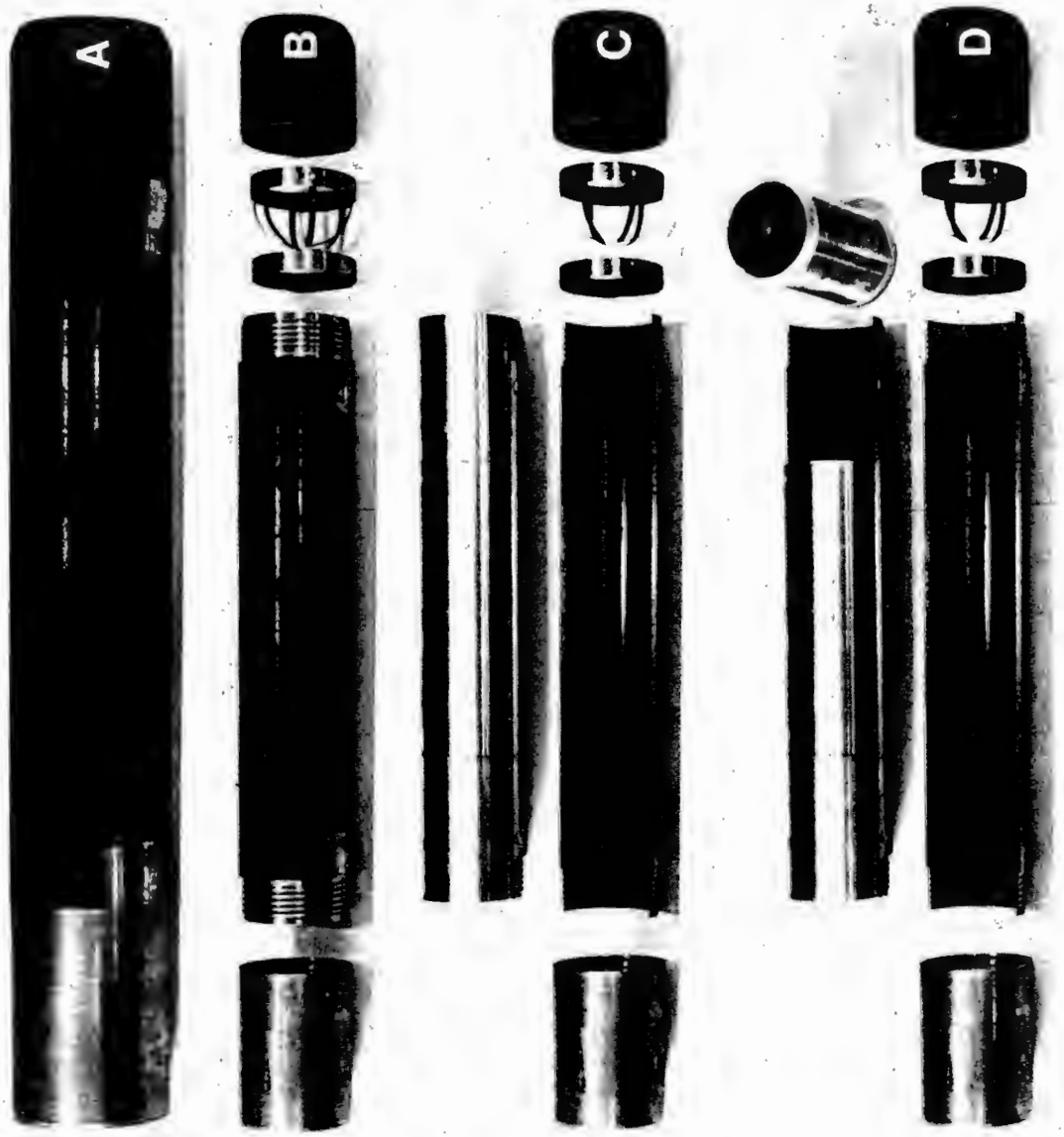

FIGURE 2

SPLIT TUBE DRIVE CORE SAMPLER

(a) Fully Assembled Sampler, (b) Sampler with Head and Drive Shoe Removed, Spacer Ring and Basket Lifter Shown at Drive Shoe, (c) Top Half of Split Tube Removed Exposing Brass Liners, (d) Brass Liner Removed and Capped for Storage.

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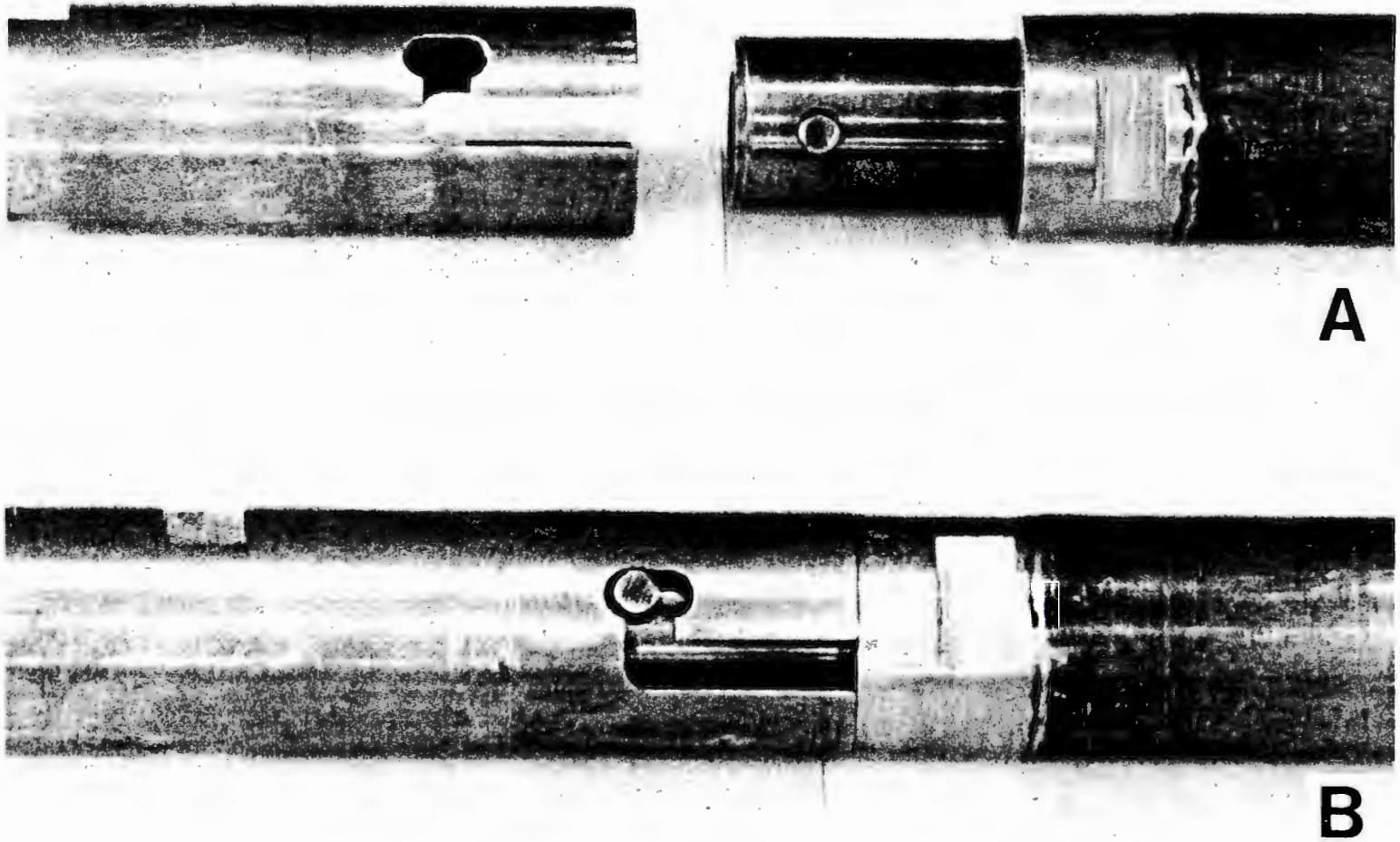


FIGURE 3

J-SLOT CONNECTOR FOR DRIVE RODS

a. Unlatched b. Latched

FIGURE 4

SAMPLING PROCEDURE

a. Centering of hoisting tripod over access hold.

b. Placement of sampling glove box.

c. Bagging in aluminum guide tube.

d. Bagging in split-tube drive core sampler.

e. Raising rod-sampler Kelly as a unit.

f. Sampler ready to be driven, note hammer above glove box with guide ring attached.

g. Motorized cathead wrench used to activate drive hammer.

h. Bagging out filled sampler.

i. Bagging out sections of used guide tube.

j. Removing hood from access hole.

k. Sealing bolted steel plate over access hole.

l. Painted access hole area.

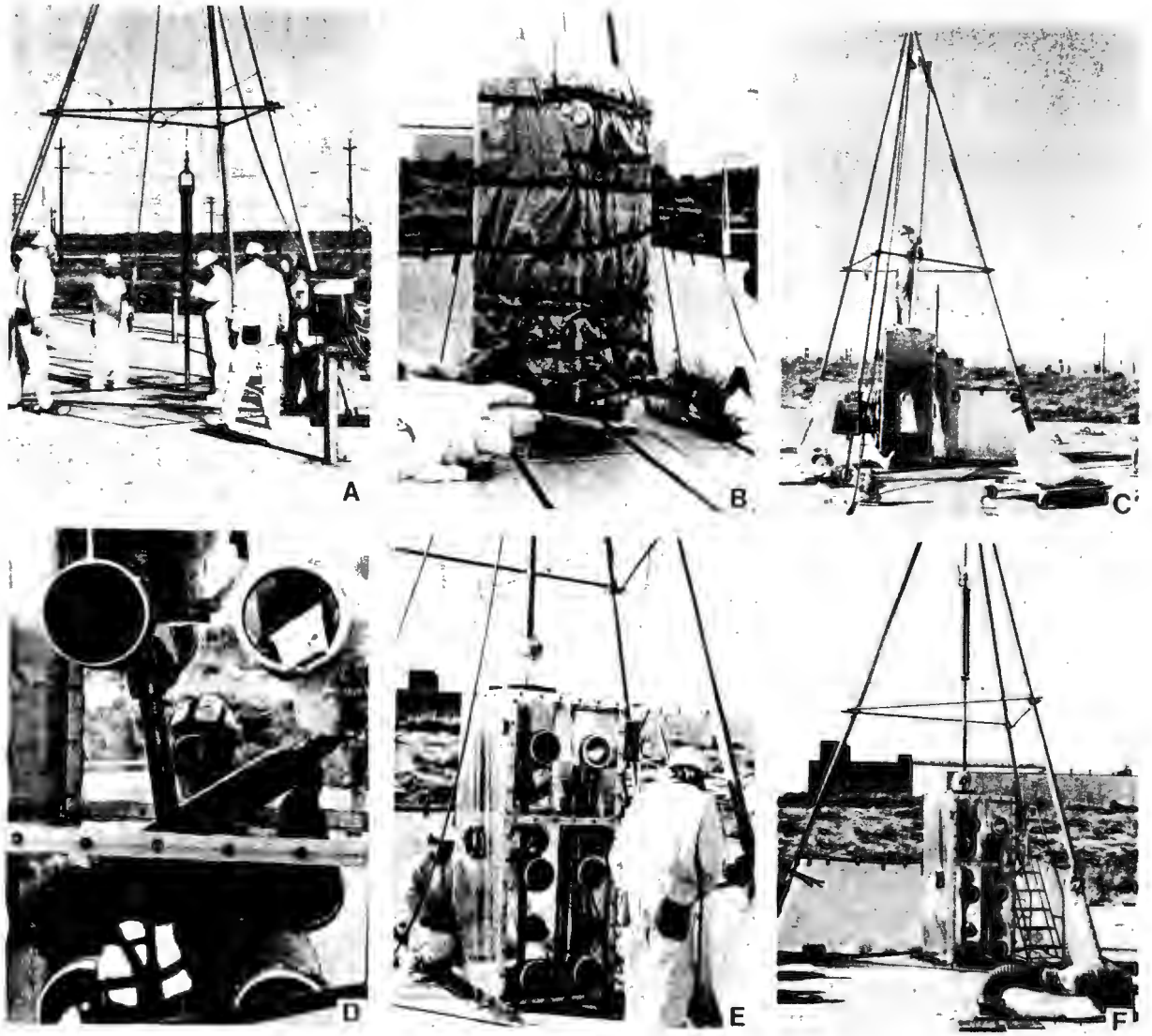


FIGURE 4

SAMPLING PROCEDURE

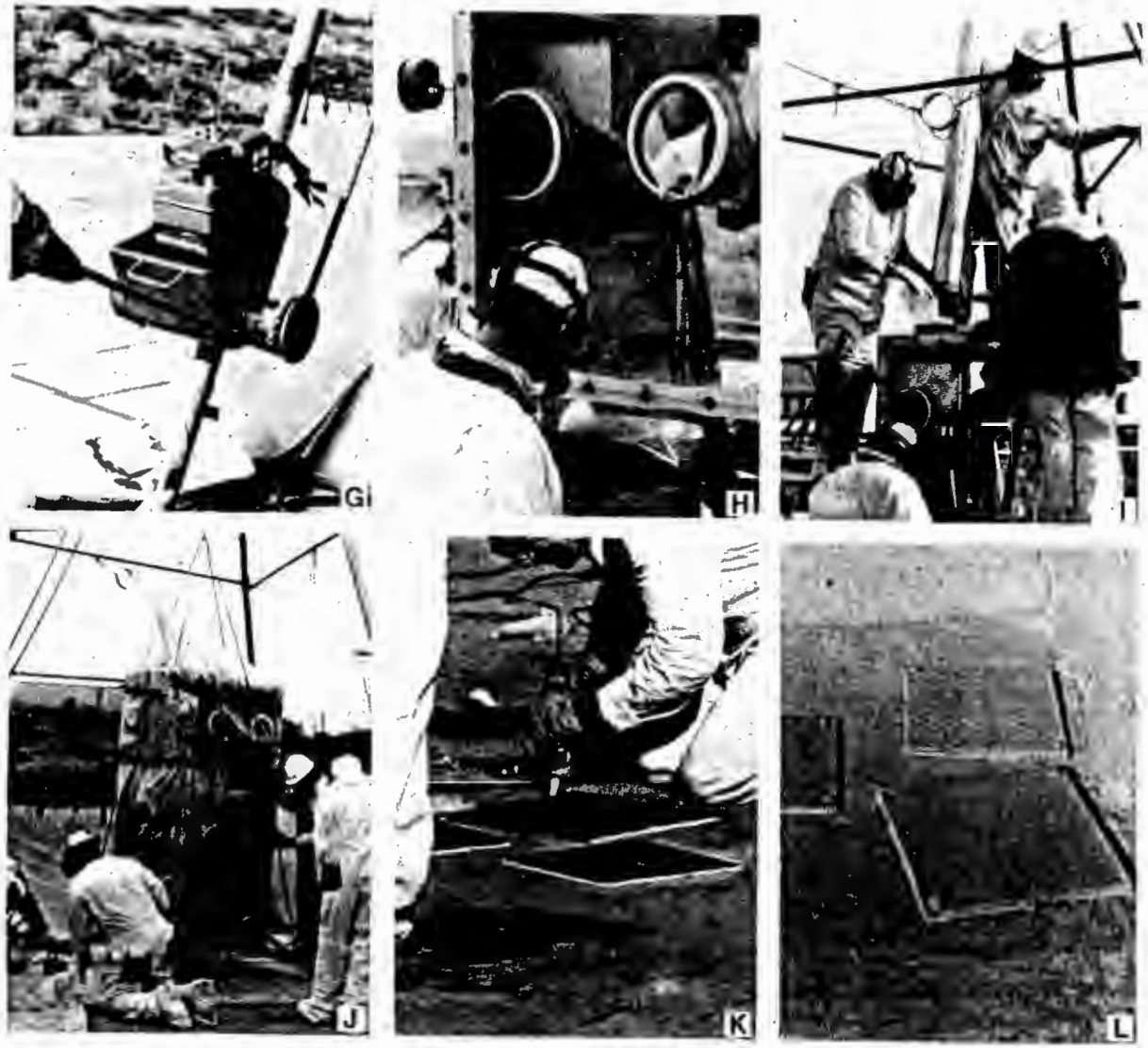


FIGURE 4 (continued)
SAMPLING PROCEDURE

APPENDIX B

LOCATION MAPS - SUMMARY SAMPLE LOGS[1]

W. H. Zimmer
V. L. Schuelein
M. C. Metz

FOREWORD

DESCRIPTION OF SAMPLING NUMBERING SYSTEM

Wells 1, 2, 3, and 4 were drilled on the edge of the 216-Z-9 (Z-9) Enclosed Trench in 1959. Wells 5, 6, 7, and 8 were drilled within the trench in 1961. Wells 9, 10, 11, and 12 were drilled and 5 through 8 were deepened in 1963. All these holes were drilled through 10-centimeter diameter access holes.

Twenty-centimeter diameter access holes A, B, and C were used to drill 2.4-meter deep sample holes in 1973. The samples removed from each hole are listed in Figure 2. The infrared, gamma, and neutron surveys made in 1973 located the region of maximum plutonium accumulation beneath Hole G. Thus in the summer of 1973, three 60-centimeter core samples were taken from Hole G and one sample each from nearby Holes D and H.

The split core samplers were 60 centimeters long and possessed an identification number, the first digit of which indicated the diameter of the sampler. There were eighteen 10-centimeter (4-inch) diameter samplers numbered from 4-1, 4-2, etc., up to 4-18. There were four 7.6-centimeter

[1] W. H. Zimmer, V. L. Schuelein, and M. C. Metz, "Interim Report: Sampling Techniques and Analyses of the 216-Z-9 Covered Trench," ARH-2752, August 1973, Atlantic Richfield Hanford Company.

(3-inch) diameter samplers labeled with numbers 3-1, 3-2, 3-3, and 3-5 (3-4 was not used). There were two 6.45-centimeter (2.5-inch) diameter samplers numbered 2.5-1 and 2.5-2. The two 5.1-centimeter (2-inch) diameter samplers were numbered 2-1 and 2-2.

Each 60-centimeter long sampler was divided into 15-centimeter sections labeled A, B, C, and D. The letter "X" was used to denote samples removed from the sampler shoe. The hyphenated numbers -1 or -2 following the letter on analytical results usually indicated that duplicate samples were taken from the 15-centimeter section. Only in the samplers taken in early summer of 1973 from Holes D, G, and H were the top two sections subdivided into smaller than 15-centimeter increments for analysis. After the work was completed and documented, an administrative decision was made to use the metric system and convert inches to centimeters. Thus the rather odd selection of depth values in centimeters may be more comprehensible when converted back to inches.

INTRODUCTION

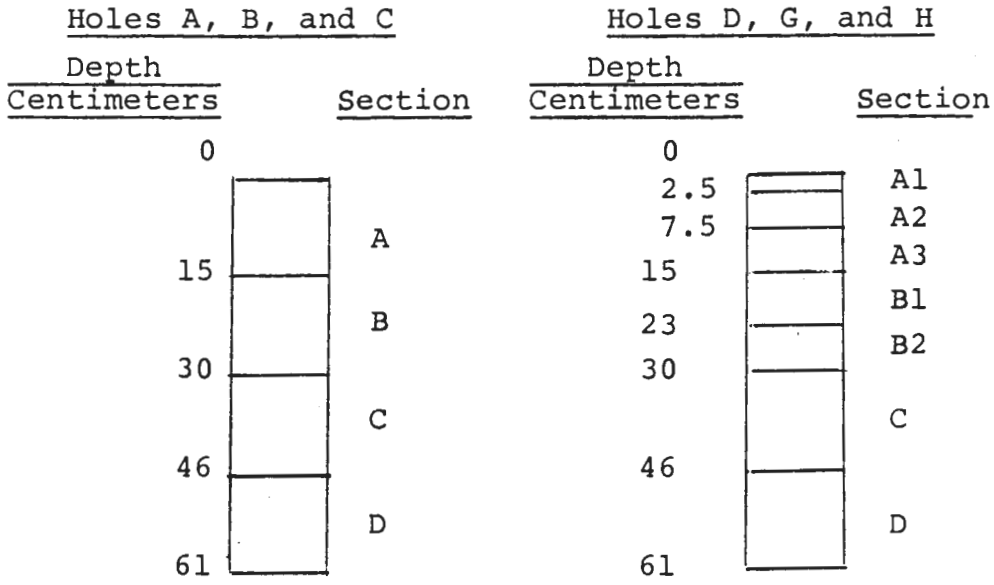
Appendix B contains four types of data pages. Pages B-4 and B-5 are sample locator references. The access holes in the cover of the enclosed trench (page B-4) and the sample core entry points in the floor of the enclosed trench (page B-5) are both located with reference to the plan of the trench and to survey coordinates of the Hanford Reservation.

The detailed numerical data pages (page B-6, for example) record the concentrations of ^{239}Pu and ^{241}Am to a given percent 2σ precision. The Sample Code entry corresponds to the identification nomenclature on the Summary Sample Logs.

The Summary Sample Log pages (page B-7 for example)

correlate the depth to which each drill hole was sampled, the presence or absence and the condition of the sampled material in each core section, and the identification nomenclature of each sample analyzed.

The concentration versus depth plots of each drill hole (see page B-8 for example) graphically show a continuous depth representation of ^{239}Pu and ^{241}Am concentrations as 2σ accuracy bars. They summarize the detailed numerical data. The plots also record the coring force necessary to drive the sample corer(s).



Duplicate samples from sampler 4-14, for example, would be labeled 4-14-A1-1 and 4-14-A1-2 from the top 2.5 centimeters and 4-14-A2-1 and 4-14-A2-2 from between 2.5 and 7.5 centimeters.

An ideal sample was not attained in every sampler. In many cases the soil in the bottom of the sampler fell back into the hole and surface soil was knocked down into the hole. The sampler was then either partly empty or it contained surface soil; that is, cross-contamination. Notations of these events were made on the summary sample logs.

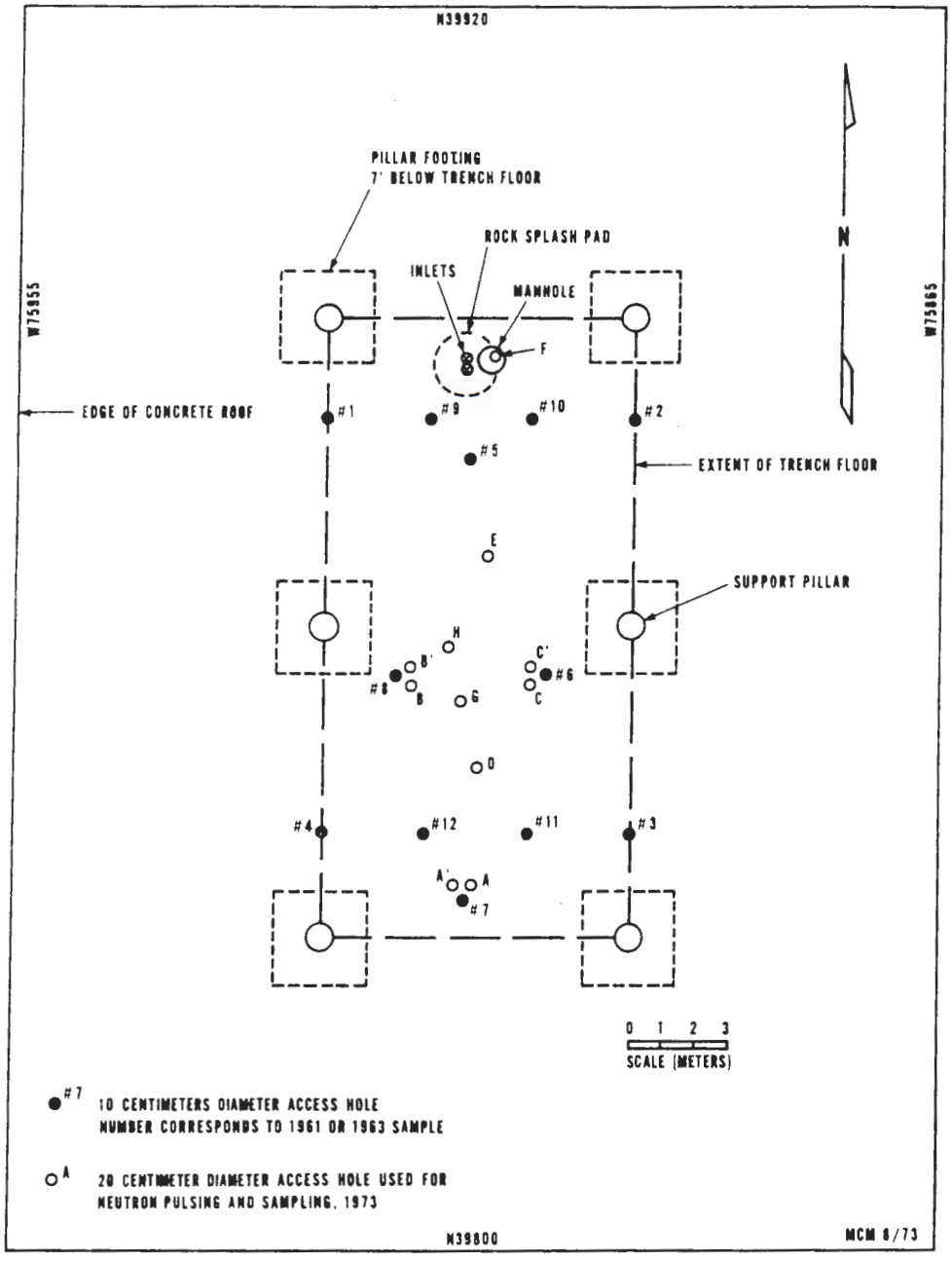


FIGURE B-1

216-Z-9 PLAN VIEW AND ACCESS HOLE LOCATION

V7312-10.6

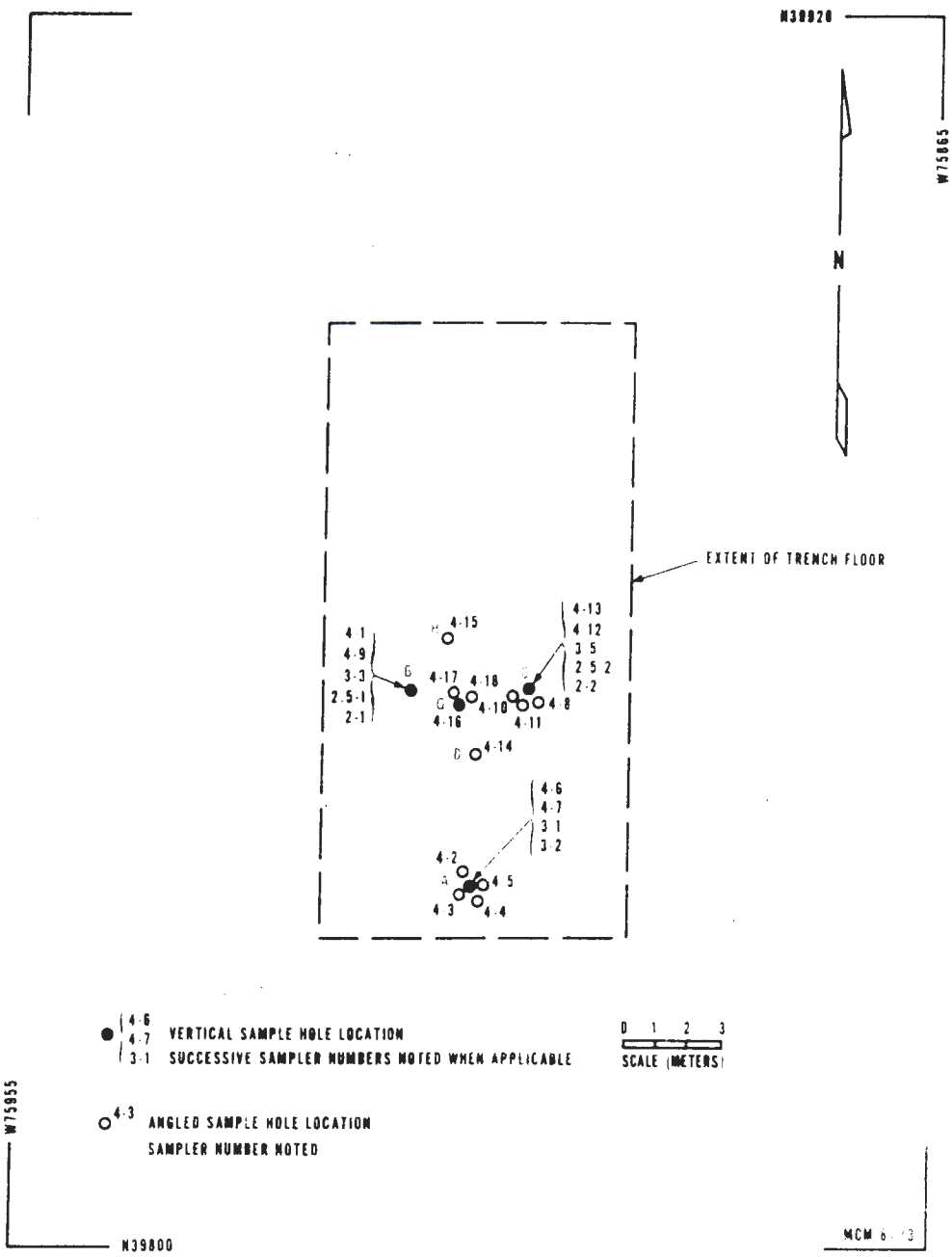


FIGURE B-2

216-Z-9 SAMPLE LOCATIONS 1973

V7312-10.7

TABLE B-I

PLUTONIUM AND AMERICIUM VALUES VERTICAL SAMPLE HOLE "A"

Sampler Number	Section Number	Depth Centimeters	Milligrams ^{239}Pu Per Liter of Soil ±Percent 2σ	Microcuries ^{241}Am Per Liter of Soil ±Percent 2σ
4-6	A-1	-	No sample	No sample
	A-2	-	No sample	No sample
	B-1	0- 8	538 ±5	3250 ±0.4
	B-2	8- 15	592 ±1	3620 ±0.1
	C-1	15- 23	237 ±11	1400 ±0.8
	C-2	23- 30	256 ±2	1670 ±0.2
	D-1	30- 46	142 ±12	999 ±0.8
	D-2	30- 46	174 ±10	1110 ±0.8
	X-1		-	-
	X-2		-	-
4-7	A-1	45- 69	399 ±9	2640 ±0.7
	A-2	45- 69	418 ±8	2660 ±0.6
	B-1	69- 84	145 ±16	823 ±1
	B-2	69- 84	153 ±15	818 ±1
	C-1	84- 99	60 ±5	343 ±0.3
	C-2	84- 99	60 ±5	350 ±0.3
	D-1	99-114	76 ±4	386 ±0.3
	D-2	99-114	84 ±4	438 ±0.3
	X-1	114-125	91 ±5	426 ±0.4
	X-2	114-125	79 ±5	363 ±0.4
3-1	A-1	107-117	421 ±4	2370 ±0.4
	A-2	107-117	412 ±6	2350 ±0.5
	B-1	117-132	381 ±9	2260 ±0.7
	B-2	117-132	No sample	No sample
	C-1	132-147	66 ±16	271 ±1
	C-2	132-147	94 ±5	424 ±0.4
	D-1	147-163	89 ±5	395 ±0.4
	D-2	147-163	92 ±5	413 ±0.4
	X-1	163-173	-	-
	X-2	163-173	-	-
3-2	A-1	173-178	No sample	No sample
	A-2	173-178	No sample	No sample
	B-1	178-193	85 ±21	385 ±2
	B-2	178-193	88 ±4	420 ±0.3
	C-1	193-208	58 ±6	302 ±0.5
	C-2	193-208	56 ±5	277 ±0.4
	D-1	208-224	49 ±5	262 ±0.4
	D-2	208-224	52 ±6	270 ±0.4
	X-1	224-234	-	-
	X-2	224-234	-	-

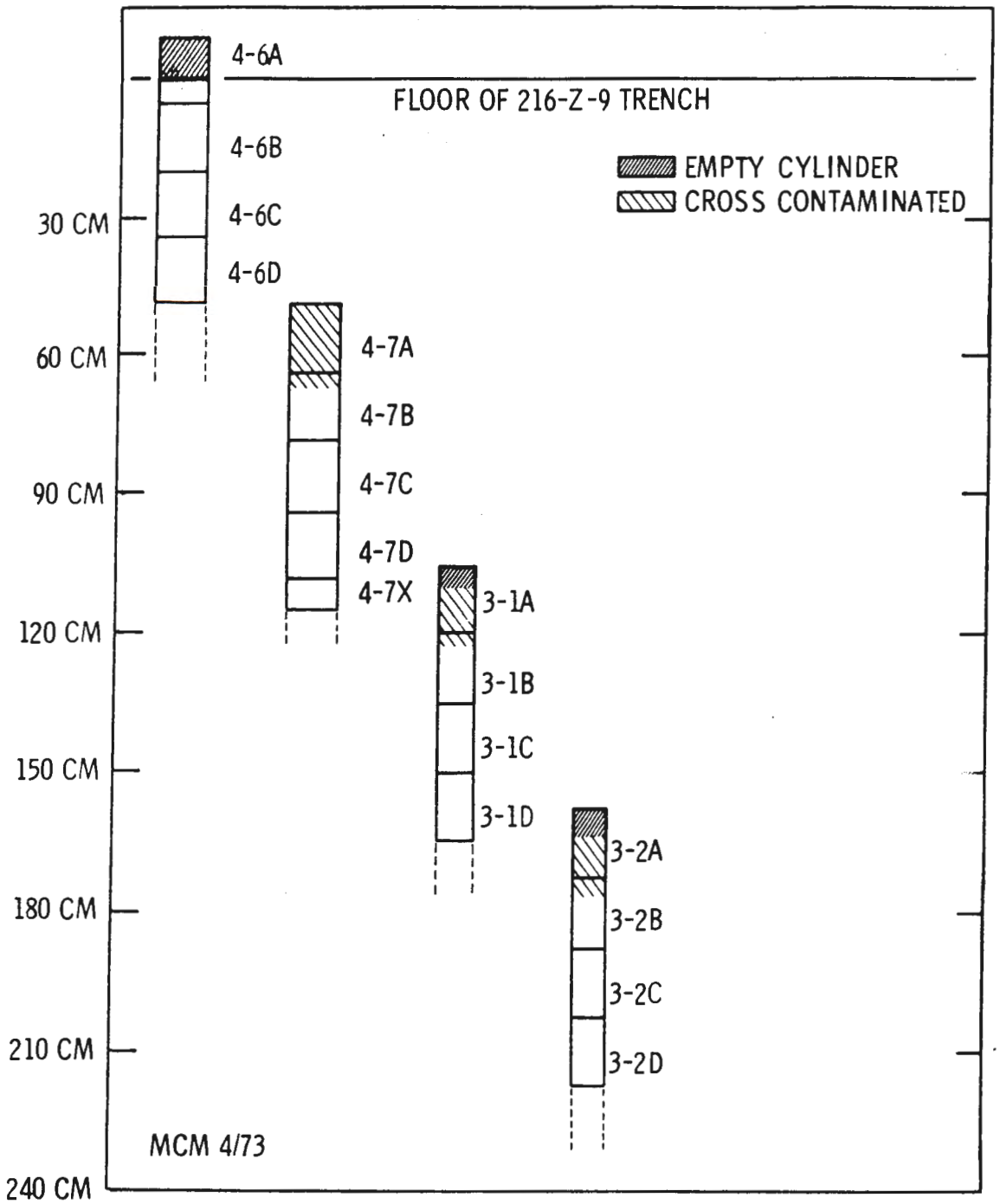


FIGURE B-3

SUMMARY SAMPLE LOG, VERTICAL DRILL HOLE,
20-cm ACCESS HOLE "A", 216-Z-9 TRENCH

V7312-10.8

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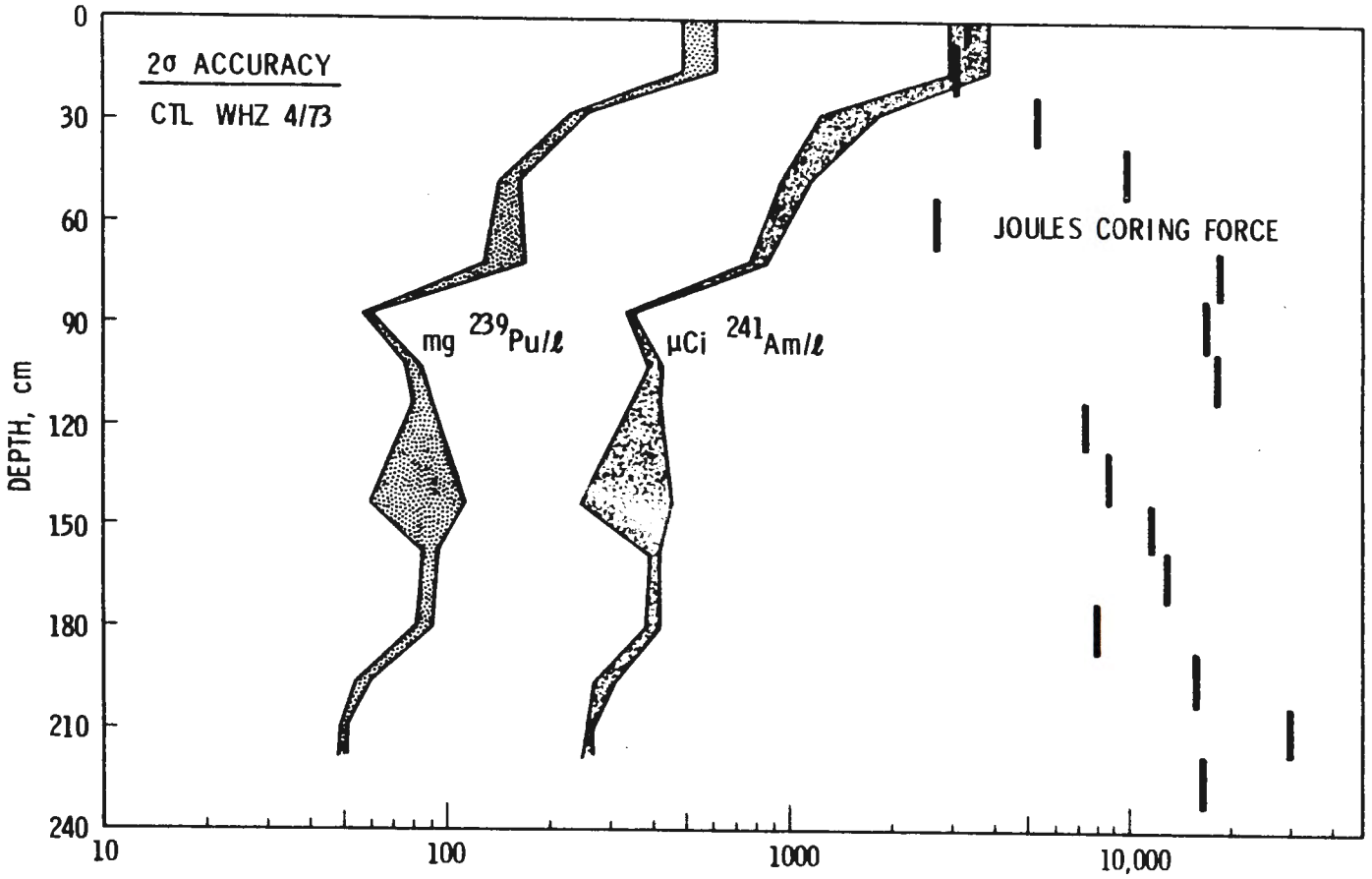


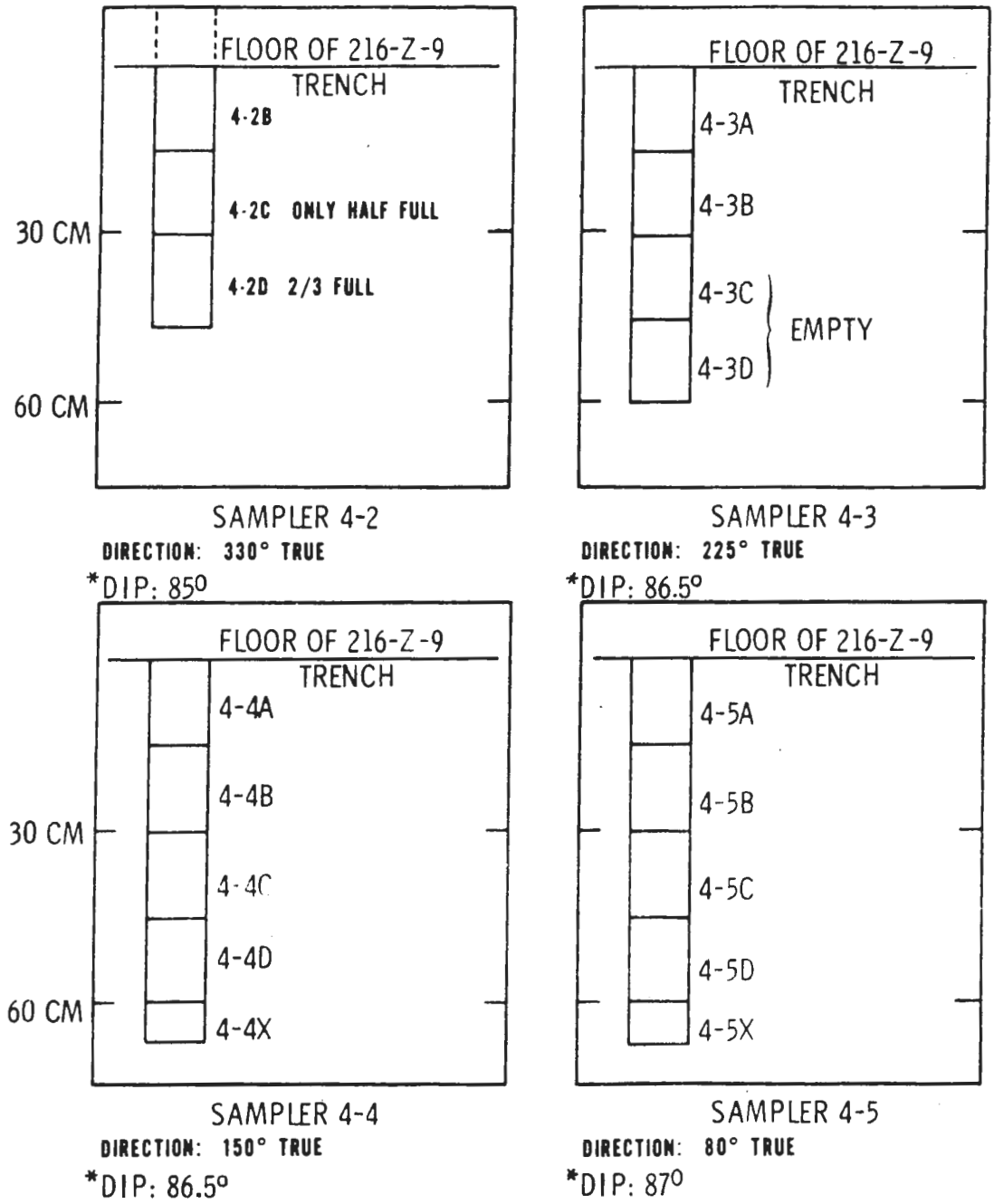
FIGURE B-4

VERTICAL SAMPLE HOLE "A", 216-Z-9

TABLE B-II

PLUTONIUM AND AMERICIUM VALUES ANGLED SAMPLES THROUGH HOLE "A"

Sampler Number	Section Number	Depth Centimeters	Milligrams ^{239}Pu Per Liter of Soil ±Percent 2σ	Microcuries ^{241}Am Per Liter of Soil ±Percent 2σ
4-2	B-1	7.6-15.2	640 ±7	4320 ±0.6
	B-2	0 - 7.6	2200 ±0.9	14000 ±0.1
	C-1	15.2-22.9	207 ±12	1450 ±0.9
	C-2	22.9-30.5	328 ±6	2150 ±0.4
	D-1	30.5-38.0	137 ±16	1050 ±1
	D-2	38.0-45.7	128 ±4	987 ±0.3
4-3	A-1	0 - 7.6	846 ±3	4810 ±0.2
	A-2	7.6-15.2	1230 ±4	7410 ±0.3
	B-1	15.2-22.9	230 ±7	1840 ±0.4
	B-2	22.9-30.5	296 ±11	2200 ±0.8
4-4	A-1	0 - 7.62	1630 ±4	10400 ±0.4
	A-2	7.6-15.2	926 ±6	5800 ±0.4
	B-1	15.2-22.9	140 ±15	879 ±1
	B-2	22.9-30.5	161 ±9	969 ±0.7
	C-1	30.5-38.1	121 ±11	680 ±0.9
	C-2	38.1-45.7	144 ±9	858 ±0.7
	D-1	45.7-53.3	-	-
	D-2	53.3-61.0	112 ±18	610 ±1.0
	X-1	61.0-68.6	58 ±6	289 ±0.5
	X-2	61.0-68.6	58 ±6	295 ±0.5
4-5	A-1		1119 ±3	8050 ±0.2
	A-2		-	-
	B-1		695 ±8	4730 ±0.5
	B-2		-	-
	C-1		407 ±11	-
	C-2		-	2470 ±0.6
	D-1		208 ±10	1140 ±0.7
	D-2		-	-



*DIP FROM HORIZONTAL

FIGURE B-5

SUMMARY SAMPLE LOGS FOR ANGLED SAMPLE HOLES ORIGINATING THROUGH 20-cm ACCESS HOLE "A", 216-Z-9 TRENCH

V7312-10.10

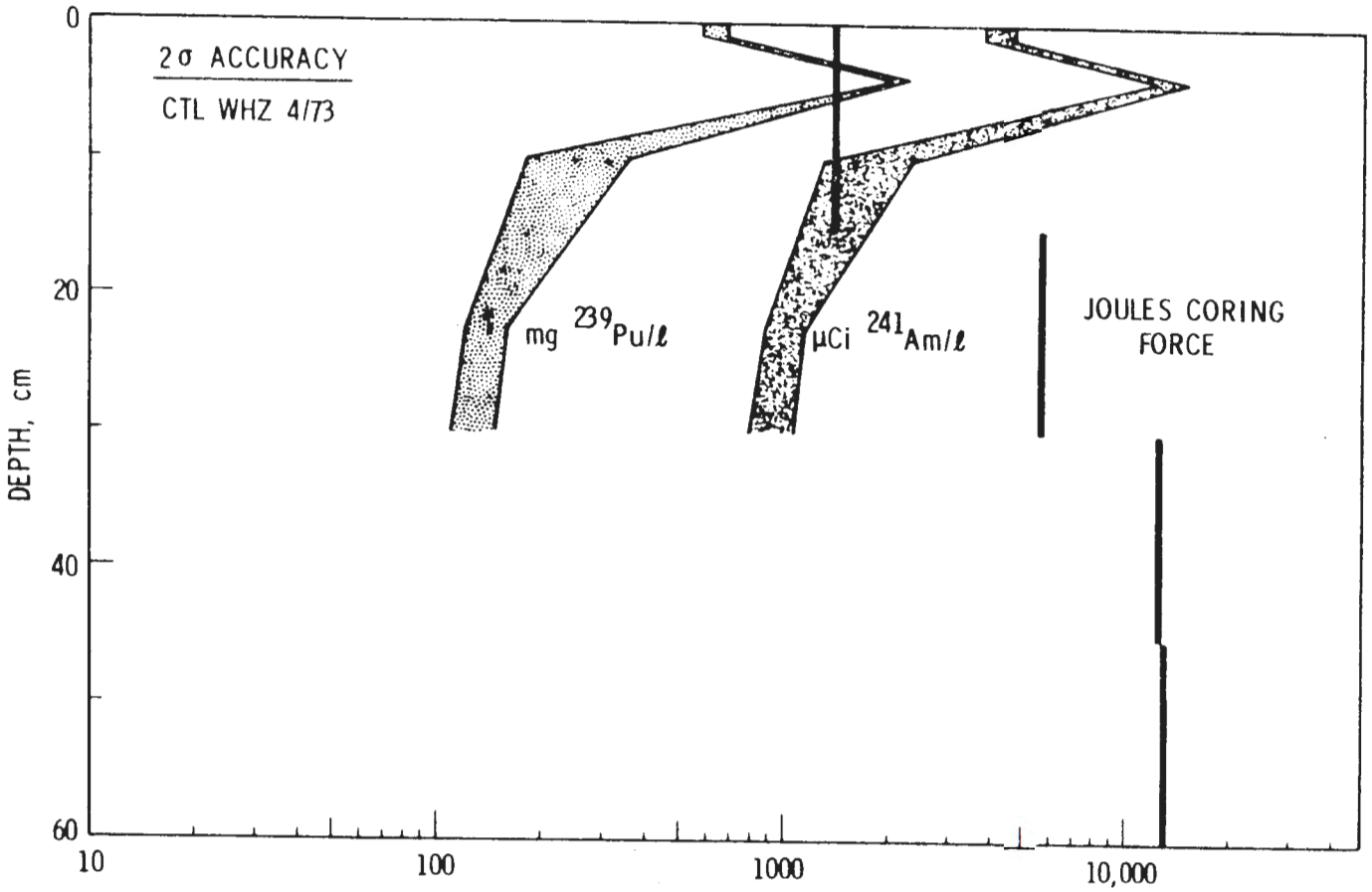


FIGURE B-6

ANGLED SAMPLE HOLE "A"
330° TRUE - 85° DIP
216-Z-9 4-2

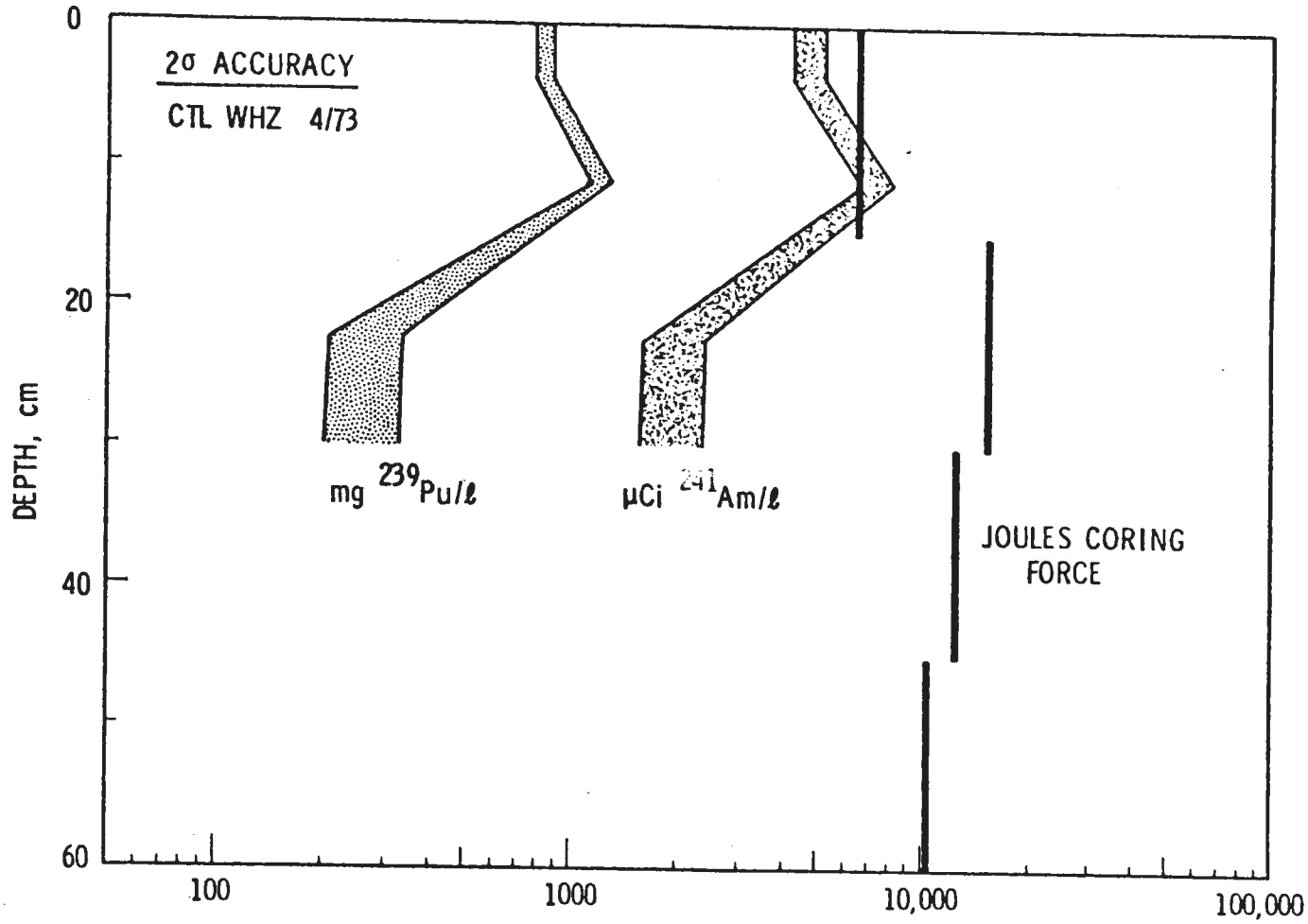


FIGURE B-7

ANGLED SAMPLE HOLE "A"
225° TRUE - 86.5° DIP
216-Z-9 4-3

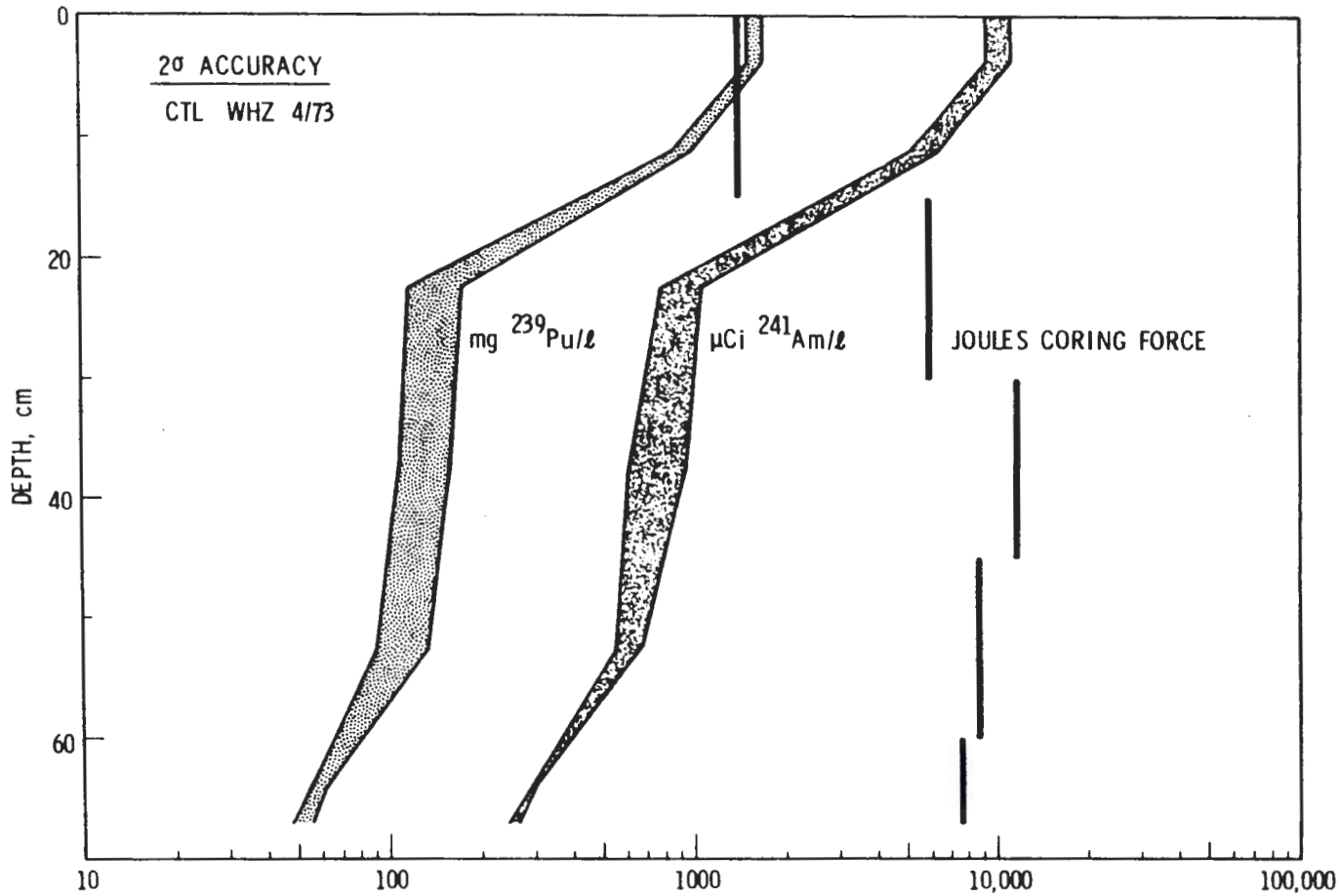


FIGURE B-8

ANGLED SAMPLE HOLE "A"
150° TRUE - 86.5° DIP
216-Z-9 4-4

ANGLED SAMPLE HOLE "A"

80° TRUE - 87° DIP

216-Z-9 4-5

This sampler was used by Battelle Pacific Northwest Laboratories for particle size, plutonium and mineral analysis. No depth versus plutonium graphs were prepared for this sampler.

TABLE A-III

PLUTONIUM AND AMERICIUM VALUES
VERTICAL SAMPLE HOLE "B"

Sampler Number	Section Number	Depth Centimeters	Milligrams ^{239}Pu Per Liter of Soil ±Percent 2σ	Microcuries ^{241}Am Per Liter of Soil ±Percent 2σ
4-1	A-1	0- 8 (sludge)	12300 ±2	79400 ±0.1
	A-2	8- 15	297 ±10	1810 ±0.8
	B-1	15- 30	98 ±12	608 ±0.9
	B-2	15- 30	130 ±11	818 ±0.9
	C-1	30- 46	105 ±12	580 ±0.9
	C-2	30- 46	130 ±11	716 ±0.9
	D-1	46- 61	115 ±11	614 ±0.9
	D-2	46- 61	122 ±10	646 ±0.9
4-9	B-1	48- 64	275 ±8	1670 ±0.6
	B-2	48- 64	171 ±10	1010 ±0.8
	C-1	64- 79	104 ±8	579 ±0.6
	C-2	64- 79	91 ±13	465 ±1.0
	D-1	79- 94	88 ±5	503 ±0.4
	D-2	79- 94	98 ±10	480 ±0.9
3-3	C-1	76-107	264 ±7	1730 ±0.5
	C-2	76-107	309 ±7	2040 ±0.5
	D-1		No sample	No sample
	D-2	?-122	599 ±5	3890 ±0.4
2.5-1	C-1	157-173	110 ±12	604 ±1
	C-2	157-173	126 ±10	684 ±0.9
	D-1	173-188	92 ±13	434 ±1
	D-2	173-188	117 ±10	556 ±1
2-1	B-1	206-221	110 ±10	491 ±1
	B-2	206-221	93 ±12	420 ±1
	C-1	221-236	103 ±5	494 ±0.4
	C-2	221-236	110 ±10	478 ±1
	D-1	236-251	119 ±10	543 ±1
	D-2	236-251	106 ±5	512 ±0.4

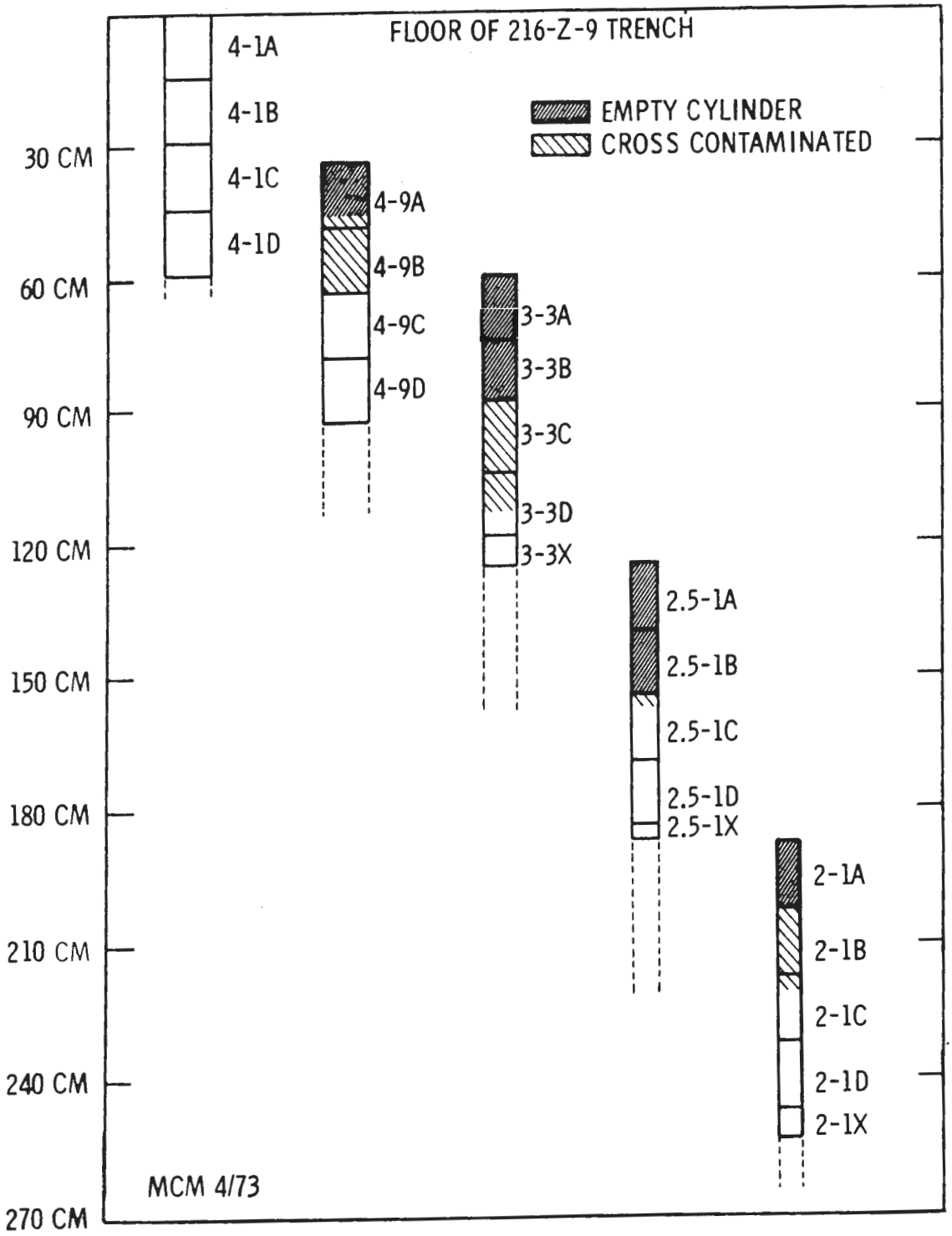


FIGURE B-9

SUMMARY SAMPLE LOG, VERTICAL DRILL HOLE, 20-cm ACCESS HOLE "B", 216-Z-9 TRENCH

V7312-10.14

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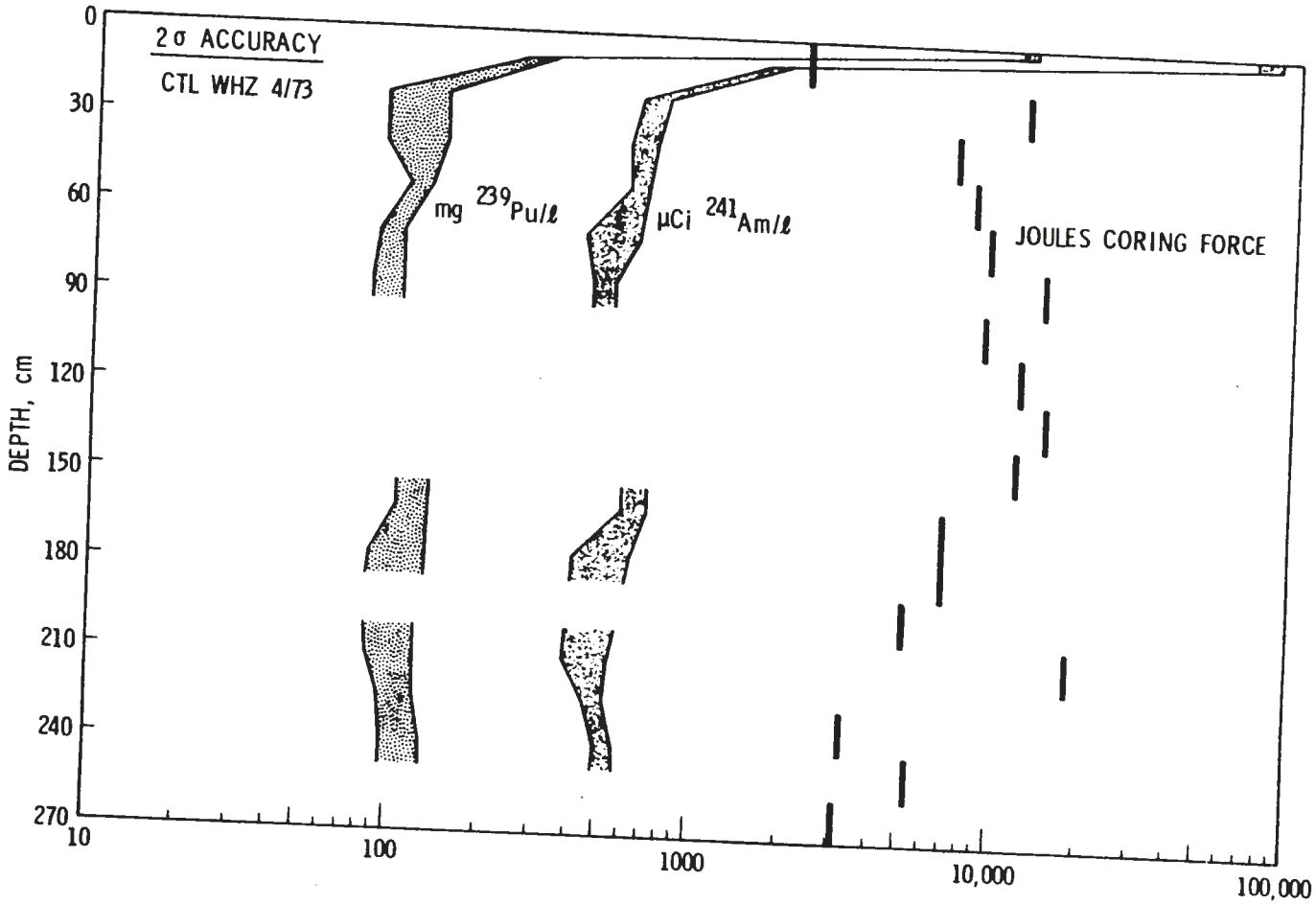

FIGURE B-10
VERTICAL SAMPLE HOLE "B"
216-Z-9

TABLE B-IV

PLUTONIUM AND AMERICIUM VALUES
VERTICAL SAMPLE HOLE "C"

Sampler Number	Section Number	Depth Centimeters	Milligrams ^{239}Pu Per Liter of Soil ±Percent 2σ	Microcuries ^{241}Am Per Liter of Soil ±Percent 2σ
4-13	A-1	2- 15	333 ±8	1,850 ±0.7
	A-2	2- 15	397 ±8	1,740 ±0.7
	B-1	15- 30	161 ±10	1,020 ±0.8
	B-2	15- 30	169 ±10	1,050 ±0.8
	C-1	30- 46	140 ±11	788 ±1.0
	C-2	30- 46	115 ±12	633 ±1.0
	D-1	46- 61	120 ±10	565 ±0.9
	D-2	46- 61	148 ±10	725 ±0.9
	X-1	61- 71	119 ±11	558 ±1
	X-2	61- 71	15,000 ±2	100,000 ±0.1
4-12	B-1	61- 76	1,980 ±8	12,700 ±0.2
	B-2	61- 76	2,250 ±8	14,800 ±0.6
	C-1	76- 91	110 ±10	479 ±0.9
	C-2	76- 91	102 ±19	477 ±0.2
	D-1	91-102	76 ±10	339 ±0.9
	D-2	91-102	106 ±11	486 ±1
3-5	A-1	102-122	850 ±4	5,060 ±0.3
	A-2	102-122	1,280 ±4	7,680 ±0.3
	B-1	122-152	233 ±9	1,240 ±0.8
	B-2	122-152	260 ±8	1,530 ±0.6
	C-1	152-168	86 ±11	395 ±0.9
	C-2	152-168	90 ±10	411 ±0.9
	D-1	168-183	55 ±15	263 ±1
	D-2	168-183	51 ±16	246 ±1
2.5-2	B-1	168-183	89 ±13	497 ±1
	B-2	168-183	81 ±14	463 ±1
	C-1	183-198	29 ±21	145 ±18
	C-2	183-198	41 ±19	171 ±2
	D-1	198-213	21 ±13	126 ±1
	D-2	198-213	16 ±16	105 ±1
2-2	A-1	211-226	120 ±11	663 ±0.9
	A-2	211-266	118 ±12	635 ±1
	B-1	226-241	42 ±17	210 ±1
	B-2	226-241	51 ±18	297 ±2
	C-1	241-256	39 ±16	222 ±1
	C-2	241-256	45 ±13	252 ±1
	D-1	256-272	31 ±18	124 ±2
	D-2	256-272	33 ±14	139 ±1

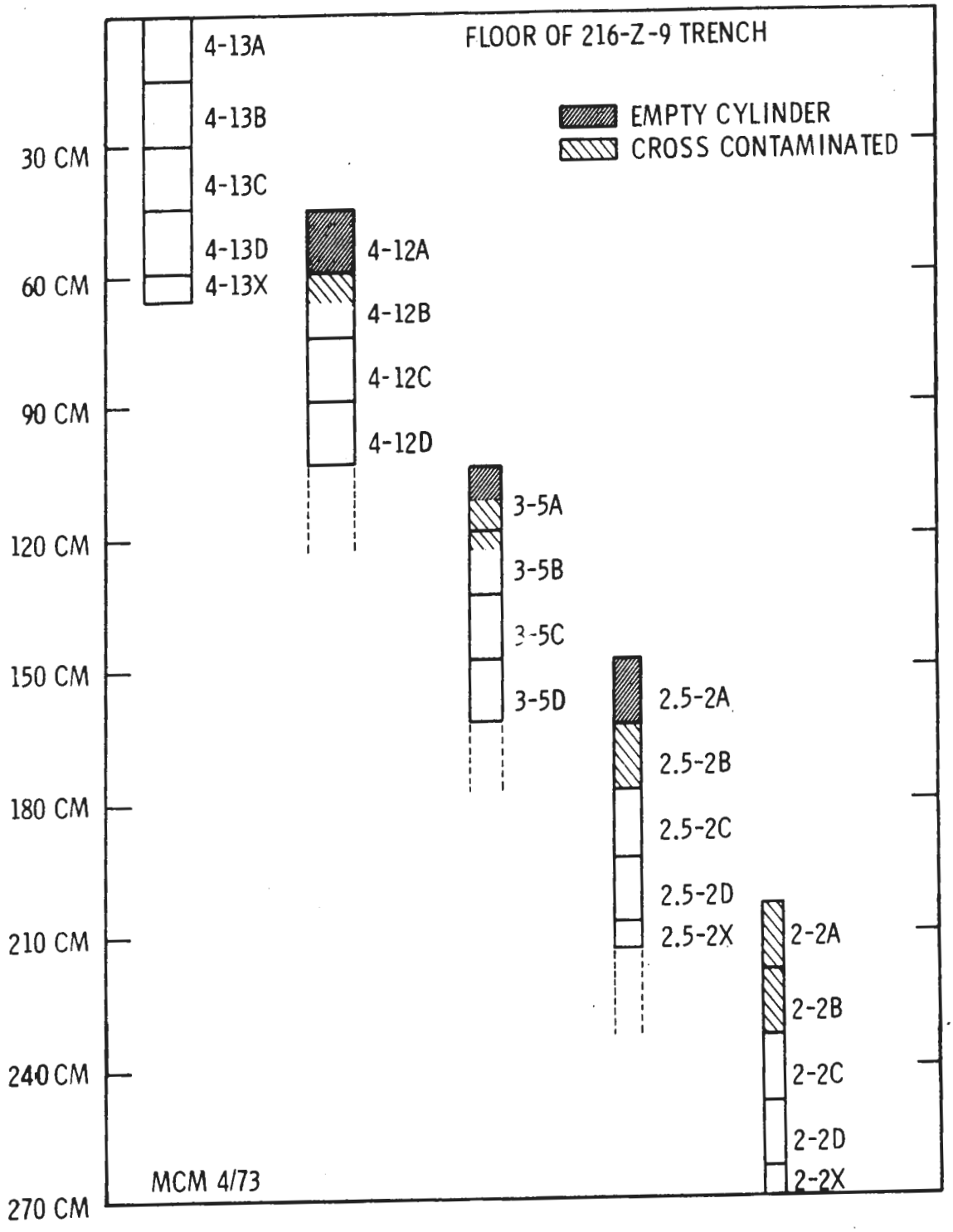

FIGURE B-11

SUMMARY SAMPLE LOG, VERTICAL DRILL HOLE.
20-cm ACCESS HOLE "C", 216-Z-9 TRENCH

V7312-10.16

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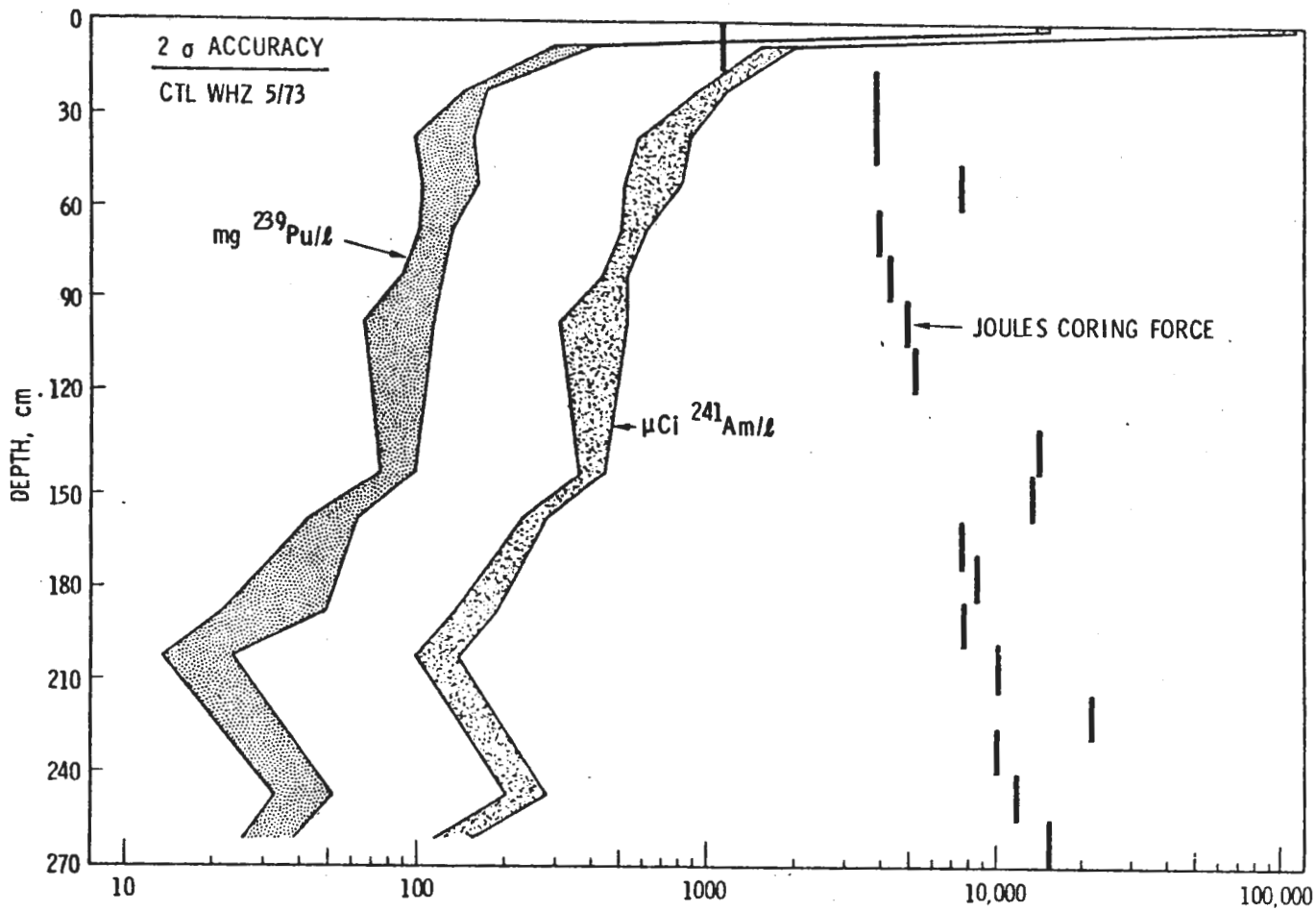

FIGURE B-12

VERTICAL SAMPLE HOLE "C"
216-Z-9

TABLE B-V

PLUTONIUM AND AMERICIUM VALUES
ANGLED SAMPLE HOLE "C"

Sampler Number	Section Number	Depth Centimeters	Milligrams ^{239}Pu Per Liter of Soil ±Percent 2σ	Microcuries ^{241}Am Per Liter of Soil ±Percent 2σ
4-8	A-1	0- 5	2,980 ±2	17,700 ±0.2
	A-2	0- 5	2,870 ±2	16,800 ±0.2
	B-1	5-20	293 ±7	1,940 ±0.6
	B-2	5-20	262 ±8	1,610 ±0.6
	C-1	20-36	118 ±12	674 ±1
	C-2	20-36	102 ±12	601 ±1
	D-1	36-51	127 ±11	645 ±1
	D-2	36-51	90 ±11	443 ±0.9
4-10	A-1	0- 2	2,760 ±2	18,800 ±0.1
	A-2	7-15	225 ±8	1,260 ±0.6
	B-1	15-30	170 ±10	925 ±0.8
	B-2	15-30	140 ±8	776 ±0.7
	C-1	30-46	120 ±11	558 ±0.9
	C-2	30-46	129 ±11	649 ±0.9
	D-1	46-61	103 ±4	541 ±0.3
	D-2	46-61	134 ±11	609 ±1
4-11	A-1		2,899 ±4	21,600 ±0.1
	B-1		373 ±9	3,440 ±0.9
	B-2		-	-
	C-1		263 ±9	2,470 ±0.8
	C-2		-	-
	D-1		170 ±7	946 ±0.7
	D-2		-	-
	X-1	61-71	164 ±10	708 ±0.9
	X-2	61-71	168 ±10	765 ±0.9

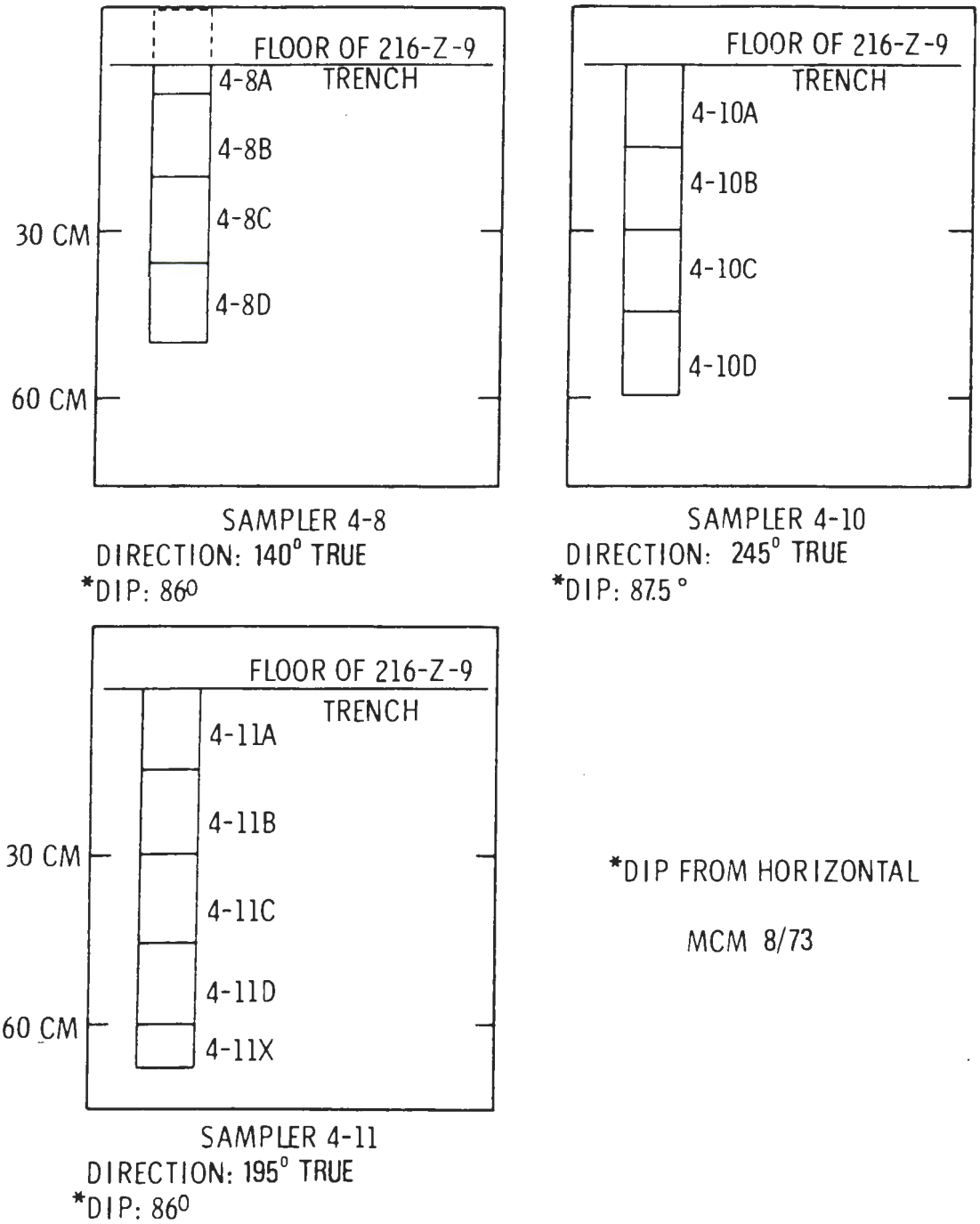

FIGURE B-13

SUMMARY SAMPLE LOGS FOR ANGLED SAMPLE HOLES ORIGINATING THROUGH 20-cm ACCESS HOLE "C", 216-Z-9 TRENCH

V7312-10.18

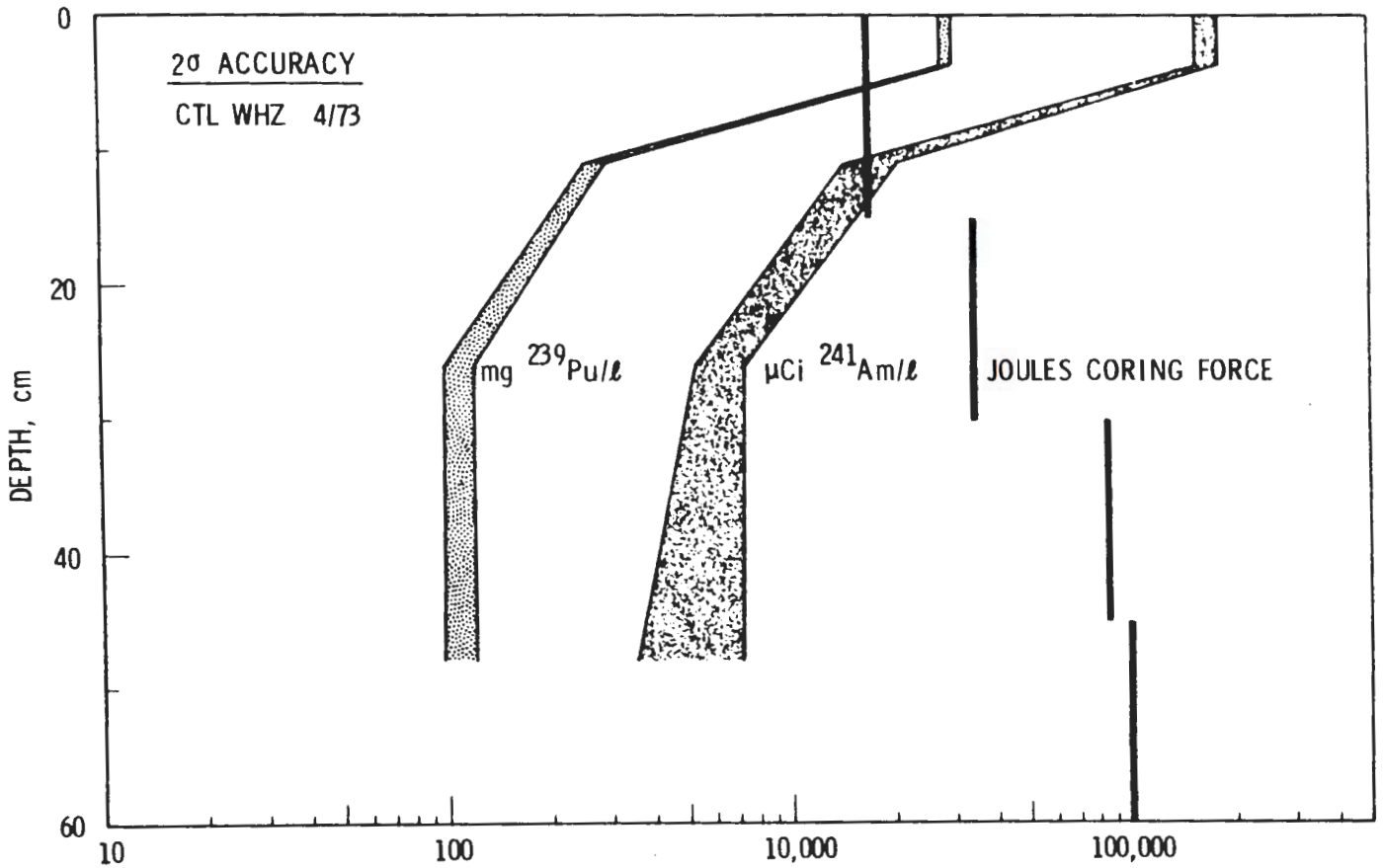

FIGURE B-14

ANGLED SAMPLE HOLE "C"
140° TRUE - 86° DIP
216-Z-9 4-8

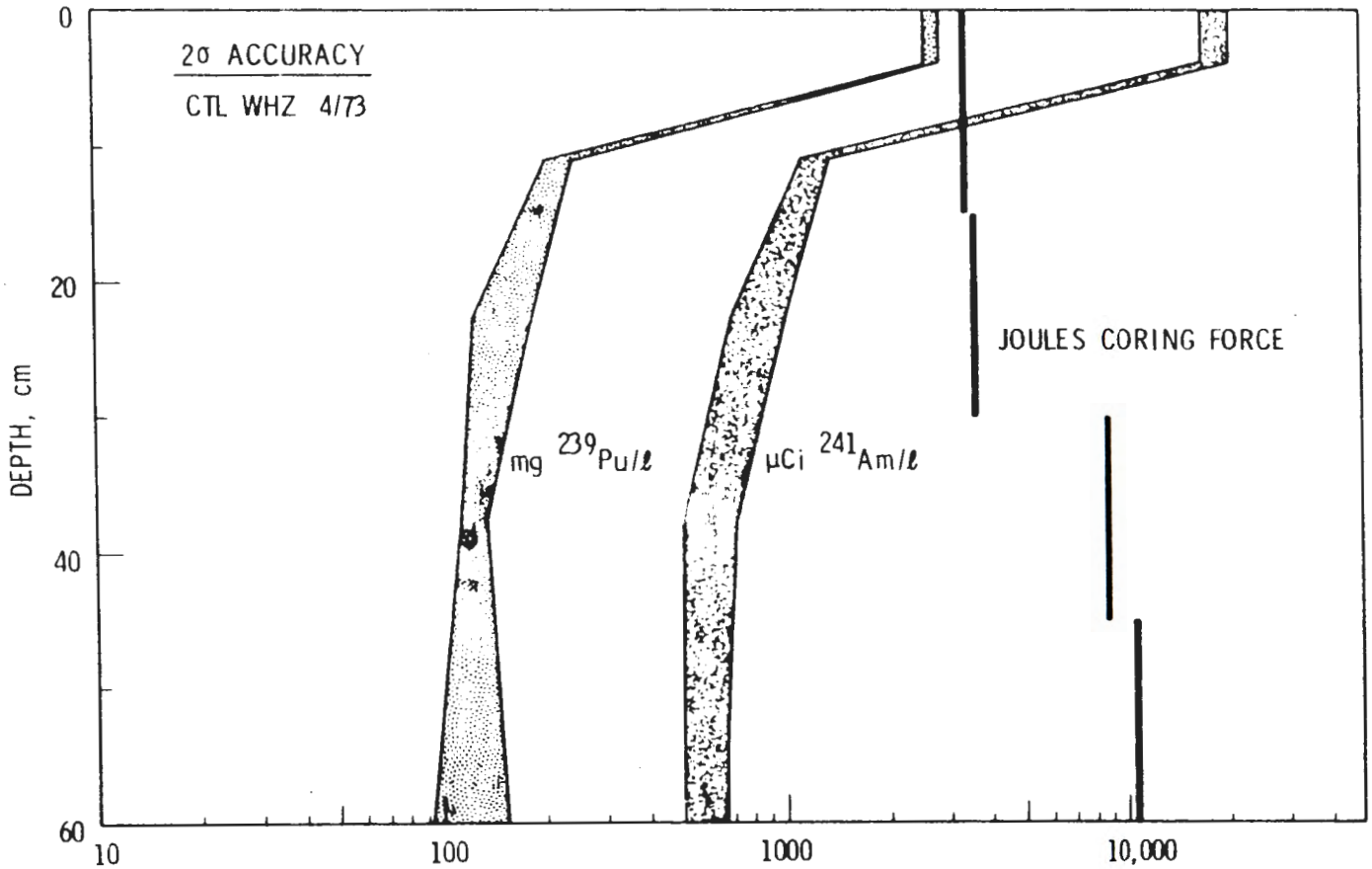

FIGURE B-15

ANGLED SAMPLE HOLE "C"
240° TRUE - 86.5° DIP
216-Z-9 4-10

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ANGLED SAMPLE HOLE "C"

195° TRUE - 86° DIP

216-Z-9 4-11

This sampler was used by Battelle Pacific Northwest Laboratories for particle size, plutonium and mineral analysis. No depth versus plutonium graphs were prepared for this sampler.

TABLE B-VI

PLUTONIUM AND AMERICIUM VALUES ANGLED SAMPLES THROUGH HOLE "D"

Sampler Number	Section Number	Depth Centimeters	Milligrams ^{239}Pu Per Liter of Soil ±Percent 2σ	Microcuries ^{241}Am Per Liter of Soil ±Percent 2σ
4-14	A1-1	0- 2	14,900 ±2	105,000 ±0.1
	A1-2	0- 2	12,700 ±2	89,200 ±0.1
	A2-1	2- 8	1,230 ±4	8,910 ±0.3
	A2-2	2- 8	1,160 ±4	8,450 ±0.3
	A3-1	8-15	171 ±10	743 ±0.9
	A3-2	8-15	155 ±10	726 ±0.9
	B1-1	15-23	107 ±10	508 ±0.9
	B1-2	15-23	102 ±10	468 ±0.9
	B2-1	23-30	88 ±11	378 ±1
	B2-2	23-30	96 ±10	410 ±1
	C-1	30-46	100 ±10	397 ±1
	C-2	30-46	74 ±10	288 ±0.9
	D-1	46-61	100 ±7	370 ±0.7
	D-2	46-61	93 ±9	327 ±0.9
	X-1	61-71	114 ±9	395 ±1
	X-2	61-71	106 ±10	358 ±1

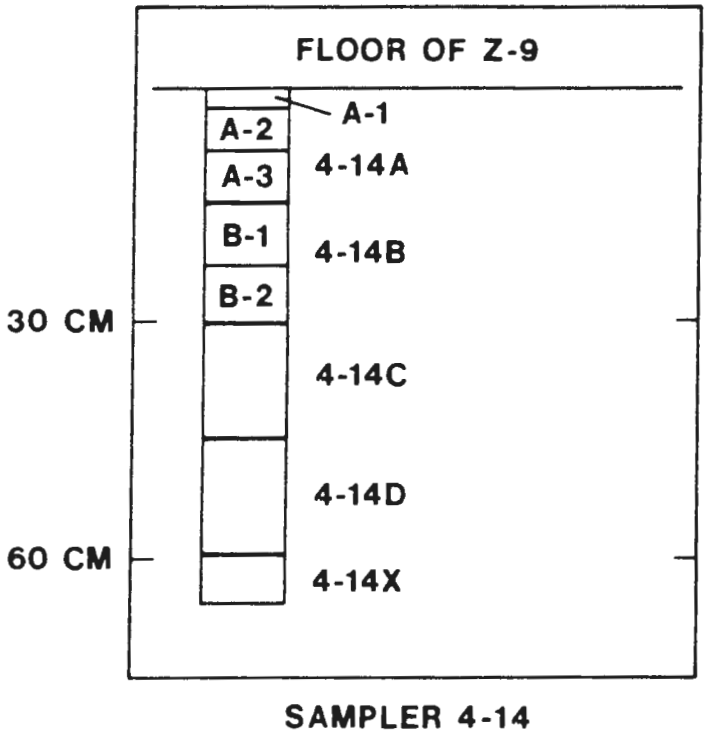

FIGURE B-16

SUMMARY SAMPLE LOGS FOR ANGLED SAMPLE HOLE THROUGH 20-cm ACCESS HOLE "D", 216-Z-9

V7312-10.21

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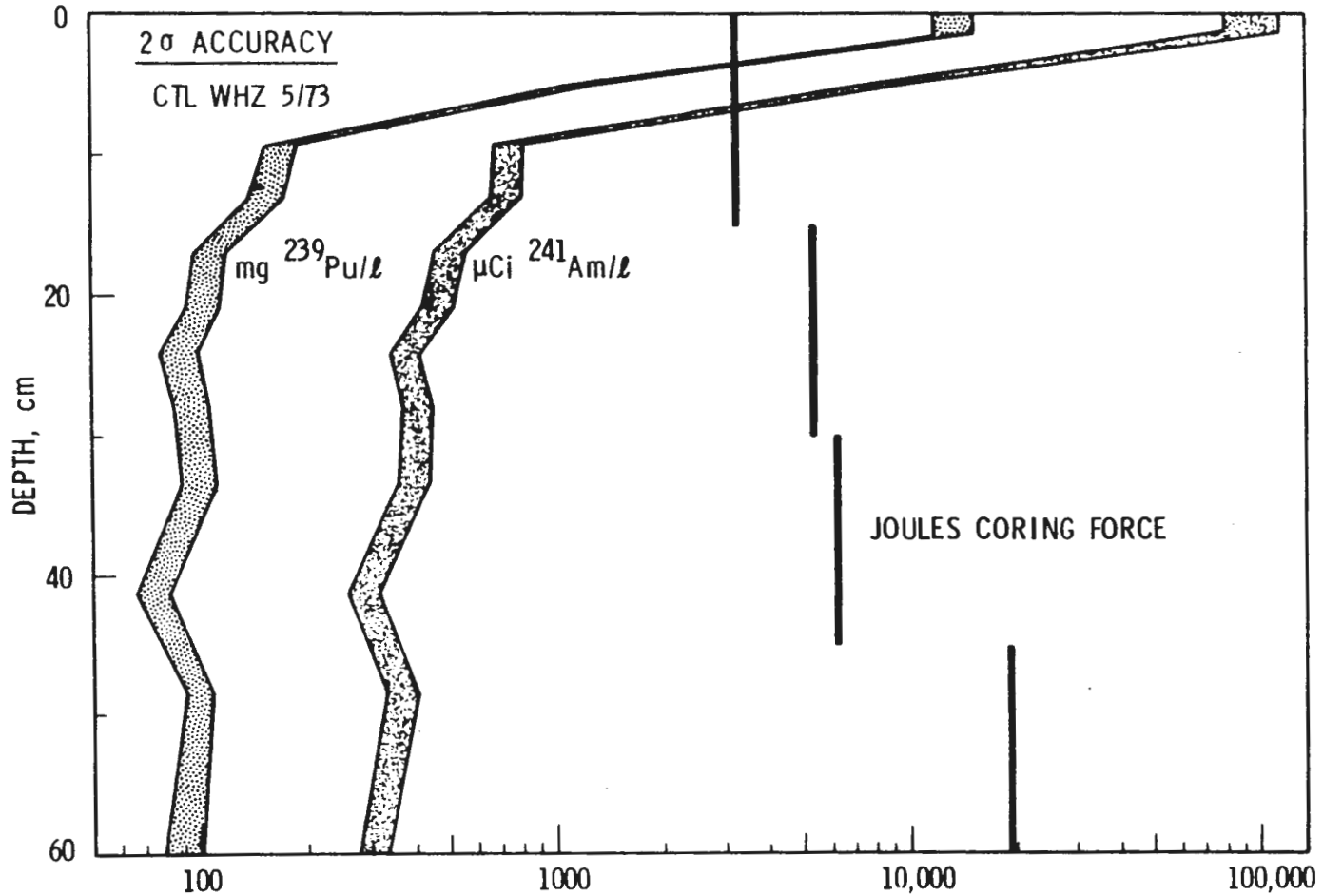

FIGURE B-17

ANGLED SAMPLE HOLE "D"
360° TRUE - 86.5° DIP
216-Z-9 4-14

TABLE B-VII

PLUTONIUM AND AMERICIUM VALUES
VERTICAL SAMPLE HOLE "G"

Sampler Number	Section Number	Depth Centimeters	Milligrams ^{239}Pu Per Liter of Soil ±Percent 2σ	Microcuries ^{241}Am Per Liter of Soil ±Percent 2σ
4-16	A1-1	0- 2	19,400 ±2	138,000 ±0.2
	A1-2	0- 2	20,200 ±2	143,000 ±0.2
	A2-1	2- 8	3,130 ±3	22,700 ±0.2
	A2-2	2- 8	5,700 ±2	41,400 ±0.1
	A3-1	8-15	186 ±9	1,350 ±0.7
	A3-2	8-15	111 ±11	844 ±0.8
	B1-1	15-23	103 ±11	763 ±0.7
	B1-2	15-23	122 ±10	869 ±0.7
	B2-1	23-30	100 ±10	787 ±0.7
	B2-2	23-30	105 ±10	765 ±0.7
	C-1	30-46	111 ±10	836 ±0.7
	C-2	30-46	89 ±11	620 ±0.8
	D-1	46-61	115 ±9	627 ±0.8
	D-2	46-61	104 ±8	524 ±0.7

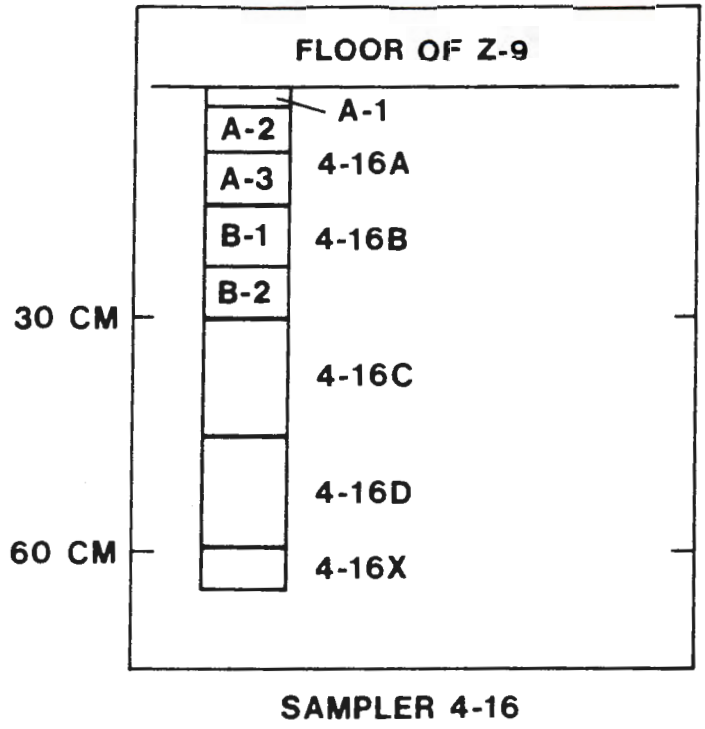

FIGURE B-18

SUMMARY SAMPLE LOGS FOR ANGLED SAMPLE HOLE THROUGH 20-cm ACCESS HOLE "G", 216-Z-9

V7312-10.23

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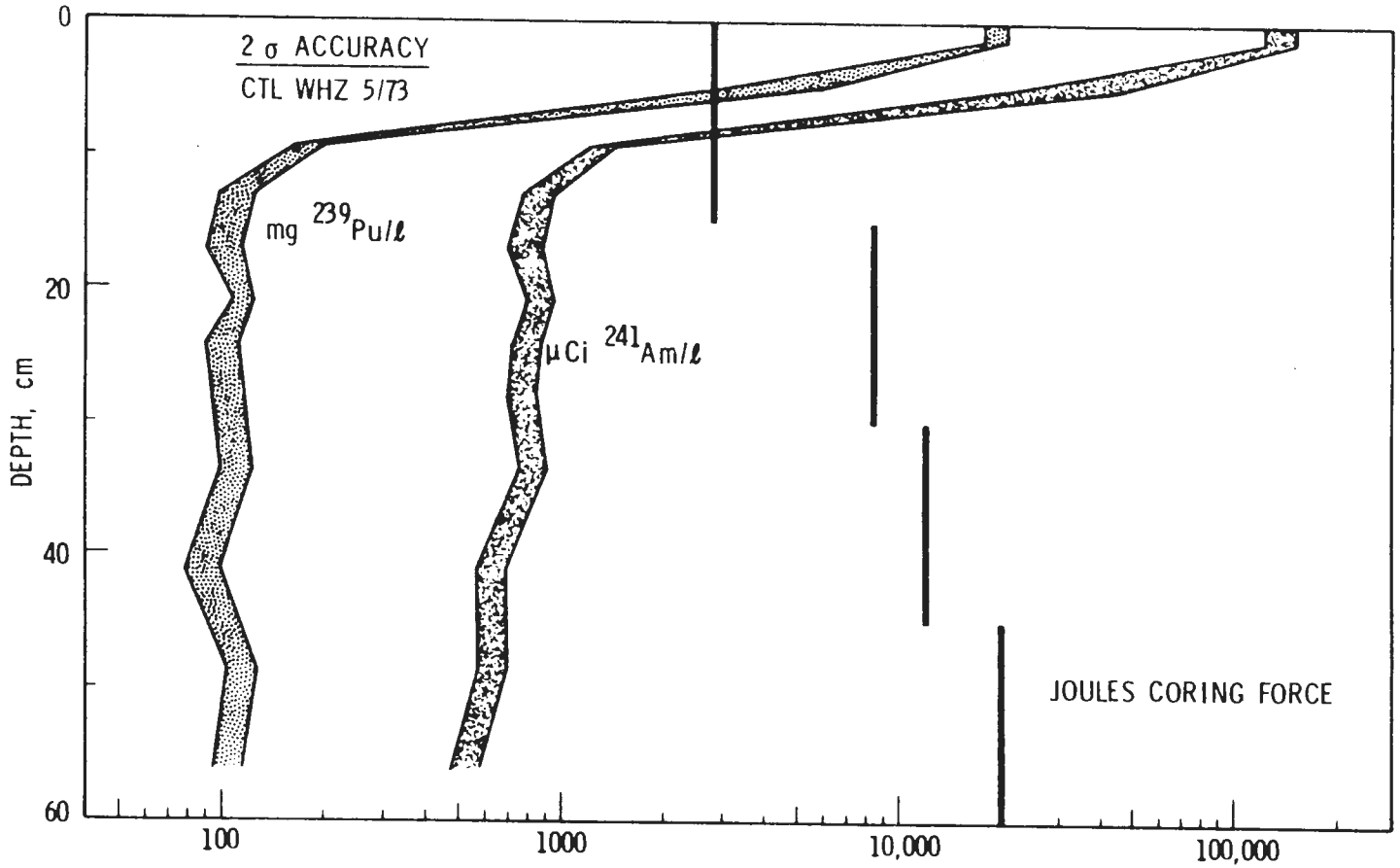


FIGURE B-19

VERTICAL SAMPLE HOLE "G"
216-Z-9 4-16

TABLE V-III

PLUTONIUM AND AMERICIUM VALUES ANGLED SAMPLES THROUGH HOLE "G"

Sampler Number	Section Number	Depth Centimeters	Milligrams ^{239}Pu Per Liter of Soil ±Percent 2σ	Microcuries ^{241}Am Per Liter of Soil ±Percent 2σ
4-17	A1-1	0- 2	18,200 ±2	133,000 ±0.2
	A1-2	0- 2	13,500 ±3	101,000 ±0.2
	A2-1	2- 8	1,480 ±3	11,000 ±0.2
	A2-2	2- 8	1,770 ±3	12,700 ±0.2
	A3-1	8-15	726 ±5	3,780 ±0.4
	A3-2	8-15	724 ±5	3,870 ±0.4
	B1-1	15-23	298 ±7	1,630 ±0.6
	B1-2	15-23	288 ±7	1,640 ±0.6
	B2-1	23-30	216 ±7	1,280 ±0.5
	B2-2	23-30	216 ±7	1,300 ±0.5
	C-1	30-46	132 ±9	723 ±0.7
	C-2	30-46	145 ±8	869 ±0.7
	D-1	46-61	104 ±2	562 ±0.1
	D-2	46-61	106 ±8	570 ±0.6
4-18	A1-1	0- 2	17,500 ±2	126,000 ±0.2
	A1-2	0- 2	18,700 ±2	140,000 ±0.2
	A2-1	2- 8	8,710 ±3	61,100 ±0.2
	A2-2	2- 8	7,820 ±3	55,500 ±0.2
	A3-1	8-15	2,690 ±2	18,500 ±0.2
	A3-2	8-15	2,590 ±2	17,100 ±0.2
	B1-1	15-23	734 ±5	4,450 ±0.4
	B1-2	15-23	754 ±4	4,530 ±0.4
	B2-1	23-30	286 ±7	1,720 ±0.6
	B2-2	23-30	368 ±6	2,130 ±0.5
	C-1	30-46	119 ±11	695 ±0.9
	C-2	30-46	115 ±9	672 ±0.8
	D-1	46-61	110 ±8	607 ±0.7
	D-2	46-61	136 ±7	795 ±0.6

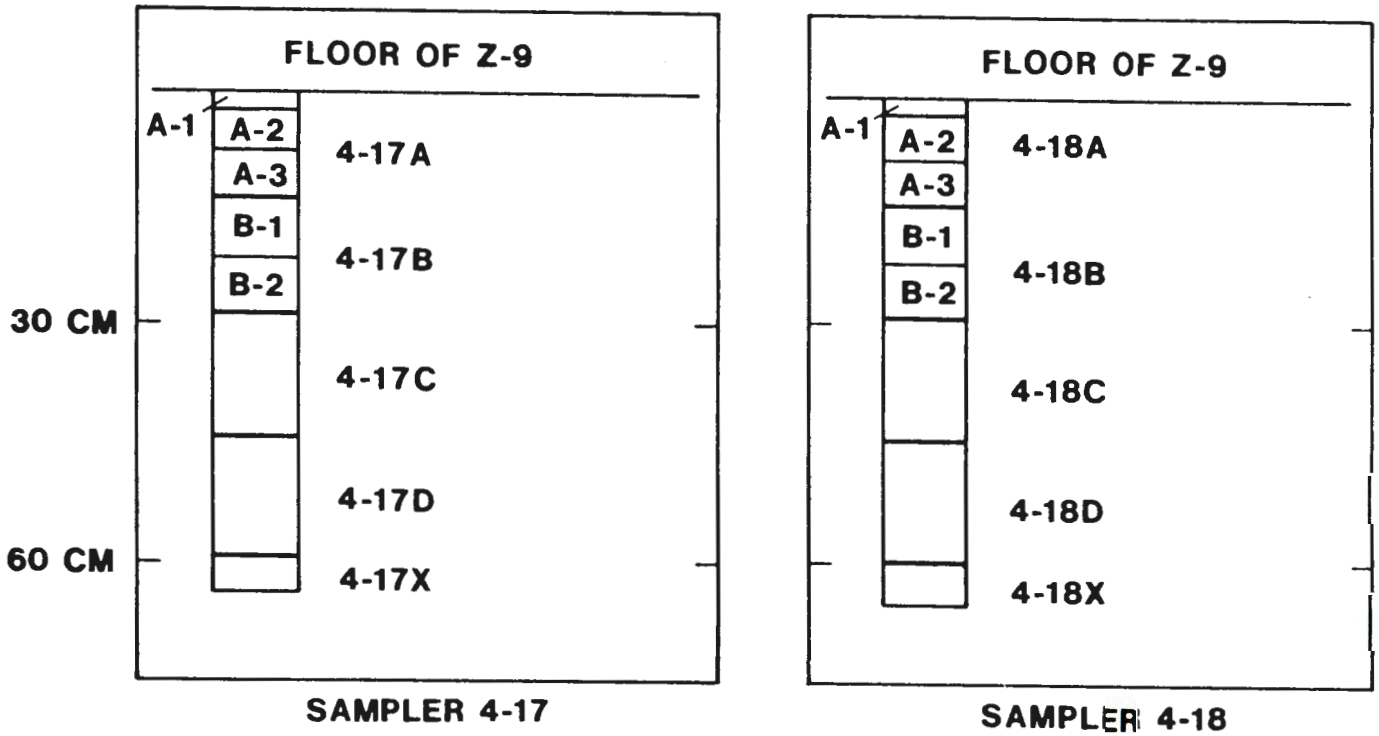


FIGURE B-20

SUMMARY SAMPLE LOGS FOR ANGLED SAMPLE HOLE THROUGH 20-cm ACCESS HOLE "G", 216-Z-9

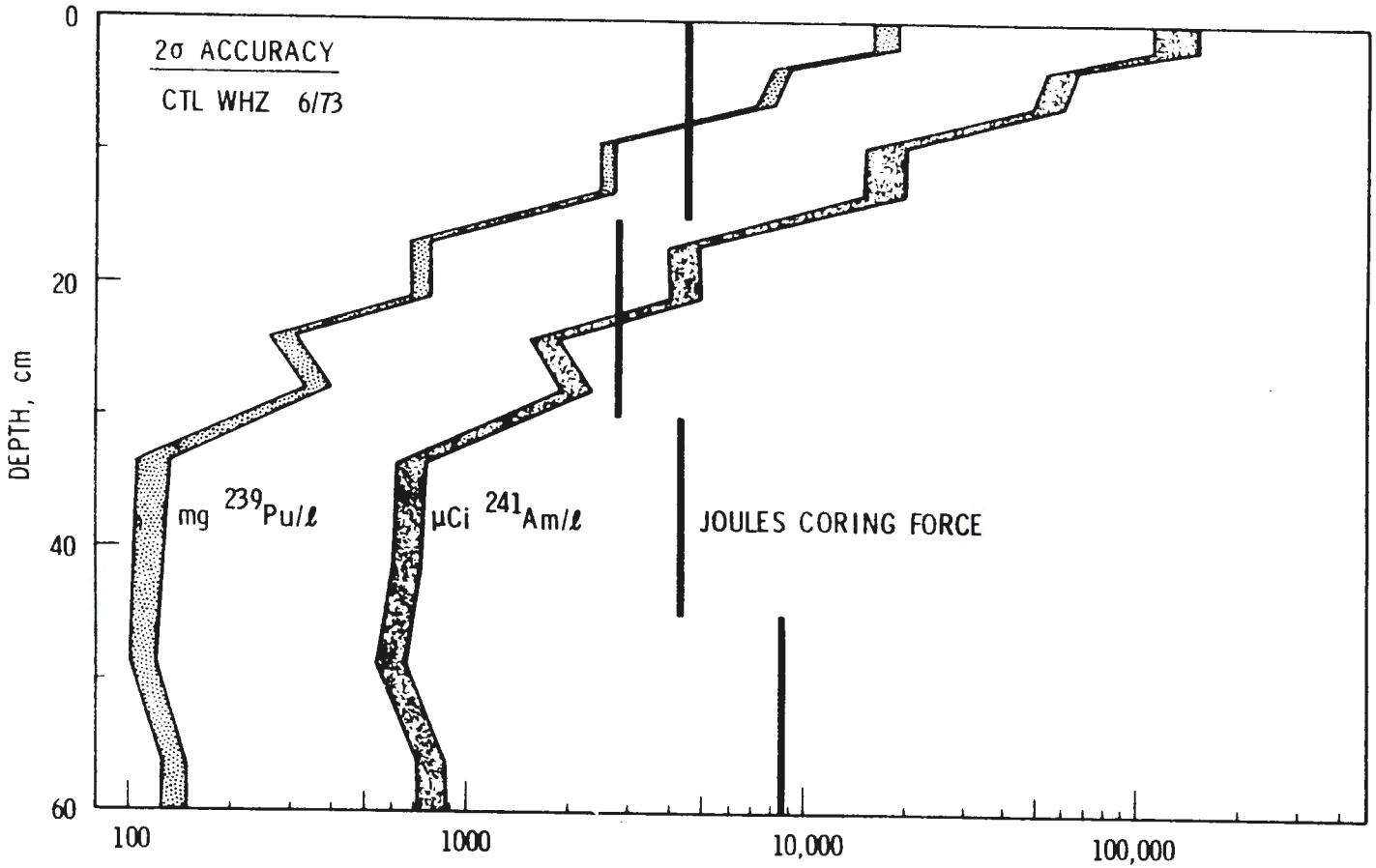


FIGURE B-21

ANGLED SAMPLE HOLE "G"
60° TRUE - 86.5° DIP
216-Z-9 4-18

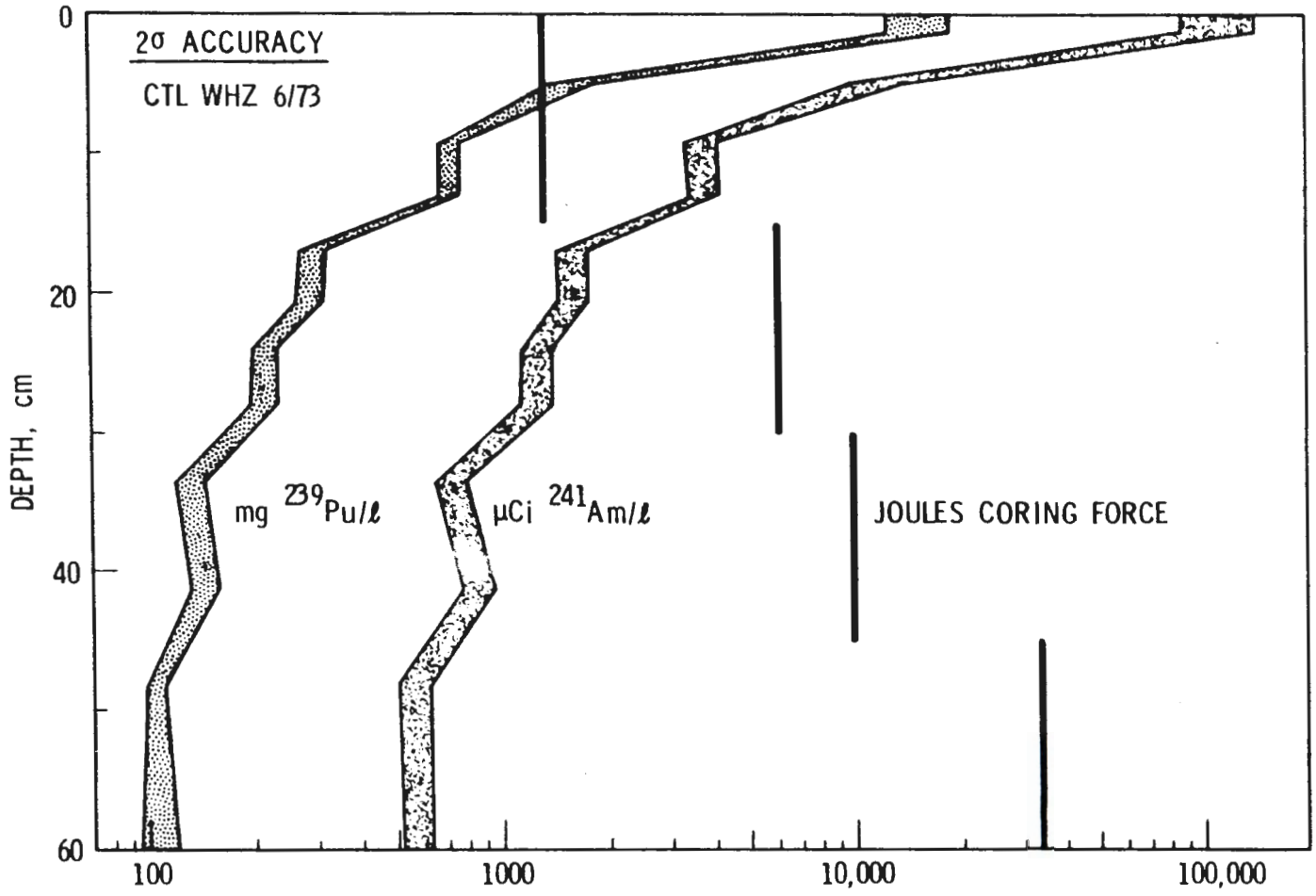


FIGURE B-22

ANGLED SAMPLE HOLE "G"
340° TRUE - 87° DIP
216-Z-9 4-17

TABLE B-IX

PLUTONIUM AND AMERICIUM VALUES
ANGLED SAMPLES THROUGH HOLE "H"

Sampler Number	Section Number	Depth Centimeters	Milligrams ^{239}Pu Per Liter of Soil ±Percent 2σ	Microcuries ^{241}Am Per Liter of Soil ±Percent 2σ
4-15	A1-1	0- 2	18,800 ±2	123,000 ±0.1
	A1-2	0- 2	18,300 ±2	122,000 ±0.2
	A2-1	2- 8	5,520 ±2	35,000 ±0.1
	A2-2	2- 8	5,100 ±2	33,000 ±0.1
	A3-1	8-15	283 ±6	1,700 ±0.5
	A3-2	8-15	175 ±7	1,180 ±0.6
	B1-1	15-23	191 ±7	1,050 ±0.6
	B1-2	15-23	192 ±9	1,090 ±0.6
	B2-1	23-30	110 ±9	629 ±0.7
	B2-2	23-30	122 ±9	671 ±0.7
	C-1	30-46	121 ±9	644 ±0.7
	C-2	30-46	123 ±9	611 ±0.8
	D-1	46-61	137 ±9	700 ±0.8
	D-2	46-61	120 ±6	573 ±0.5

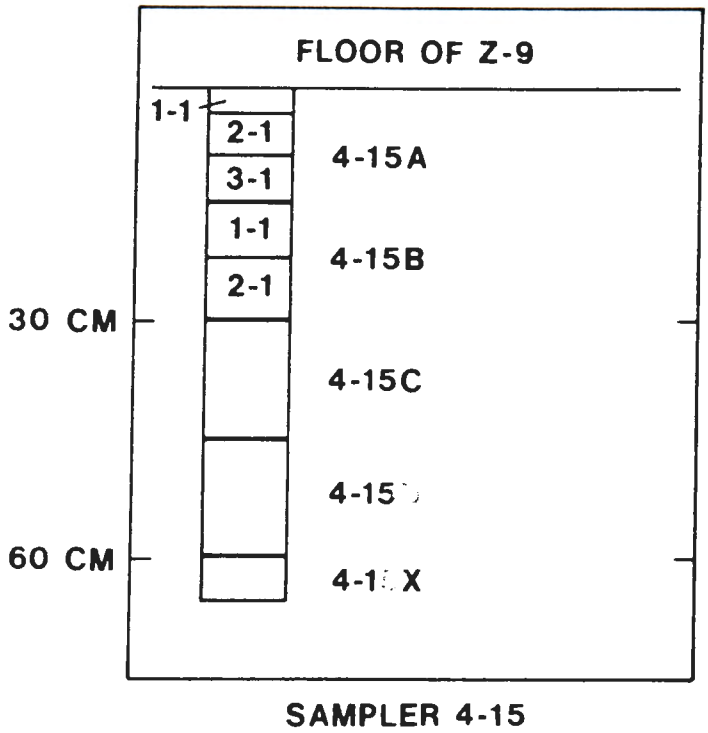


FIGURE B-23

SUMMARY SAMPLE LOGS FOR ANGLED SAMPLE HOLE THROUGH 20-cm ACCESS HOLE "H", 216-Z-9

V7312-10.28

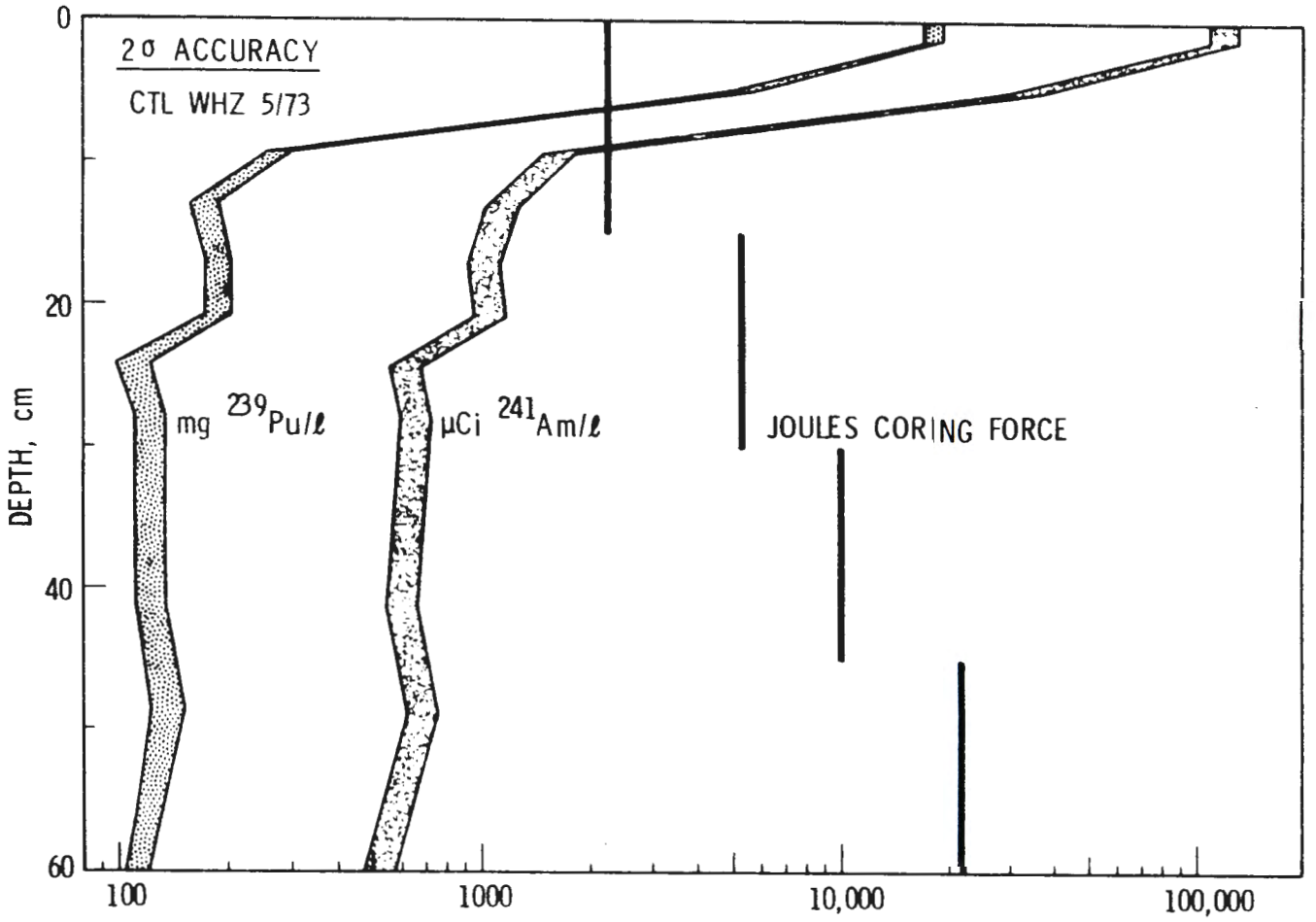


FIGURE B-24

ANGLED SAMPLE HOLE "H"
360° TRUE - 87° DIP
216-Z-9 4-15

APPENDIX C

FIELD NOTES - TEN-CENTIMETER SAMPLERS[1]

M. C. Metz

Appendix C contains the field notes for the 10-centimeter diameter samplers. Photographs of samples are located in Appendix G. The reader should note that the vertical rectangle drawn between the "Depth" and "Description" columns is a graphic distribution of lithological distribution. An empty rectangle with the description of "coarse sand" means that the entire soil sample was coarse sand. As the soil description changes, the rectangle is sectioned and the new soil described. Thus a column with a division at 71 centimeters may have under description "sandy" on the upper portion and "gravelly" on the lower portion to indicate that the soil column changed from sand to gravel at 71 centimeters.

[1] W. H. Zimmer, V. L. Schuelein, and M. C. Metz, "Interim Report: Sampling Techniques and Analyses of the 216-Z-9 Covered Trench," ARH-2752, August 1973, Atlantic Richfield Hanford Company.

SAMPLER 4-1

Location: Vertical sample through 20-centimeter access hole "B", 216-Z-9 Trench

Interval: 0 to 68.6 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
0		Very coarse sand			
	A	Dark-gray, fine-grained cohesive layer			
15.2		Gravelly, very coarse sand	30.5	12	15.2
	B	← Gravels to 4 cm			
		← Gravels 6 to 7 cm	30.5	65	15.2
30.5		Gravelly, coarse sand			
	C		61.0	19	15.2
45.7		Gravelly, very coarse sand			
	D		61.0	22	15.2
61.0		Empty			
68.6	X		61.0	16	7.6

Comments: (a) Exterior of sampler wet when recovered.
(b) GM reading at drive shoe opening was 7500 counts per minute (cpm) (GM = geiger-müller).

SAMPLER 4-2

Location: Angled sample through 20-centimeter access hole "A", 216-Z-9 Trench. Direction - 330° true, dip - 85° from horizontal

Interval: 0 to 68.6 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
0					
	A	Empty	45.7	5	15.2
15.2					
	B		45.7	20	15.2
30.5					
	C	Slightly gravelly, very coarse sand	45.7	44	15.2
45.7					
	D		45.7	46	15.2
61.0					
	X	Empty	45.7	24	7.6
68.6					

Comments:
(a) Exterior of sampler damp when recovered.
(b) GM reading at drive shoe opening was 3000 cpm.
(c) Drive shoe damaged.

SAMPLER 4-3

Location: Angled sample through 20-centimeter access hole "A", 216-Z-9 Trench. Direction - 225° true, dip - 86.5° from horizontal

Interval: 0 to 68.6 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
0					
	A	Gravelly, very coarse sand			
15.2		← Gravels to 4 cm	45.7	23	15.2
	B		61.0	41	15.2
30.5					
	C	Empty	61.0	33	15.2
45.7					
	D		61.0	27	15.2
61.0					
	X		61.0	18	7.6
68.6					

Comments:
(a) Exterior of sampler wet when recovered.
(b) GM reading at drive shoe was 2000 cpm.
(c) Basket lifter fingers sheared.

SAMPLER 4-4

Location: Angled sample through 20-centimeter access hole "A", 216-Z-9 Trench. Direction - 150° true, dip - 86.5° from horizontal

Interval: 0 to 68.6 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
0		Fine, silty sand			
	A	Slightly gravelly, very coarse sand	45.7	5	15.2
15.2					
	B	Gravelly, very coarse sand	45.7	21	15.2
30.5					
	C		61.0	31	15.2
45.7					
	D	Very coarse sand, to gravel	61.0	23	15.2
61.0					
	X		61.0	20	7.6
68.6					

Comments: (a) Exterior of sampler wet when recovered.
(b) GM reading at drive shoe opening was 2000 cpm.

SAMPLER 4-5

Location: Angled sample through 20-centimeter access hole "A", 216-Z-9 Trench. Direction - 80° true, dip - 87° from horizontal

Interval: 0 to 68.6 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
0					
	A	Gravelly, very coarse sand	45.7	12	15.2
15.2					
	B		45.7	10	15.2
30.5					
	C		45.7	17	15.2
45.7					
	D		45.7	56	15.2
61.0					
	X		45.7	18	7.6
68.6					

Comments:
(a) Exterior of sampler slightly damp when recovered.
(b) GM reading at drive shoe opening was 6000 cpm.
(c) Observed small piece of wood at top of Sample 4-5-B.

SAMPLE 4-6

Location: Vertical sample through 20-centimeter access hole "A", 216-Z-9 Trench

Interval: 0 to 68.6 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
0					
	A	Empty	45.7	10	15.2
15.2		Gravelly, very coarse sand			
	B	Gravels 5 to 7 cm	45.7	11	15.2
30.5					
	C		45.7	19	15.2
45.7					
	D		45.7	35	15.2
61.0					
	X	Empty	45.7	26	7.6
68.6					

Comments: (a) Exterior of sampler wet when recovered.
(b) GM reading at drive shoe opening 6000 cpm.

SAMPLER 4-7

Location: Vertical sample through 20-centimeter access hole "A", 216-Z-9 Trench

Interval: 50.8 to 120 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
50.8					
	A	Slightly gravelly, very coarse sand	15.2	29	15.2
66.0					
	B		45.7	66	15.2
81.3		Sandy, medium gravel			
	C		45.7	60	15.2
96.5					
	D		45.7	65	15.2
112.					
	X	Very coarse sand	45.7	38	7.6
119.					

Comments:
(a) Exterior of sampler damp when recovered.
(b) GM reading at drive shoe opening was 4000 cpm.
(c) Sampler was difficult to recover.

SAMPLER 4-8

Location: Angled sample through 20-centimeter access hole "C", 216-Z-9 Trench. Direction - 140° true, dip - 86° from horizontal

Interval: 0 to 68.6 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
0	A	Empty	30.5	9	15.2
15.2	B	Gravelly, very coarse sand	30.5	18	15.2
30.5	C		45.7	30	15.2
45.7	D		61.0	26	15.2
61.0	X	Empty	61.0	11	7.6
68.6					

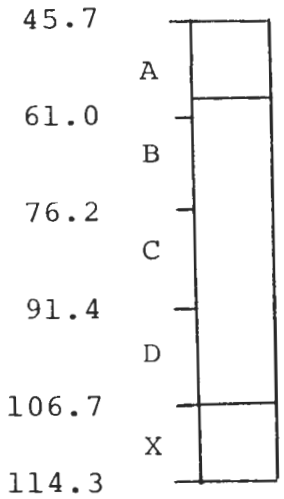
Comments: (a) Sampler exterior damp when recovered.
(b) GM reading 20,000 cpm at drive shoe opening.

SAMPLER 4-9

Location: Vertical sample through 20-centimeter access hole "B", 216-Z-9 Trench

Interval: 45.7 to 114.3 centimeters

Hammer Weight: 63 kilograms



Depth cm	Description	Hammer Drop cm	Number Drives	Distance Driven cm
A	Empty	30.5	16	15.2
B	Gravelly, very coarse sand	45.7	33	15.2
C	Large gravels 3 to 5 cm	61.0	38	15.2
D	Large gravels 3 to 6 cm	45.7	32	15.2
X	Empty	45.7	18	7.6

Comments: (a) Sampler exterior wet when retrieved.
(b) GM reading 6000 cpm at drive shoe opening.

SAMPLER 4-10

Location: Angled sample through 20-centimeter access hole "C", 216-Z-9 Trench. Direction - 245° true, dip - 86.5° from horizontal

Interval: 0 to 68.6 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
0	A	Light-to-dark-gray fine-grained cohesive layer	30.5	18	15.2
15.2	B	Gravelly, very coarse sand	30.5	19	15.2
30.5	C		45.7	31	15.2
45.7	D	← Gravels 3 to 5 cm	61.0	28	15.2
61.0	X	Empty	61.0	22	7.6
68.6					

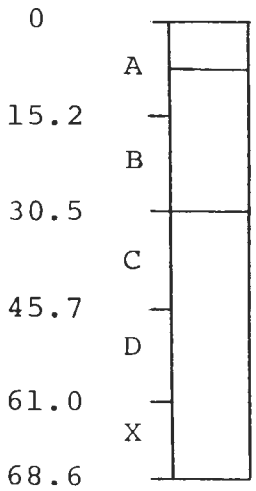
Comments:
(a) Sampler exterior damp when recovered.
(b) GM reading 35,000 cpm at drive shoe opening.
(c) Sampler 4-10-B and 4-10-C reddish-yellow in color.

SAMPLER 4-11

Location: Angled sample through 20-centimeter access hole "C", 216-Z-9 Trench. Direction - 195 ° true, dip - 86° from horizontal

Interval: 0 to 68.6 centimeters

Hammer Weight: 63 kilograms



Description	Hammer Drop cm	Number Drives	Distance Driven cm
Light-to-dark-brown fine grained cohesive layer	30.5	13	15.2
Sandy, fine gravel	30.5	26	15.2
Gravelly, very coarse sand	30.5	33	15.2
	45.7	56	15.2
	61.0	45	7.6

Comments:
(a) Visible clear liquid on outside of sampler when recovered.
(b) GM reading 10,000 cpm at drive shoe opening.
(c) Clear liquid dripped from sampler top when opened.

SAMPLER 4-12

Location: Vertical sample through 20-centimeter access hole "C", 216-Z-9 Trench

Interval: 61 to 129.5 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
61.0					
	A	Empty	30.5	21	15.2
76.2					
	B	Gravelly, very coarse sand	30.5	23	15.2
91.4					
	C	Slightly gravelly, very coarse sand	30.5	26	15.2
106.7					
	D	Gravelly, very coarse sand	30.5	28	15.2
121.9					
	X	Empty	30.5	18	7.6
129.5					

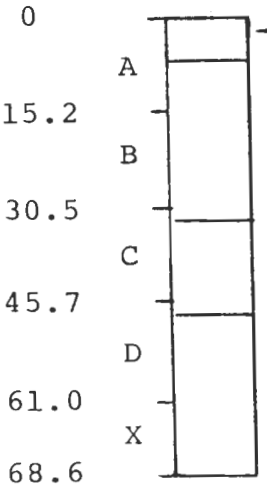
Comments: (a) Sampler exterior damp when recovered.
(b) GM reading 20,000 cpm at drive shoe opening.

SAMPLER 4-13

Location: Vertical sample through 20-centimeter access hole "C", 216-Z-9 Trench

Interval: 0 to 68.6 centimeters

Hammer Weight: 63 kilograms



Depth cm	Description	Hammer Drop cm	Number Drives	Distance Driven cm
	Fine-grained layer			
	Slightly gravelly, very coarse sand	30.5	6	15.2
		30.5	20	15.2
	Gravelly, very coarse sand			
		30.5	20	15.2
	Slightly gravelly, very coarse sand	30.5	40	15.2
		30.5	23	7.6

Comments: (a) Sampler exterior wet when recovered.
(b) GM reading 25,000 cpm at drive shoe opening.

SAMPLER 4-14

Location: Angled sample through 20-centimeter access hold "D", 216-Z-9 Trench. Direction - 360° true, dip - 86° from horizontal

Interval: 0 to 68.6 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
0					
	A	Gravelly, coarse sand	30.5	16	15.2
15.2					
	B	Gravelly, coarse sand	45.7	19	15.2
30.5					
	C	Gravelly, coarse sand	45.7	22	15.2
45.7					
	D		61.0	51	15.2
61.0					
	X		61.0	60	7.6
68.6					

Comments: (a) Sampler exterior wet when retrieved.
(b) GM reading 30,000 cpm at drive shoe opening.

SAMPLER 4-15

Location: Angled sample through 20-centimeter access hole "H", 216-Z-9 Trench. Direction - 360° true, dip - 87° from horizontal

Interval: 0 to 68.6 centimeters

Hammer Weight:: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
0	A	Cohesive, fine-grained layer	30.5	12	15.2
15.2	B	Coarse, sandy gravel Gravelly, coarse sand Gravels 2 to 7 cm	30.5	28	15.2
30.5	C		45.7	35	15.2
45.7	D	Gravelly, coarse sand	61.0	62	15.2
61.0	X		61.0	58	7.6
68.6					

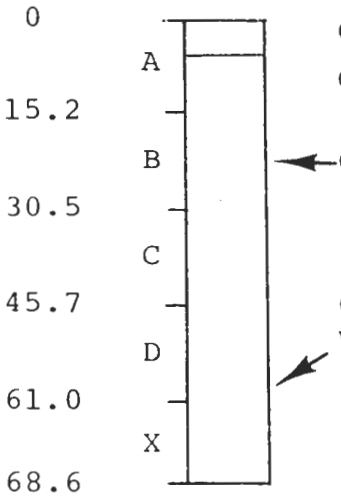
Comments:
(a) Sampler wet on exterior.
(b) Shoe not full.
(c) GM reading 16,000 cpm at shoe.

SAMPLER 4-16

Location: Vertical sample through 20-centimeter access hole "G", 216-Z-9 Trench

Interval: 0 to 68.6 centimeters

Hammer Weight: 63 kilograms



Depth cm	Description	Hammer Drop cm	Number Drives	Distance Driven cm
	Cohesive coarse sand			
	Gravelly, coarse sand	30.5	15	15.2
	Gravels 2 to 7 cm	45.7	30	15.2
		45.7	43	15.2
	Gravelly, coarse sand with cobbles 8 to 10 cm	61.0	53	15.2
		61.0	46	15.2

Comments: (a) Sampler exterior damp when retrieved.
(b) GM reading 60,000 cpm at drive shoe opening.

SAMPLER 4-17

Location: Angled sample through 20-centimeter access hole "G", 216-Z-9 Trench. Direction - 340° true, dip - 87° from horizontal

Interval: 0 to 68.6 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
0	A	Cohesive, fine-grained layer	30.5	7	15.2
15.2	B	Coarse sand Gravelly, coarse sand	30.5	32	15.2
30.5	C		45.7	35	15.2
45.7	D	Gravelly, coarse sand	61.0	90	15.2
61.0	X	Cobble 11 cm	61.0	32	7.6
68.6					

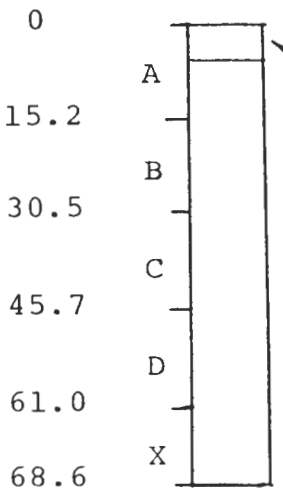
Comments: (a) Sampler wet on exterior when retrieved.
(b) GM reading 30,000 cpm at drive shoe opening.

SAMPLER 4-18

Location: Angled sample through 20-centimeter access hole "G", 216-Z-9 Trench. Direction - 60° true, dip - 86.5° from horizontal

Interval: 0 to 68.6 centimeters

Hammer Weight: 63 kilograms



Depth cm	Description	Hammer Drop cm	Number Drives	Distance Driven cm
0 – 15.2	Cohesive layer with coarse gravels and tile fragments	30.5	24	15.2
15.2 – 30.5	Gravelly, coarse sand	30.5	15	15.2
30.5 – 45.7	Gravelly, coarse sand	45.7	23	15.2
45.7 – 61.0		45.7	46	15.2
61.0 – 68.6		45.7	31	7.6

Comments: (a) Sample dry when retrieved.
(b) GM reading of 20,000 cpm at drive shoe opening.

APPENDIX D

FIELD NOTES: 8-CENTIMETER SAMPLERS[1]

M. C. Metz

[1] W. H. Zimmer, V. L. Schuelein, and M. C. Metz, "Interim Report: Sampling Techniques and Analyses of the 216-Z-9 Covered Trench," ARH-2752, August 1973, Atlantic Richfield Hanford Company, Richland, Washington.

SAMPLER 3-1

Location: Vertical sample through 20-centimeter access hole "A", 216-Z-9 Trench

Interval: 114 to 183 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
114		Empty			
	A	Gravelly, very coarse sand	30.5	39	15.2
130					
	B		30.5	46	15.2
145					
	C		45.7	41	15.2
160					
	D	6 cm gravel in basket fingers	45.7	46	15.2
175					
	X		61.0	44	7.6
183					

Comments:
(a) Sampler exterior damp when retrieved.
(b) Geiger-Müller (GM) reading 4000 counts per minute (cpm) at drive shoe opening.
(c) Sampler retrieved without use of jacks.

SAMPLER 3-2

Location: Vertical sample through 20-centimeter access hole "A", 216-Z-9 Trench

Interval: 170 to 239 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
170		Empty			
	A	Gravelly, very coarse sand	30.5	42	15.2
185					
	B		45.7	56	15.2
201					
	C		61.0	79	15.2
216					
	D		61.0	44	15.2
231					
	X	Empty	61.0	28	7.6
239					

Comments:
(a) Sampler exterior damp when retrieved.
(b) GM reading 4000 cpm at drive shoe opening.
(c) Sampler became stuck in casing.

SAMPLER 3-3

Location: Vertical sample through 20-centimeter access hole "B", 216-Z-9 Trench

Interval: 91 to 160 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
91					
	A	Empty	30.5	29	15.2
107					
	B	Empty	45.7	43	15.2
122					
	C	Sandy, fine gravel ← Large gravels to 4 cm	61.0	39	15.2
137					
	D		61.0	31	15.2
152					
	X		61.0	15	7.6
160					

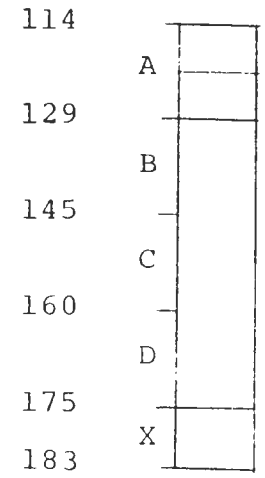
Comments: (a) Sampler exterior dry when retrieved.
(b) GM reading 6000 cpm at drive shoe opening.

SAMPLER 3-5

Location: Vertical sample through 20-centimeter access hole "C", 216-Z-9 Trench

Interval: 114 to 183 centimeters

Hammer Weight: 63 kilograms



Depth cm	Description	Hammer Drop cm	Number Drives	Distance Driven cm
114	Empty			
A	Gravelly, very coarse sand	30.5	30	15.2
129				
B	Sandy fine-to-medium gravel	45.7	50	15.2
145				
C		45.7	47	15.2
160				
D	← Gravels 5 to 6 cm	30.5	40	15.2
175				
X	Empty	30.5	30	7.6
183				

Comments: (a) Sampler exterior damp when recovered.
(b) GM reading 5000 cpm at drive shoe opening.

APPENDIX E

FIELD NOTES: 6.4-CENTIMETER SAMPLERS[1]

M. C. Metz

[1] W. H. Zimmer, V. L. Schuelein, and M. C. Metz, "Interim Report: Sampling Techniques and Analyses of the 216-Z-9 Covered Trench," ARH-2725, August 1973, Atlantic Richfield Hanford Company, Richland, Washington.

SAMPLER 2.5-1

Location: Vertical sample through 20-centimer access hole "B", 216-Z-9 Trench

Interval: 158 to 226 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
158					
	A	Empty	45.7	24	15.2
173					
	B	Empty	45.7	24	15.2
188					
	C	Sandy, fine gravel	45.7	18	15.2
203					
	D	← Large gravels to 6 cm	61.0	48	15.2
218					
	X	Empty	61.0	37	7.6
226					

Comments: (a) Sampler exterior dry when retrieved.
(b) GM reading 4000 cpm at drive shoe opening.

SAMPLER 2.5-2

Location: Vertical sample through 20-centimeter access hole "C", 216-Z-9 Trench

Interval: 170 to 239 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
170					
	A	Empty	45.7	30	15.2
185					
	B	Sandy fine-to-medium gravel	45.7	27	15.2
201					
	C	Sandy, fine gravel	45.7	36	15.2
216					
	D	Sandy, fine gravel with gravels to 6 cm	61.0	57	15.2
231					
	X		61.0	30	7.6
239					

Comments: (a) Sampler exterior dry when recovered.
(b) GM reading 2000 cpm at drive shoe opening.

APPENDIX F

FIELD NOTES: 5-CENTIMETER SAMPLERS[1]

M. C. Metz

[1] W. H. Zimmer, V. L. Schuelein, and M. C. Metz, "Interim Report: Sampling Techniques and Analyses of the 216-Z-9 Covered Trench," ARH-2752, August 1973, Atlantic Richfield Hanford Company, Richland, Washington.

SAMPLER 2-1

Location: Vertical sample through 20-centimeter access hole "B", 216-Z-9 Trench

Interval: 208 to 277 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
208					
	A	Empty	30.5	6	15.2
223					
	B	Sandy, fine gravel ← Large gravels 5 to 6 cm	30.5	17	15.2
239					
	C	← Large gravels 3 to 4 cm	45.7	19	15.2
254		Stratified coarse sand			
	D		45.7	11	15.2
269					
	X		45.7	16	7.6
277					

Comments: (a) Sampler exterior dry when recovered.
(b) GM reading 2500 cpm at drive shoe opening.

SAMPLER 2-2

Location: Vertical sample through 20-centimeter access hole "C", 216-Z-9 Trench

Interval: 211 to 279 centimeters

Hammer Weight: 63 kilograms

Depth cm		Description	Hammer Drop cm	Number Drives	Distance Driven cm
211					
	A	Sandy, fine gravel	30.5	17	15.2
226		← Large gravels ← Gravels 3 to 5 cm			
	B		45.7	35	15.2
241					
	C	Stratified coarse sand	61.0	31	15.2
256					
	D		61.0	40	15.2
272					
	X		45.7	44	7.6
279					

Comments: (a) Sampler exterior dry when recovered.
(b) GM reading 3500 cpm at drive shoe opening.

APPENDIX G

PHOTOGRAPHS OF SOIL SAMPLES

V. L. Schuelein

Sample Number	Depth Centimeters
4-14-A	0 -15
4-14-B	15 -30
4-14-C	30 -46
4-14-D	46 -60
4-15-A1	0 - 2.54
4-15-A2	2.54- 7.5
4-15-A3	7.5 -15

Sections A, B, C, and D from Sampler 4-14 are representative of the upper 60 centimeters of 216-Z-9 (Z-9) soil. The sediments appear to be coarse and sandy. The actinide values are shown in Appendix B and the geologists' field log is found in Appendix C (see Index Maps, pages B-5 and B-6).

Sections A1, A2, and A3 from Sampler 4-15 are representative of the upper 15 centimeters divided into 0- to 2.5-, 2.5- to 7.5-, and 7.5- to 15-centimeter sections. A sludge layer was observed in the upper 2.5 centimeters with traces as deep as 7.5 centimeters. As seen in Sample 4-15-A3, the soil in the 7.5- to 15-centimeter layer appeared normal; *i.e.*, gravelly, coarse sand.

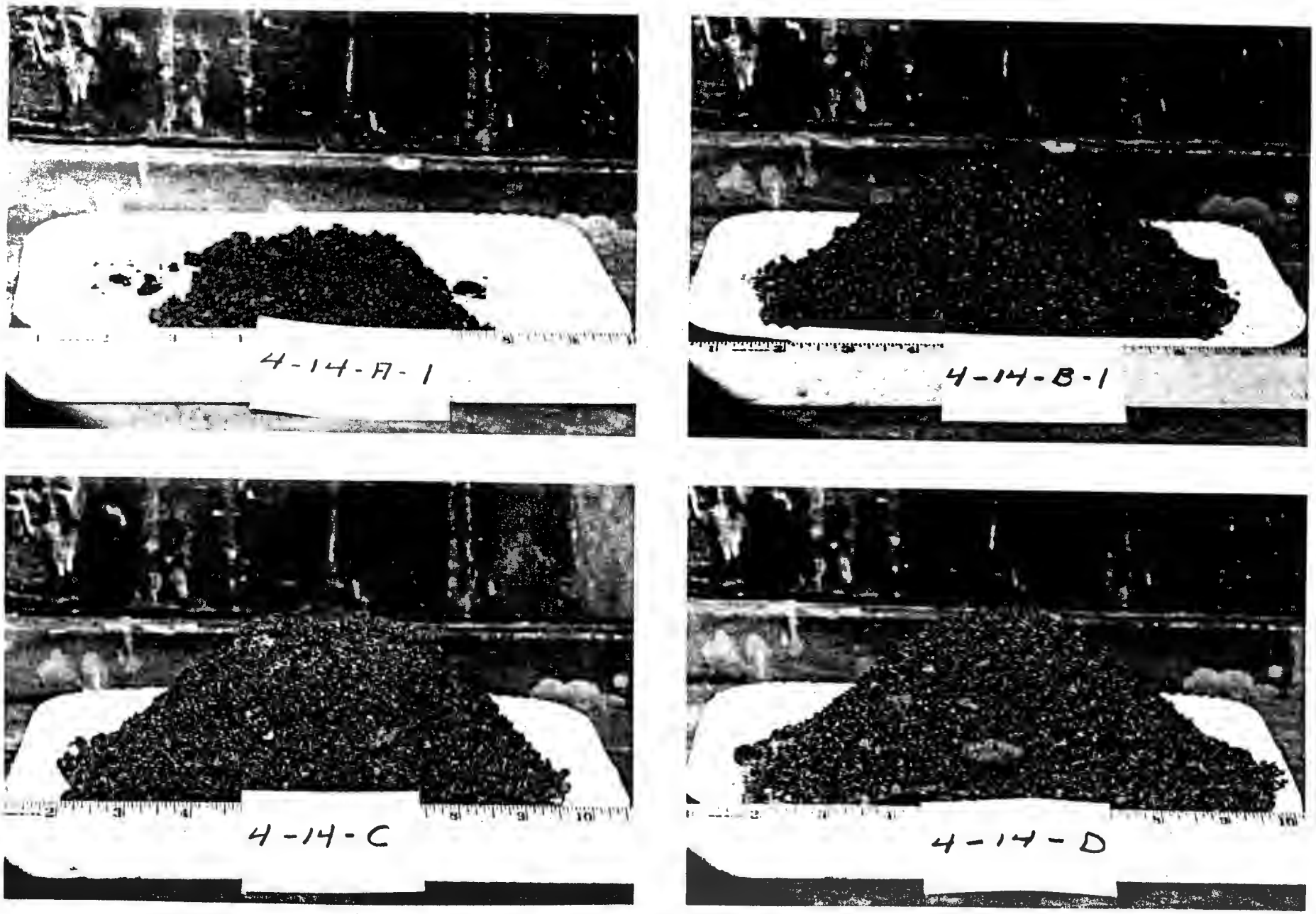
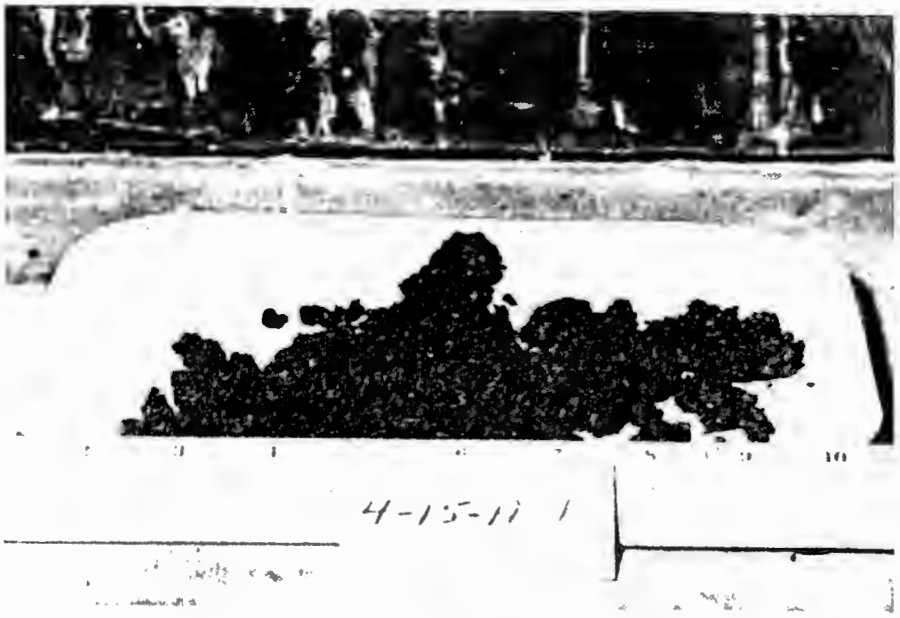


FIGURE 1. SOIL SAMPLES FROM 216-Z-9 ENCLOSED TRENCH



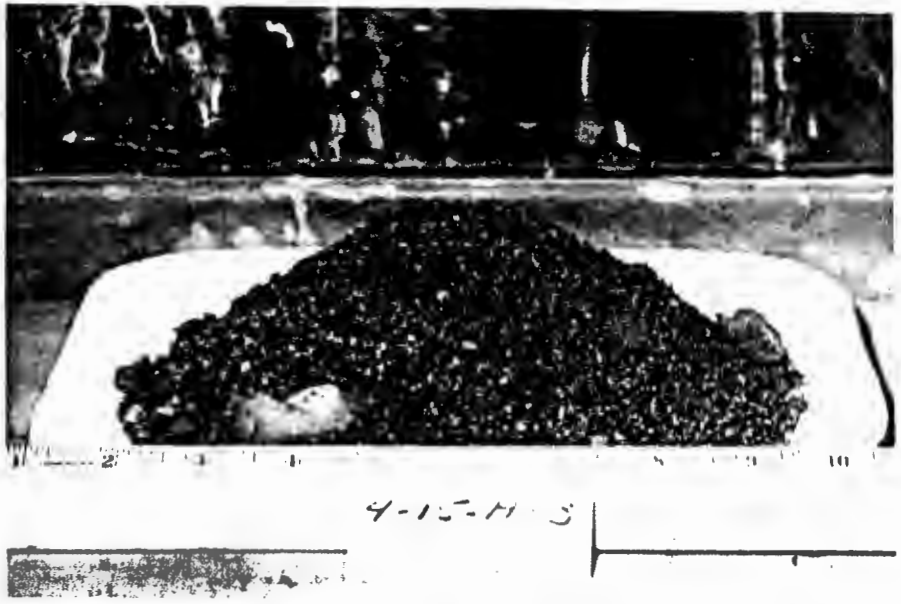


FIGURE 2. SOIL SAMPLES FROM 216-Z-9 ENCLOSED TRENCH

THERMAL IR SURVEY OF THE 216-Z-9 CRIB INTERIOR

S. B. Ailes
J. R. Eliason
H. P. Foote

BATTELLE PACIFIC NORTHWEST LABORATORIES
Richland, Washington

June 1973

ABSTRACT

Radioisotope concentration and distribution patterns of the 216-Z-9 crib interior were qualitatively determined, based on their induced heating of the crib bottom, by using the AGA Thermovision infrared scanner. From laboratory calibrations and emissivity measurements the average heat flux due to radioisotope heating was determined to be approximately 5 to 10 watts/M^2. Maximum heat flux values of from 30 to 40 watts/M^2 were observed in small areas.

Due to the qualitative nature of the study, only probable heat flux values and distribution patterns were determined. Analysis of 216-Z-9 crib bottom soils and calibration would be necessary for a quantitative survey.

INTRODUCTION

A study was conducted to qualitatively determine radioisotope concentrations in the 216-Z-9 crib using the AGA Thermovision infrared detection system. This system is sensitive to the 3μ to 5μ infrared wavelengths emitted by materials, intensity being a function of material type and temperature. It was expected that the presence of high concentrations of radioactive materials in the crib would

cause a rise in temperature which would be detectable by infrared thermal imagery.

The scanner was remotely operated through an 0.6-meter diameter manhole in the crib roof. A simple mechanical system was developed to accurately position the scanner and protect the instrumentation from contamination.

RESULTS AND DISCUSSION

An initial qualitative survey of the 216-Z-9 crib was made with the AGA Thermovision scanner which, although quite sensitive, has a very narrow field of view (10° x 10°), requiring several hundred photographs to cover the crib interior (see Figure 1). Absolute temperature measurements of the crib bottom were not made during this preliminary survey.

Laboratory tests were conducted to determine the relationship between soil temperature differences as measured by the AGA scanner and the corresponding power/M^2 emitted by a calibrated heat source two centimeters below the soil surface. Figure 2 is a plot of calibration source power versus soil surface ΔT. The detection limit for the AGA system was determined to be approximately 0.05 °C ΔT, which corresponds to approximately 1.5 watts/M^2.

There is a significant variation among the material types in the present 216-Z-9 crib bottom. Each soil or material type has a different emissivity which may cause variations in the apparent temperatures detected by the AGA Thermovision system. Thus various soil samples representative of the Hanford Reservation along with core samples from the immediate vicinity of the 216-Z-9 crib were collected for investigation. Laboratory tests were conducted on these

samples to determine the effect of emissivity on the apparent temperatures measured. The maximum apparent ΔT due to emissivity for the samples studied was found to be approximately 0.2 °C.

Figure 3, a plot of the soil reflectance found in the 216-Z-9 crib, indicates the variety of soil types present. This was prepared from a color photographic mosaic of the 216-Z-9 crib. Although slight variations occur, there appear to be four major surface soil types ranging in color from very light- to dark-brown. The color variations are very pronounced on the original color mosaic which was not reproduced for this report.

Figure 4 is a thermal plot of the 216-Z-9 crib. The plot was determined from the AGA infrared imagery and is based on dividing the image contrast into six levels representing six different temperatures and heat flux ranges. Areas disturbed by core sampling and breaks in the surface crust due to drying have the lowest temperatures and appear darkest in the infrared pictures. These areas were assigned contour level 1 and represent the base line (assuming no heat output) from which all temperature and corresponding heat output differences are measured. Contour level 3 (5 to 10 watts/M^2) encompasses the largest areas in the crib and was approximately 0.2 °C above the lowest contour level. The maximum observed temperature difference in the crib was less than 1.0 °C, which corresponds to 40 watts/M^2, and appears to be located in the region defined by contour levels 5 and 6.

Patterns observed indicate that there is a warm surface layer deposited over the crib bottom which is approximately 0.5 °C above the temperature of the soil material exposed by mud cracks and mechanical disturbance of the crib bottom.

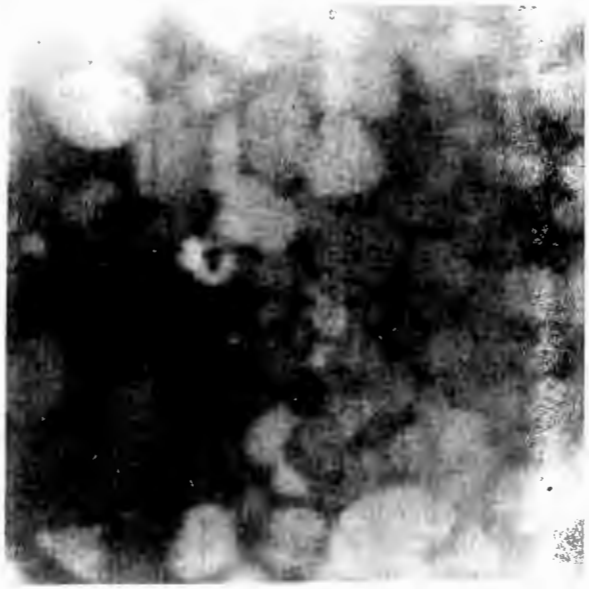
Erosion of the crib bottom near the discharge splash pad and along a path toward the apparent low corner of the crib is evident in the thermal imagery and in photographs of the crib interior. Eroded areas appear cooler, and areas of apparent deposition and the low corner of the crib where infiltration would be expected to occur under low discharge flow conditions appear warmer.

Results contained in this report were collected under severely limiting conditions and represent only a preliminary determination of the thermal patterns; they did not permit precise locations of possible concentrations of radioactive materials. However, considering emissivity and detection sensitivity, areas which appear warmer (lighter) in the thermal imagery are considered to be areas of possible isotope concentration, particularly when these areas correlate with areas of low emissivity.

A more quantitative study of actual temperatures would require analyses of soil samples from the crib bottom, determination of their emissivity, and corresponding calibration of the AGA Thermovision.

Picture of 216-Z-9 Infrared Image Mosaic

Single 10°x10° IR Image of Crib Bottom Showing Cracks in Soil and Sampling Area



Single 10°x10° IR Image of Splash-pad in 216-Z-9 Crib Showing Variation in Apparent Temperatures

FIGURE 1

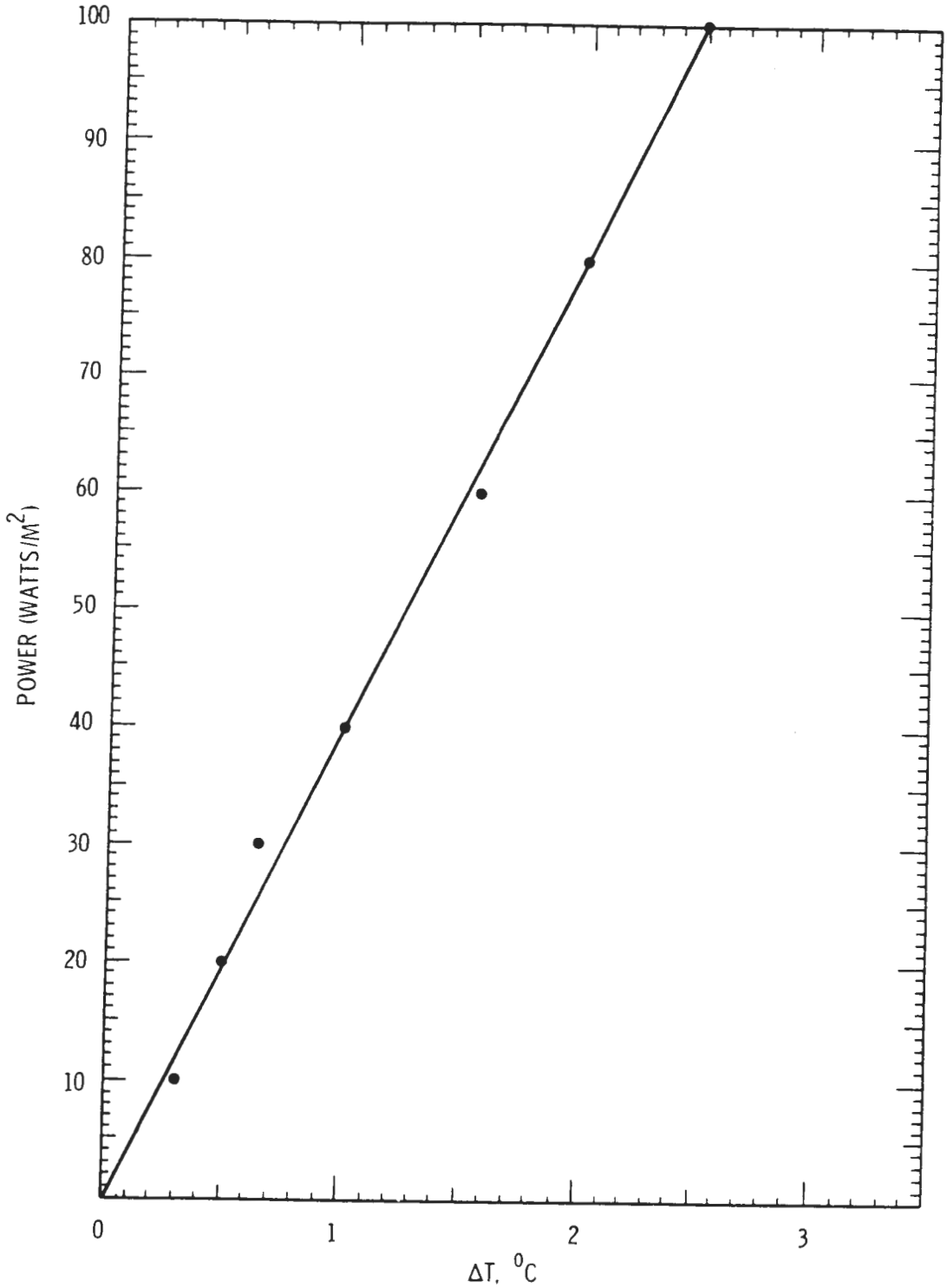


FIGURE 2

PLOT OF SOIL ΔT VERSUS HEAT FLUX IN WATTS/M^2

V7312-10.31

216-Z-9 CRIB BOTTOM
REFLECTANCE CHARACTERISTICS

SOIL REFLECTANCE LEVELS

HIGH — LIGHT GREY
LIGHT BROWN
DULL GREENISH-BROWN
LOW — DARK BROWN

0 1 2
SCALE-METERS

• SAMPLE PORTS
SUPPORT COLUMNS

FIGURE 3

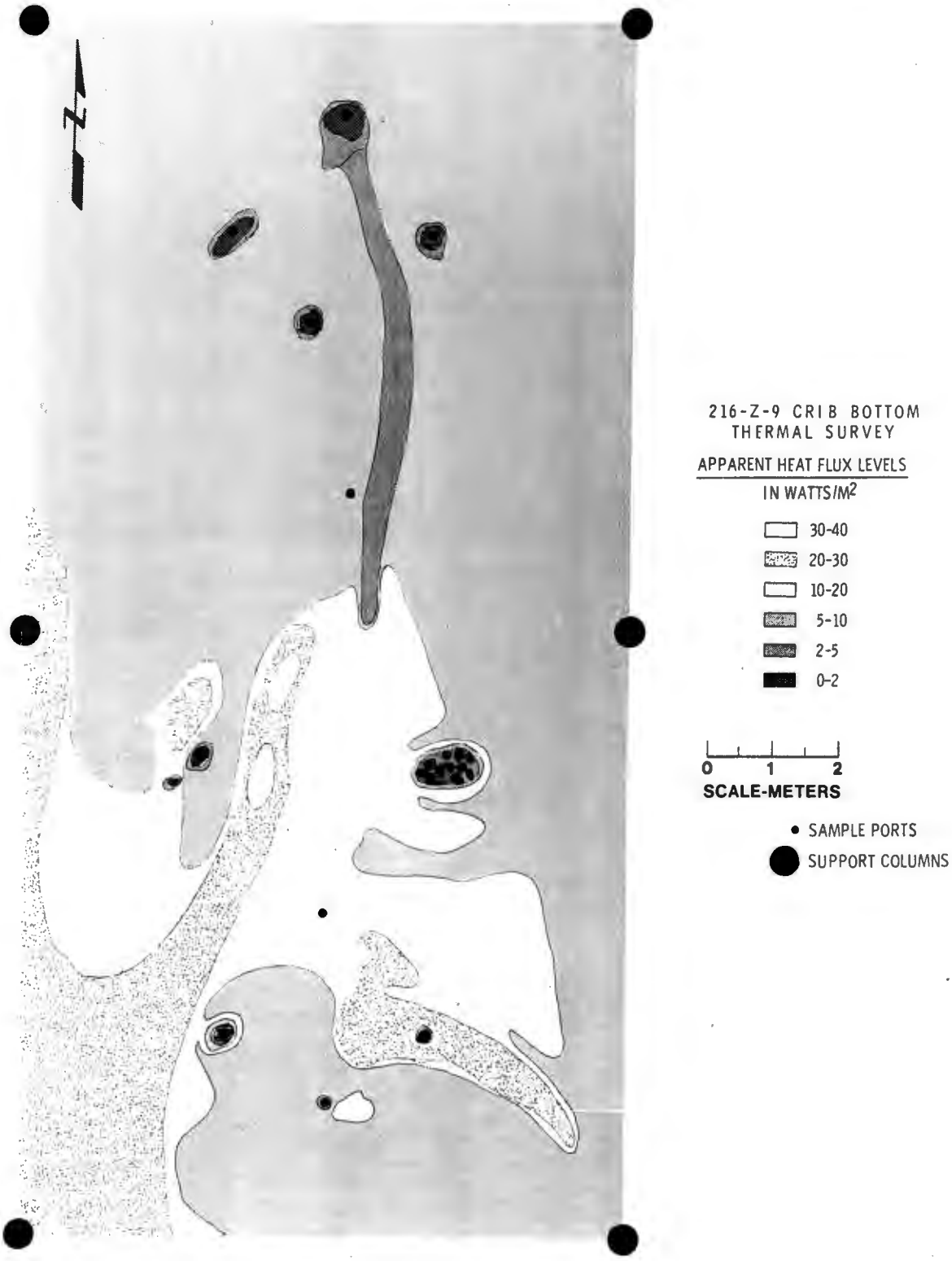

N
216-Z-9 CRIB BOTTOM
THERMAL SURVEY
APPARENT HEAT FLUX LEVELS
IN WATTS/M2
30-40
20-30
10-20
5-10
2-5
0-2
0 1 2
SCALE-METERS
SAMPLE PORTS
SUPPORT COLUMNS

FIGURE 4

APPENDIX I

GAMMA SURVEY

Issued Internally As:

ARH-2815

THE ISODOSE MAPPING OF THE 216-Z-9 TRENCH FLOOR

William H. Zimmer

INTRODUCTION

The purpose of isodose mapping of the 216-Z-9 Trench floor was to determine the relative distribution of plutonium-239 for future sampling and disposal. It is not meant to eliminate the need for sampling, nor does it apply to distribution as a function of depth.

SUMMARY

CAUTION: This is an isodose map--a map with connecting areas of like radiation dose. It is a map of the trench "surface" which is of undefined depth. Correlation has been made between analyzed samples and the areas from which they were taken. It is known and readily apparent from the isodose map that sampling introduced discontinuities in the surface dose reading. Reported sample units are grams ^{239}Pu per liter; but since the depth of the high-grade surface is unknown, the increased dosage could as easily be caused by a greater depth of high-grade plutonium matrix. The isodose map does the only thing required of it--it defines the areas of maximum plutonium concentration.

MAPPING PARAMETERS

Analysis of the 1973 samples showed that the only gamma emitters of consequence are ^{239}Pu and ^{241}Am. Moreover, they are present in approximately the same ratio over a much greater depth than could be penetrated by their gamma radiation. These conditions allowed the determination of plutonium distribution on the trench surface by means of an isodose map.

The detector, Figure 1, is a 1.27-cm by 2.54-cm diameter right cylinder of NaI(Tl) in "Integral Line" configuration with a 4-cm multiplier phototube. The voltage dividing network, bias supply lead, and signal output lead are potted to prevent possible shorting. A 20-cm Plexiglas closed cylinder with 0.3-cm walls was used as a hold-off. The entire assembly was loaded into one of two probes which were pre-bent, 5-cm aluminum irrigation pipe.

The signal from the detector was routed through the irrigation pipe probe to a scintillation preamplifier, discriminator, and rate meter. Between the hold-off, the aluminum pipe, and the discriminator setting the energy band read by the rate meter was from approximately 80 KeV and higher. This essentially eliminated the emissions of ^{241}Am.

The 9-meter lengths of irrigation pipe were pre-bent so that one pipe would carry the detector in a 3-meter radius circle and the other in a 1.5-meter radius circle. The first probe was used in all the holes sampled to take eight readings at the major compass points. The second probe was used to obtain four readings at the 1.5-meter radius and one central reading through the 20-cm holes only. In all, 101 readings were taken.

The 216-Z-9 Trench has a floor surface 9 x 18 meters and is 6.4 meters below a 28-cm thick roof. In the roof there are five 10-cm and six 20-cm access holes that were used in the isodose mapping.

Using current nomenclature, the 20-cm holes are lettered "A", "B", "C", etc., and the 10-cm holes are numbered. Sample rate readings are coded by the hole code followed by a numerical code for the compass points starting at "1" for north and proceeding clockwise through "8". The four 1.5-meter radius samplings from the lettered, 20-cm holes continued logically with "9" as north and ending with "12" as west. For a reading directly under a hole, "0" was used. Consequently "9-4" would designate the rate reading from a point 3 meters southeast of hole number "9".

CORRELATION

The correlation of the rate readings to plutonium concentrations was performed through a series of relative approximations. First, even though the detector was 20 cm from the trench floor, it was operating in a highly variable background radiation field--the effect of which had to be removed from the readings. Secondly, every time the probe touched the trench floor it received a charge of material which built to a fixed level unique to the sample hole and acted as additional background. This effect was eliminated by repeating readings around the points of the compass until the readings duplicated themselves.

As mentioned previously, the dose-to-plutonium concentration correlation was done on the basis of 1973 samples taken and analyzed from basically three areas. These values were then extrapolated to all other locations by correlating

"net" rate readings with duplicate reading points from two or more sampling holes.

The net dose readings are accurate to ±25%, while the relation to plutonium concentration is entirely subject to interpretation.

FIGURE 1
THE ISODOSE DETECTOR ASSEMBLY

V7312-10.34

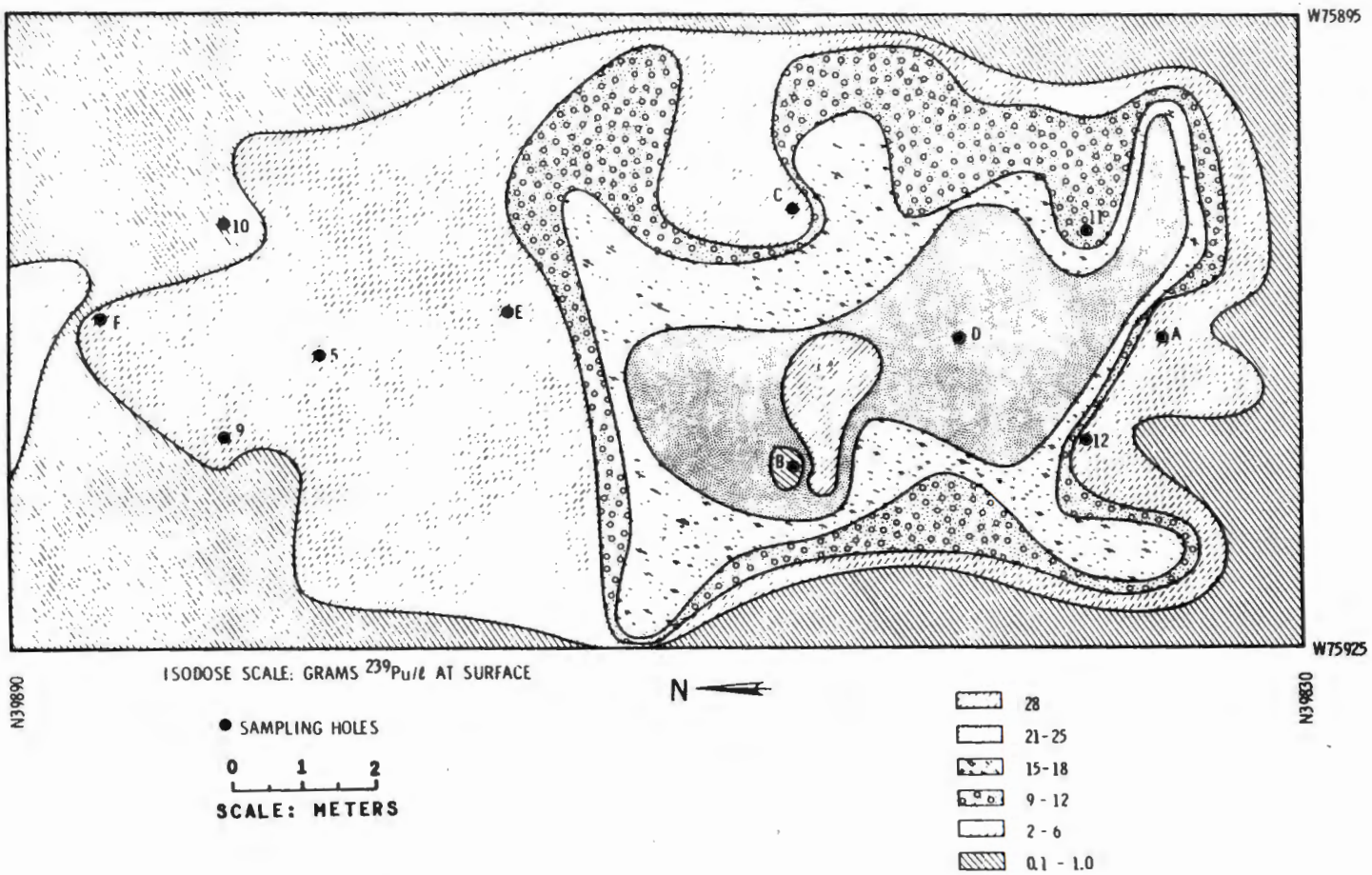


FIGURE 2

1973 216-Z-9 ISODOSE

APPENDIX J

NEUTRON SURVEY

L. E. Bruns

INTRODUCTION

A directional neutron survey system was devised and tested for monitoring the neutron flux in the 216-Z-9 (Z-9) crib. Calibrations were made by using standards of PuO_2 scattered on a floor below the directional detector at heights of 0.3, 0.6, 1.2, and 2.4 meters above the floor. The system was calibrated for angular response resulting in approximating the area the detector could "see." Background and moisture effects were also considered. Two detector systems were devised—one for the 20-centimeter holes (A, B, C, D, E, and F) and one for the 10-centimeter openings (5, 9, 10, 11, and 12). The 20-centimeter hole system consisted of a 5-centimeter BF_3 detector 30 centimeters long and encased in a 15-centimeter outside diameter polyethylene cylinder comprised of 5-centimeter slices of polyethylene interspersed with cadmium sheet. The BF_3 probe was surrounded with a cadmium sheet except for 60° of the detector circumference (see Figure 1). The smaller diameter, 10-centimeter hole detector system is shown in Figure 2.

SUMMARY

The theory of neutron emissions, moderation effects, and neutron capture is briefly reviewed. The method of calibration is described and the calibration curve is given in Figure 3. The procedure used for trench monitoring is

summarized along with assumptions used in arriving at the numbers given in Figure 4. Conclusions are made which show that (1) relative neutron flux measurements are estimated to be within ±30%, (2) g/liter values are based on the highest concentration believed possible, (3) fast to slow neutrons can be approximated, and (4) initial try at directional neutron surveying showed feasibility and future surveys would be improved by experience gained in this survey.

THEORY

Neutrons are emitted from plutonium by spontaneous fission and by alpha,neutron reactions of plutonium and americium. Americium has approximately 50 times the alpha of plutonium and similar alpha energies; hence it will have about 50 times the α,n contribution per unit mass. For plutonium metal, only spontaneous neutrons are emitted. As solid compounds or solution held by solids, the main contribution will be from the α,n reaction. Since alpha particles can only penetrate a very thin layer, the alpha,neutron reaction will be directed mainly at the closest element to plutonium, essentially elements within the compounds. The α,n contribution in solid compounds will vary with the type of compound since cross-sections to alpha particles vary widely. The variation in neutrons emitted from a 6% ^{240}Pu, 93% ^{239}Pu isotopic composition is as follows:

	Relative Counts
Plutonium metal	1 (spontaneous only)
Plutonium oxide (PuO_2)	7 (spontaneous + α,n with oxygen)
Plutonium fluoride (PuF_4)	200 (spontaneous + α,n with fluorine)

The bulk of the plutonium in Z-9 is probably PuO , $Pu(OH)_x$, $Pu(NO_3)_4$, $Pu(NO_3)_4 \cdot 2TBP$, $Pu(NO_3)_4 \cdot 2DBP$, and generally compounds that have a Pu-O bond. Hence, the α,n contributor is mainly plutonium alpha particles striking oxygen. Though considerable fluoride was put into the crib, the strong affinity of aluminum for fluoride (as compared with the plutonium-fluoride affinity) minimizes formation of PuF_4. Americium is also considered to be bonded with oxygen. Since the amount of americium is less than 0.5% of the plutonium, the contribution to neutron flux from this element is about 15% of the total.

Neutrons from both spontaneous fission and α,n reactions are in the two to three MeV range. By the law of conservation of momentum, the neutrons are rapidly slowed down by elements similar to the weight of a neutron (for example, hydrogen) to what are called thermal neutrons. A thermal neutron is a particle whose energy (about 0.04 electron volts) is such that it gains as much kinetic energy as it loses, since it is in equilibrium with the thermal motion of the material. A neutron detector using a boron-fluoride gas under a vacuum (BF_3 detector) sees mainly thermal neutrons. A helium gas under pressure comprises nother sensing medium. The helium tubes have a higher efficiency than the BF_3 detectors but will pick up some neutrons with energies between thermal and fast and are more sensitive to gamma.

The bulk of the fast neutrons are slowed to thermal by placing a material high in hydrogen content around the detector tube. Figure 3 shows the effect of polyethylene moderation on the number of neutrons counted by a typical neutron detector system. The presence of water absorbed in Z-9 soil must be considered in evaluation of the neutron readings. Beyond the maximum count in Figure 3, the count

drops--signifying capture of thermal neutrons by the polyethylene medium before the neutron can reach the detector. If the amount of water in the soil is known and the moderation due to soil is determined, the effect of moderation can be estimated.

Thermal neutrons can be captured by all materials; however these materials vary widely in their ability to capture thermal neutrons. Cadmium, for example, has a high cross-section for thermal neutrons, and an 0.2-cm sheet of cadmium will capture more than 99% of the thermal neutrons. Hence, the capture capability of cadmium makes it an excellent material for shielding portions of a detector tube from "seeing" neutrons. The neutrons must first be slowed to thermal neutrons before this can be accomplished. Therefore the optimum amount of moderator should be placed around the detector if possible; *i.e.*, if size of hole allows optimum moderation. Cadmium sheet is placed around the detector tube except for the portion directed at the crib floor (see Figures 1 and 2).

CALIBRATION

The detector systems were calibrated by placing a number of oxide standards on the floor of a room and placing the directional detector system 0.3, 0.6, 1.2, and 2.4 meters above the standards. The standards were bunched and spread out to determine the area "seen" by the counter. The detector was turned upside-down to note the ability of the detector system to be directional. Moderation was placed between standards and detector to note the detector system's efficiency for moderation. Moderation was removed from the directional area of the detector to note the variation of fast versus thermal neutrons.

216-Z-9 CRIB MONITORING

Calibration curves were devised for both detectors simulating as close as possible the crib floor. The 5-cm BF_3 detector assembly was lowered into six 20-cm holes to levels 0.3, 0.6, 1.2, and 2.4 meters from the crib floor, keeping the unshielded portion of the tube "looking" directly at the floor and the tube in a horizontal position parallel to the floor. A similar procedure prevailed for the 2.5-cm ^3He system in the five 10-cm diameter holes.

Assumptions were made to give a "worst case" situation. Actual values could be taken as about 0.25 of the shown values, +200%, -50%. The assumptions to give the values as noted are:

- Greater than 99.9% of the plutonium has a Pu-O bond as PuO_2, $Pu(OH)_x$, $Pu(NO_3)_4$, etc.; the α,n effect is from oxygen. Any plutonium compounded with the fluoride will give a higher than actual plutonium concentration.
- The contribution of americium is not considered in the neutron flux. This should, at most, give a 20% high plutonium concentration.
- The depth that the neutron counter "sees" is based on the moderation from the water in the soil (from laboratory analyses) and on the moderation of the soil itself. The reciprocal radius effect is essentially offset by the increase in area that the detector sees as the depth into the soil increases. The depth that the counter "sees" is assumed to be, on the average, between 13 and 16 cm.
- The background was taken by measurements above the

trench concrete cover. The effect of back-scattering throughout the trench was assumed to be the same.

The map of the neutron survey is shown in Figure 4. Each enclosed area includes the total area and each number representing the area is the average neutron flux, plutonium concentration, and fast-to-slow neutron ratio over the entire area. The rounded squares represent readings with the 5-cm BF_3 system; the circles represent the 2.5-cm ^3He system. The first and smallest area for the BF_3 system represents about 1.8 square meters, the area seen by the counter at 0.3 meter; 3.7 square meters at 0.5 meter, 12 square meters at 1.2 meters, and 49 square meters at 2.4 meters. For the ^3He system the smallest circles see *ca.* 1.5 square meters at 0.3 meters, 2.4 square meters at 0.6 meters, 5.5 square meters at 1.2 meters, and 15 square meters at 2.4 meters.

In Figure 4 the four-digit numbers are the relative neutron flux, the values in circle-type parentheses represent the average concentration in that total area, and the value in the angle-type parentheses is the thermal-to-fast estimated neutron ratio.

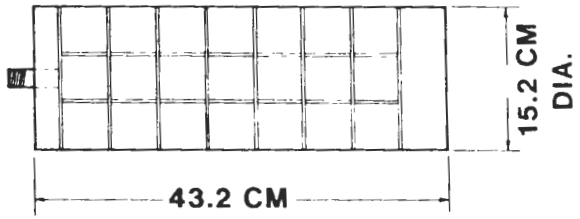
CONCLUSIONS

- Relative neutron flux measurements are within ±30%, the variation being due to inaccuracies of placement of the directional detector. Also the varying moisture content of the soil and the varying back-scattering throughout the trench account for some of the inaccuracies.
- The gram/liter values assigned to the progressively larger areas as the detector height is increased

from 0.3 to 2.4 meters are conservatively high for critical mass safety's sake. The g/liter values are estimated to be high by greater than a factor of three.

- The fast-to-slow neutron number gives an approximation of the water in the trench. The highest moderation or amount of water present is in the vicinity of holes "A" and "12".

- Directional neutron counting is feasible and helpful in approximating neutron flux, plutonium concentrations, and the amount of thermalization. Experience gained from this initial directional neutron survey may prove to be helpful in future surveys. Such things as addition of many more standards for calibration, correction for back-scattering, and correction for americium would improve accuracies.



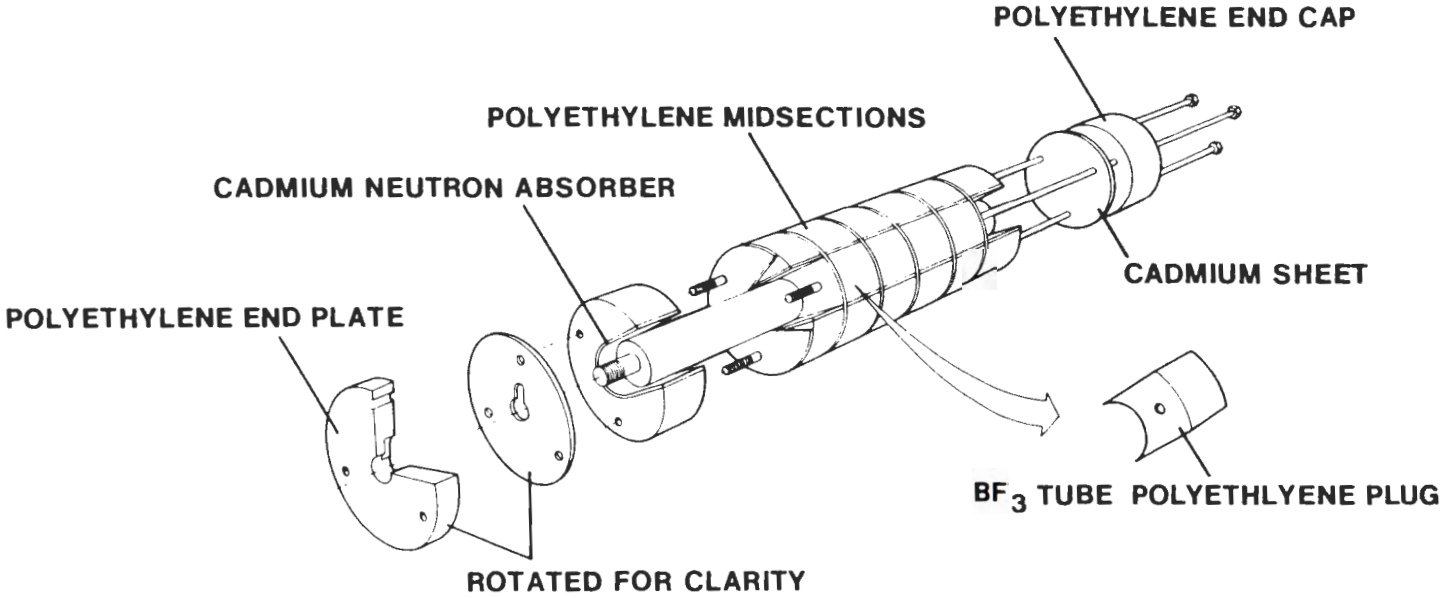


FIGURE 1

5 CENTIMETER DETECTOR SYSTEM

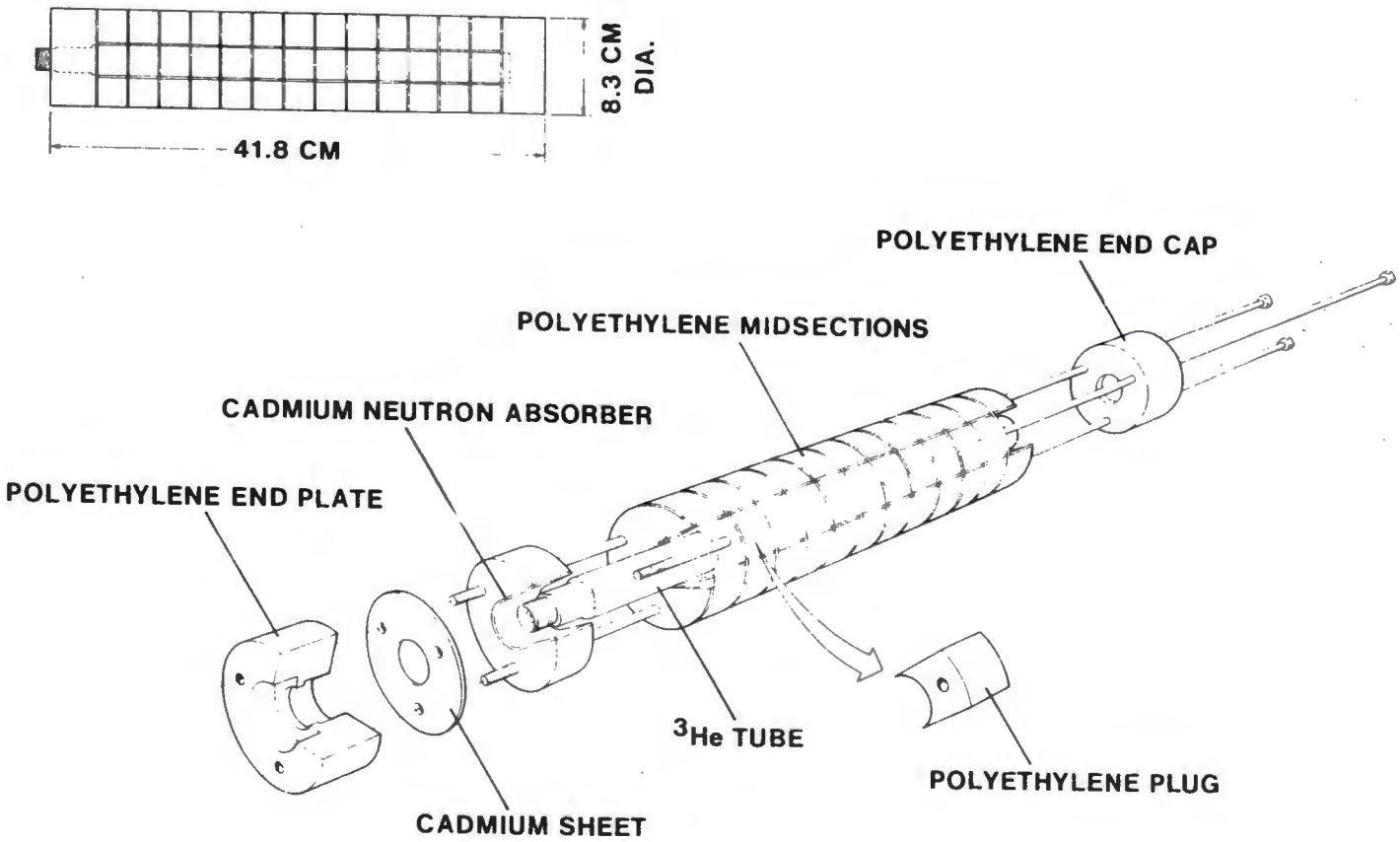


FIGURE 2

2.5 CENTIMETER DETECTOR SYSTEM

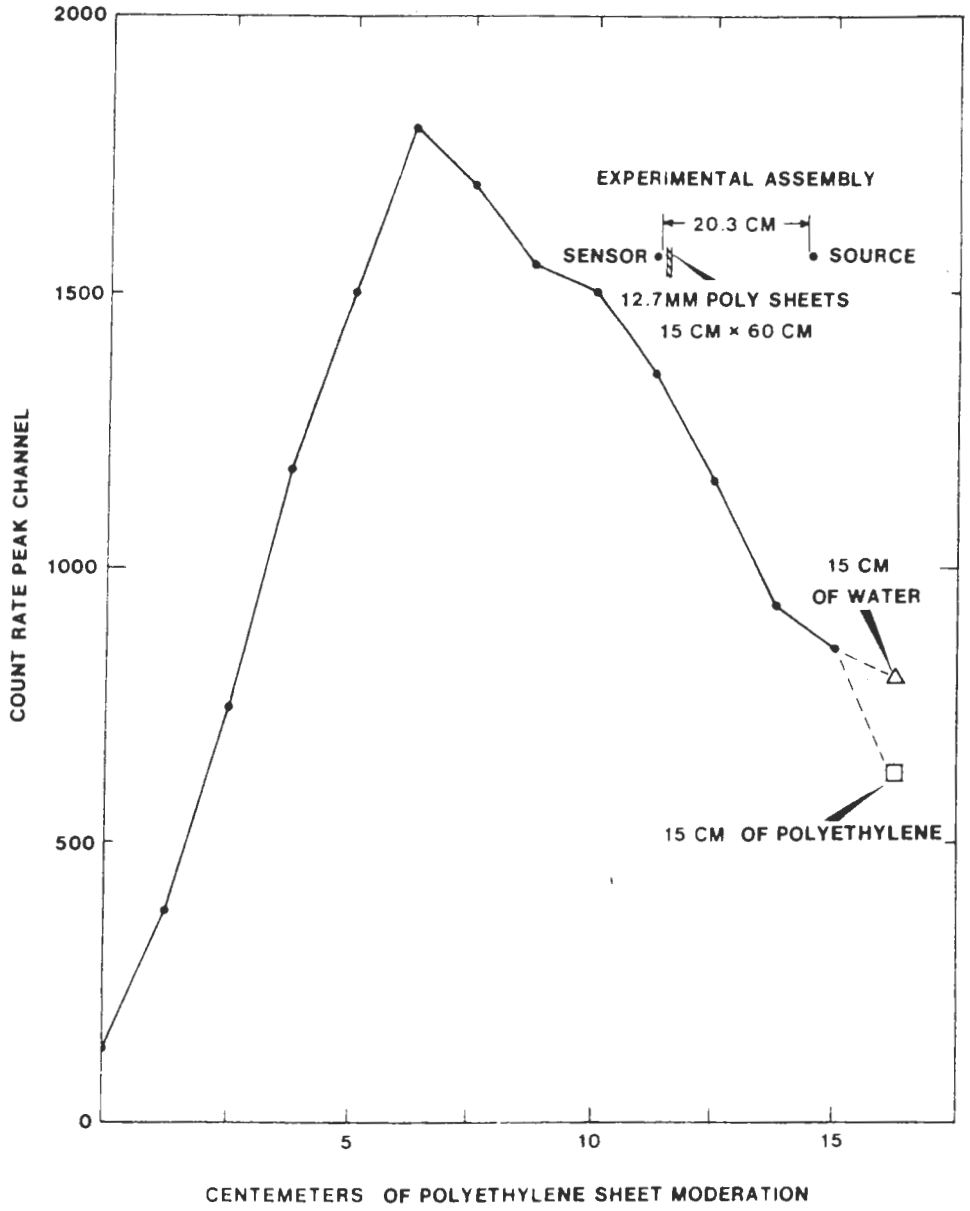
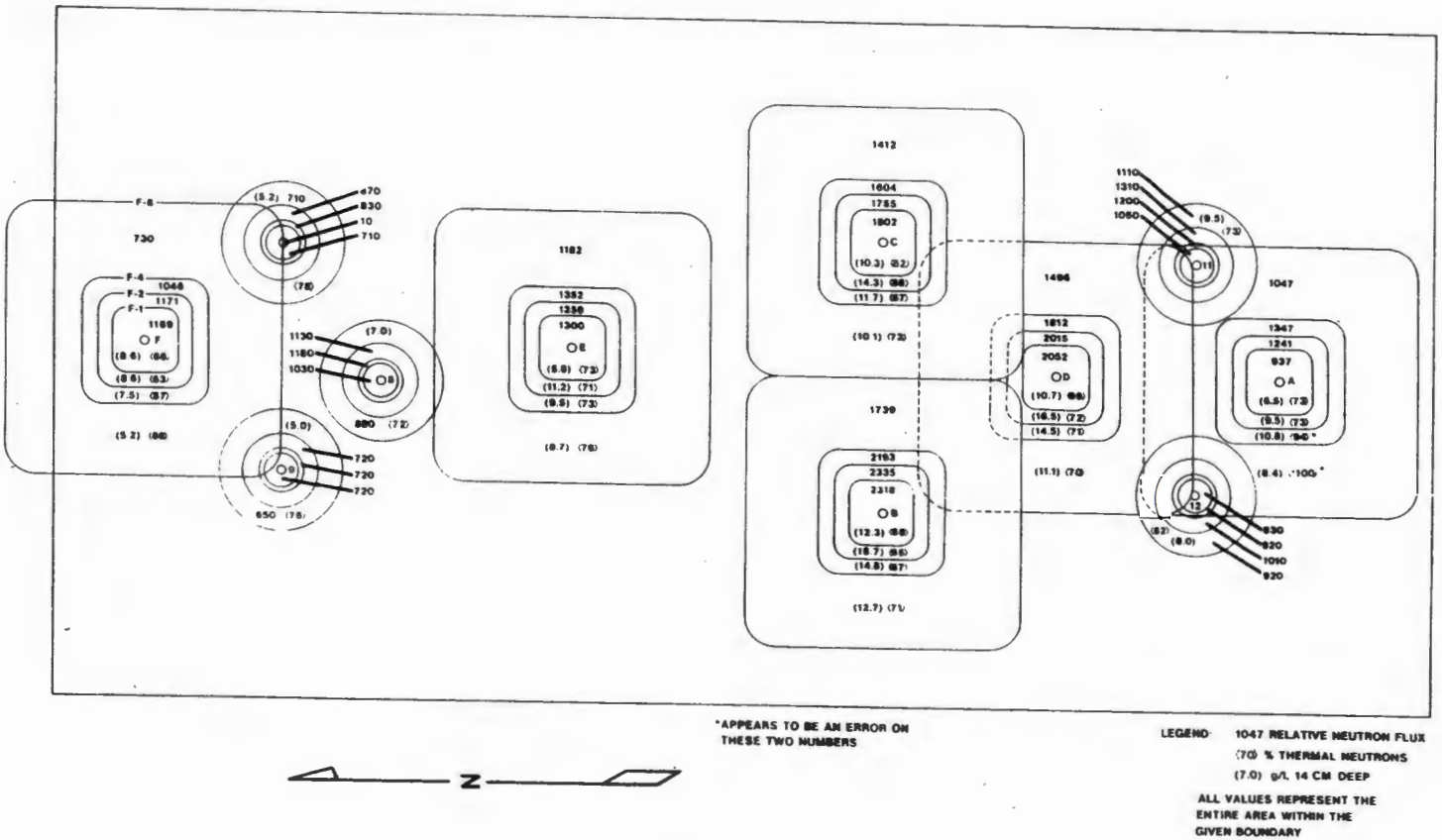


FIGURE 3

EFFECT OF MODERATION ON NEUTRON COUNT

V310-4.1



*APPEARS TO BE AN ERROR ON THESE TWO NUMBERS

LEGEND: 1047 RELATIVE NEUTRON FLUX
(70) % THERMAL NEUTRONS
(7.0) g/l, 14 CM DEEP

ALL VALUES REPRESENT THE ENTIRE AREA WITHIN THE GIVEN BOUNDARY

FIGURE 4

NEUTRON SURVEY 216-Z-9 TRENCH

APPENDIX K

CORE SAMPLES: ANALYTICAL RESULTS

V. L. Schuelein

Appendix K contains soil analytical data other than actinide values reported in Appendix B. Table I contains pH values of soil. The observation that soil pH was 4.1, slightly acidic, at the 2.4-meter depth (8') indicated that a large bulk of waste solution had percolated through that point and had decisively reduced the soil pH below normal soil pH values. Table II contains the volatiles to 150 °C. These values were used to calculate the hydrogenous content of soil for subsequent nuclear criticality calculations.

Table III contains data from Sample Hole G concerning the area of highest plutonium accumulation. These data revealed cadmium behavior in actual Z-9 soil, and was useful in calculating appropriate cadmium additions. Table IV contains data required for calculation of criticality. Table V contains some data on the sludge removed from surface samples. The distribution of plutonium on sediments according to sediment size distribution is shown in Table VI. Table VII contains a description of the counting equipment used to obtain the actinide values in Appendix B.

TABLE I
pH VALUES[1]

Sample	Depth	pH
4-13-A	15 centimeters (6 inches)	3.6
4- 1-A	15 centimeters (6 inches)	3.6
3- 2-B	1.4 meters (4 feet 6 inches)	4.8
2- 1-C	2.4 meters (8 feet)	4.1
Control soil	0	8.2
Control fine gravel	0	7.7

TABLE II
VOLATILES TO 150 °C ANALYSIS[2]

Sample	Depth Centimeters	% Water
4-13-A	0-15	12
4-10-A	0-15	12
4- 1-A sludge		31
4- 1-C	30	4
4- 1-D	60	6
4- 3-D	90	4

[1] Letter, V. L. Schuelein to M. H. Campbell, April 5, 1973, "Z-9 Core Tests," Atlantic Richfield Hanford Company.
[2] Letter, M. H. Campbell to R. E. Isaacson, April 20, 1973, "Chemical Analyses for Sludge from Z-Trench," Atlantic Richfield Hanford Company.

TABLE III

ANALYTICAL RESULTS FROM AREA OF HIGHEST PLUTONIUM ACCUMULATION[1]

Depth Centimeters	Depth Inches	pH	Density g/cm³	Cadmium Content mg/g soil	Cadmium Sorption[a] %	Cadmium Sorption mg/g soil	% Water	CEC[b] meq/100 g	Estimated Plutonium mg/g
0 - 2.5	0- 1	4.2	0.8	1.1	32	10	-	22	9.6
2.5- 7.5	1- 3	4.0	1.0	1.2	34	4	-	23	11.
7.5-15	3- 6	4.4	1.4	0.34	18	2.5	-	10	3.
15 -23	6- 9	4.0	1.6	[illegible]	3	0.3	4.85	3	0.2
23 -30	9-12	3.4	1.8	0.05	3	0.3	4.6	3.4	0.25
30 -38	12-15	3.4	1.9	0.04	7	0.9	4.1	3.1	0.2
38 -46	15-18	3.6	1.7	0.04	3	0.3	4.4	2.5	0.1
46 -53	18-21	3.4	1.3	0.07	5	0.4	5.45	5.2	0.09

[a] % cadmium sorption was the % sorption of cadmium onto soil contacted with an equal volume of 10-grams per liter cadmium solution.
[b] Cation Exchange Capacity.

[1] Personal Communication, R. C. Routson to D. J. Brown September 13, 1973.

TABLE IV

MISCELLANEOUS DATA[1]

Depth cm	Sample Number	% TBP	% Volatile 150 °C	% Volatile 750 °C	mg NO_3^-/g Soil	µg Cd/g Soil	mg Cl^-/g Soil	Density g/cm³
0 - 2.5	4-14-A-1	0.43	24.9	9.3	3.7	86.2	2.3	1.570
2.5- 7.5	4-14-A-2	0.41	8.8	2.3	0.97	8.5	0.4	1.71
7.5-15	4-14-A-3	0.70	7.7	1.4	0.20	1.5	0.08	1.77
15 -23	4-14-B-1	0.43	5.9	1.4	0.08	0.3	0.03	1.62
23 -30	4-14-B-2	0.43	5.8	1.5	0.07	0.4	0.03	1.67
30 -46	4-14-C	0.65	5.8	1.6	0.14	0.4	0.05	1.68
46 -61	4-14-D	0.46	5.8	1.3	0.44	<5.	0.14	1.74
61 -71	4-14-X	0.17	5.5	1.6	0.63	4.4	0.17	1.70
0 - 2.5	4-15-A-1	0.50	42.8	20.7	17.2	173	5.1	1.49
2.5- 7.5	4-15-A-2	0.26	12.3	4.3	7.0	100	2.2	1.74
7.5-15	4-15-A-3	0.59	5.6	2.1	6.0	54	0.97	1.72
15 -23	4-15-B-1	0.27	4.2	1.9	5.6	59	0.68	1.70
23 -30	4-15-B-2	0.28	3.7	1.2	6.4	57	0.46	1.69
30 -46	4-15-C	0.31	3.6	1.5	4.0	54	0.32	1.72
46 -61	4-15-D	-	-	-	5.5	58	0.27	1.74
0 - 2.5	4-16-A-1	0.65	39.3	21.9	5.0	211	6.0	1.56
2.5- 7.5	4-16-A-2	0.50	11.9	4.0	2.2	65	2.1	1.72
7.5-15	4-16-A-3	0.72	4.5	0	1.5	44	0.93	1.69
15 -23	4-16-B-1	0.77	3.9	0	1.4	27	0.46	1.74
23 -30	4-16-B-2	0.29	1.6	2.8	1.4	25	0.26	1.75
30 -46	4-16-C	0.48	2.1	2.7	1.5	22	0.20	1.81
46 -61	4-16-D	0.48	1.1	3.0	0.9	24	0.19	1.74
0 - 2.5	4-17-A-1	1.97	36.7	35.2	8.2	510	6.6	1.22
2.5- 7.5	4-17-A-2	-	11.7	3.6	2.9	144	2.2	1.68
7.5-15	4-17-A-3	1.60	5.4	4.9	5.3	104	1.6	1.72
15 -23	4-17-B-1	0.61	3.9	2.6	2.8	36	0.4	1.67
23 -30	4-17-B-2	1.19	1.2	3.4	2.9	27	0.3	1.60
30 -46	4-17-C	0.81	3.6	0.2	2.2	19	0.17	1.67
46 -61	4-17-D	0.67	3.5	3.7	3.0	25	0.14	1.68
0 - 2.5	4-18-A-1	3.19	46.3	22.6	6.7	230	81.2	1.34
2.5- 7.5	4-18-A-2	2.74	18.8	1.9	4.0	106	5.2	1.68
7.5-15	4-18-A-3	2.27	14.0	0	2.2	87	2.2	1.65
15 -23	4-18-B-1	0.81	9.4	0	1.8	41	1.1	1.66
23 -30	4-18-B-2	0.79	10.4	3.9	2.5	41	9.8	1.57
130 -46	4-18-C	0.62	4.3	1.9	3.4	58	0.38	1.61
46 -61	4-18-D	0.42	4.8	1.7	4.0	87	0.34	1.65

[1] Unpublished Data, Chemical Technology Laboratory, September 1973.

TABLE V

CHEMICAL ANALYSIS OF SLUDGE[1,2]

Composition of Sludge

	%
SiO_2	41.6
Al_2O_3	7.3
FeO	12.1
MgO	5.7
CaO	6.8
Na_2O	1.0
K_2O	2.1
TiO_2	0.5
Loss of ignition (750 to 800 °C)	20.8

Chemical Behavior of Sludge

One minute shake in	
H_2O	All materials settled out; no reaction.
CCl_4	No visible reaction; ≈50% material floated.
12*M* HNO_3 + 0.3*M* HF	Soil appeared to disintegrate and an emulsion formed; part of material floated.
Sludge heated for two hours at 75 °C in	
H_2O	No visible change; no layer of oil.
CCl_4	After CCl_4 evaporated, white scum left; soil still in large chunks.
12*M* HNO_3-0.3*M* HF	Gassing occurred during heating; soil appeared to disintegrate and an emulsion formed; no material floating after heating.

[1] Letter, V. L. Schuelein to M. H. Campbell, "Z-9 Core Test," April 5, 1973, Atlantic Richfield Hanford Company.
[2] Letter, M. H. Campbell to R. E. Isaacson, "Chemical Analysis for Sludge from Z-9 Trench," April 20, 1973.

TABLE VI

PLUTONIUM AND AMERICIUM CONTENTS VERSUS PARTICLE SIZE[1]
SAMPLE 4-11

Depth		Size Range - Millimeters						
Centimeters	Inches	>2	1-2	0.5-1	0.25-0.5	0.125-0.25	0.063-0.125	0.063
					Wt% Soil in Fraction			
5-15	2- 6	42	20	19	5.4	4.3	4.9	4.6
15-30	6-12	43	26	19	5.2	2.3	2.1	1.9
46-61	18-24	40	26	22	6.4	2.2	1.4	1.7
					Pu Content (mg Pu/g Soil)			
5-15	2- 6	0.13	0.22	0.60	1.8	3.0	3.2	10.7
15-30	6-12	0.093	0.093	0.14	0.29	0.36	0.86	2.48
46-61	18-24	0.082	0.10	0.10	0.18	0.28	0.39	1.13
					Wt% Pu in Fraction			
5-15	2- 6	5.1	4.1	10	9.0	12	14	45
15-30	6-12	22	14	15	8.4	4.6	10	26
46-61	18-24	26	21	18	9.4	4.9	4.4	16
					Am Content (g Am/g Pu)			
5-15	2- 6	0.0025	0.0023	0.0021	0.0022	0.0021	0.0023	0.0021
15-30	6-12	0.0023	0.0021	0.0021	0.0018	0.0019	0.0020	0.0020
46-61	18-24	0.0022	0.0020	0.0017	0.0013	0.0017	0.0016	0.0014

[1] J. L. Swanson, "Nature of Actinide Species Retained by Sediments at Hanford: Interim Progress Report," BNWL-B-296, August 1973.

TABLE VII

216-Z-9 CONTENTS ANALYSES[1]

Gamma Energy Analyses

Sampling Philosophy

1. Three sample locations.
2. Cored and sampled as a function of depth.
3. Inner core sampled for side-by-side "duplicates".

High Level

1. Detector: coaxial, closed end Ge(Li).
2. Analyzer: Nuclear Data 50/50.
3. Method: gamma energy analysis of 413.7 and 59.537 KeV peaks using 129:413.7 net peak ratio and Al absorption model for self-absorption as per J. E. Cline in ANCR-1055. Absorption calculated as an internal absorber; *i.e.*,

   $$1 \text{ observed} = 1 \text{ emitted} \left[\frac{1-e^{-ux}}{ux}\right]$$

   Random summing corrections applied to all data.
4. Absorber: 5.6 μm Cd.
5. Calibration standards: 40, 4.0, 0.4, and 0.02 g/liter ^{239}Pu from standard pin material and Baker and Adamson Sea Sand. Americium-241 calibrated from IAEA ^{241}Am source and prepared in B&A Sea Sand.
6. Geometry: 25-cc sample on rotated state: *ca.*, one or three inches from detector face to center of rotation.

Low Level

1. Detectors: three coaxial, closed end Ge(Li).
2. Analyzer: Automatic Radioactive Inventory System (ARIS).
3. Method: Gamma energy analyses ARH-SA-134 and ARH-2632.
4. Absorber: 5.6 μm Cd.
5. Geomegry: 25-cc sample viewed from three sides of a four-sided box array.

Sorting: ARIS using a 5-cm x 5-cm NaI(Tl) detector with 5.6 μm Cd absorber.

[1]W. H. Zimmer, Chemical Technology Laboratory, ARHCO.

APPENDIX L

1963 SAMPLING NOTES
COMPARISON OF 1963 AND 1973 DATA[1]

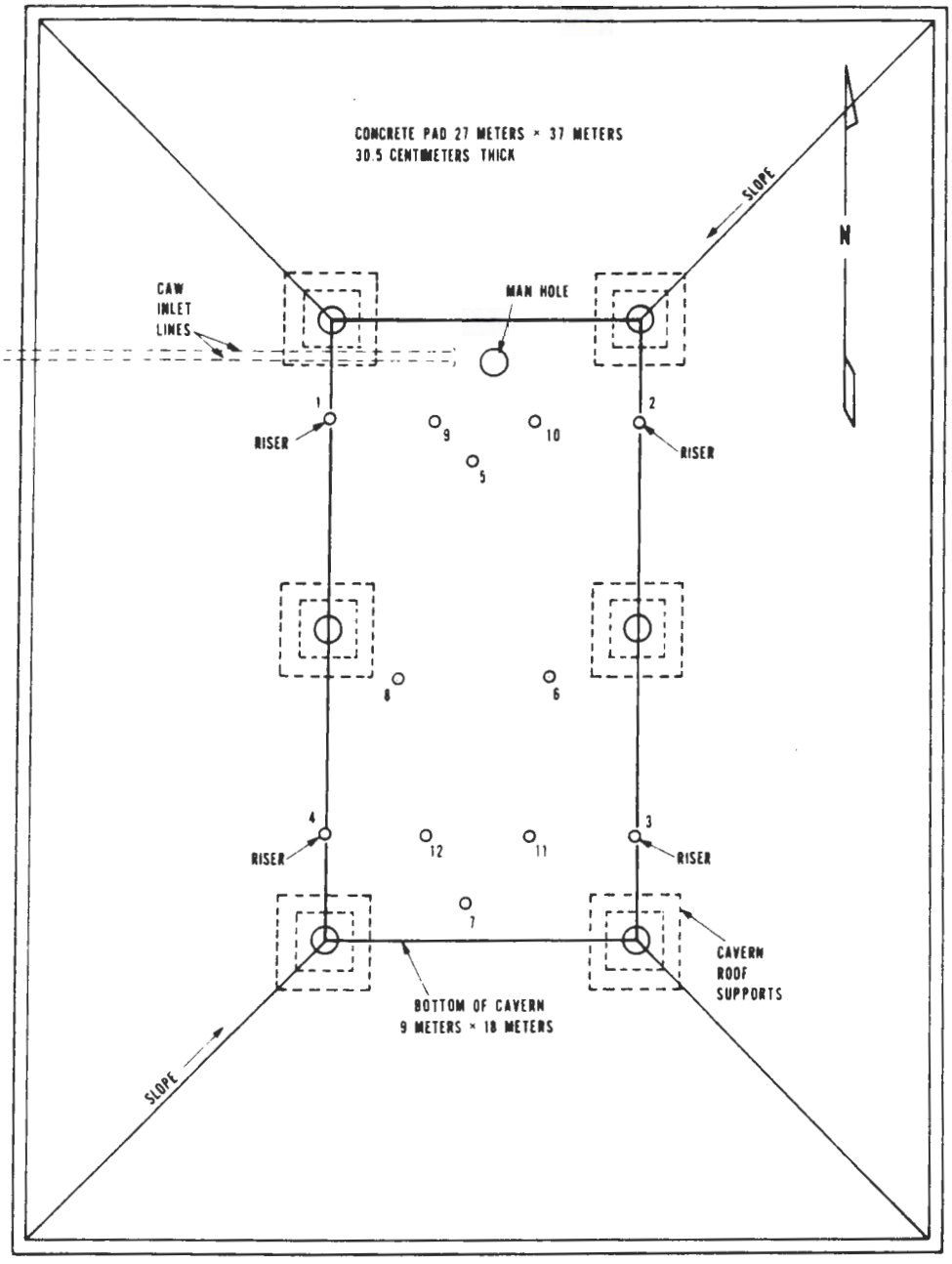
D. T. Crawley
W. H. Zimmer
R. D. Fox

The soil in the 216-Z-9 (Z-9) Enclosed Trench was sampled and analyzed for plutonium content on three occasions--August 1959, December 1961, and April 1963. The analyses were used in determining the plutonium distribution in the trench soil.

The soil sampling in 1959 was accomplished by driving a piece of 2.5-cm steel pipe 61 centimeters into the soil. The only access for sampling at that time was through four risers extending 1.2 meters above the concrete cover or slab. The riser locations are shown in Figure 1 and numbered as sampling locations 1 through 4. As Figure 1 indicates, these locations are at the periphery of the crib floor and leave some question as to how representative the samples were of the more central area of the cavern floor. The sampling crew reported contact between the soil and sampler at Position 1 about 61 centimeters above the depth indicated on the trench drawings.

The soil sampling in 1961 was done in the same manner as in 1959 except that four more sampling locations were available, for a total of eight. The four new sampling locations were made available by drilling 10-cm holes in the concrete slab in more central floor locations. The

[1]Letter, D. T. Crawley to K. R. Ridgway, "216-Z-9 Cavern Soil Sampling and Analysis," October 11, 1971, Atlantic Richfield Hanford Company.



FROM H-2-15491.92
1-4 VENT RISERS
5-8 10 CENTIMETER HOLES CUT 1961
9-12 10 CENTIMETER HOLES CUT 1962

SCALE: 1 CENTIMETER = 1 METER

OCT 9-18-63

FIGURE 1

216-Z-9 ENCLOSED TRENCH SAMPLING POINTS

V7312-10.36

locations are shown in Figure 1, numbered 5 through 8.

The ends of practically all of the pipes driven for samples were curled in, closing off the opening so that no full 61-cm cores were obtained in the 1959 and 1961 samplings. Deeper core samples were desired for the 1963 soil sampling, so different equipment was needed. A commercial drive core sampler was selected after some trials with three types of commercially available soil samplers.

The sampler consists of a drive shoe, core lifter, sample barrel, and sampler head. The drive shoe or bit is hardened tool steel and is tough enough to break small rocks and pebbles without sustaining damage. The inside diameter (ID) of the bit is slightly smaller than the core barrel ID, and the core will pass into the barrel without undue friction or compaction. The core lifter or retainer has a number of spring fingers that allow easy passage of the core into the barrel but prevent return flow of the sample out of the core barrel. The core barrel, in this case, is a split tube-type that is held together by the drive shoe and the core barrel head. The sample is easily removed by unscrewing the drive shoe and head and "splitting" the core barrel. The head, in addition to clamping the core barrel together, provides a rod coupling and contains a ball check valve to vent fluid and air from the barrel. The check valve also assists in retaining the core. The sampler used takes a 4.1-cm diameter core 0.61 meters long.

The operation of the drive sampling equipment is now described. A length of heavy wall rod or casing is attached to the core barrel head. The drive head (a heavy steel collar) is attached to the drive rod, and a short section of rod that serves as a drive hammer guide is screwed into the top of the drive head.

The drive hammer in this case is a 135-kilogram weight with a guide hole through the center. A jar-back collar is attached to the top of the guide rod. In operation, the drive hammer is repeatedly lifted by a winch and dropped against the drive head. The core barrel progresses downward as the sharpened steel shoe compresses and displaces the sample media. The sampling is completed when the core barrel has been driven its full length into the material. The weight is then raised against the jar-back collar and the core barrel jarred or lifted from the hole. The sampler may be rerun in the hole for progressive depth sampling as long as the material does not cave.

The drive sampling technique is usually successful only with soft or unconsolidated porous media where the drive shoe can compress or displace the material. A limited amount of hard material in a soft matrix, such as pebbles or gravel in sand, can be tolerated. The hard particles will be sampled, displaced, or broken up if their sizes are smaller than the core barrel diameter. Large diameter objects, such as boulders, prevent core barrel progress. With proper use, nearly undisturbed samples may be taken by the drive methods. Maximum practical sampling depth with drive coring equipment is about 15 meters in a soft material (sand, silt, clay, etc.) that will stand unsupported.

For the soil sampling in 1963, four more 10-cm holes were drilled in the concrete slab cover in the locations shown in Figure 1, numbered 9 through 12. The first four locations (1 through 4) were not sampled, but the second four (5 through 8) and the four new locations (9 through 12) were sampled or attempted. The intention was to sample to a depth of 1.8 meters in each sampled location. To reinsert the sampler in the same hole for successive 61-cm

samples to a depth of 1.8 meters, a guide had to be used. This was necessary because the top of the slab was 3 meters above the trench floor. A 7.5-cm diameter aluminum irrigation pipe was inserted in the hole in the concrete and driven a few centimeters into the soil to serve as the guide before the first 61-cm core was taken. The guide pipe was angled to one side in those locations where samples had been taken previously to avoid the old sample holes.

Because of the presence of plutonium, gloved box operations were exercised during the course of the sampling. The loaded core barrels were removed from the drive rod inside a plastic gloved box, then removed from the box and transported to a gloved box inside Z Plant for unloading. The cores were sectioned and the sections removed from the gloved box for transport to the 222-S Chemical Technology Laboratory for analysis.

In the sampling operation most of the core barrels were loaded with a drive of better than 61 centimeters (61 to 79 centimeters). The length of cores obtained in these drives varied from 10 to 71 centimeters. Upon re-insertion of a sampler, none went to the depth the previous sampler had been driven. In one case, the sampler had to be driven nearly the entire distance again and was set aside as a hole clean-out. We can only postulate what made this necessary, since we could not see what happened or what we were doing (6 meters down inside the 7.5-cm irrigation pipe).

One advantage the split tube core barrel sampler had over the ordinary pipe samplers used in the 1959 and 1961 samplings was that the soil core could be visually observed before it was disturbed in the process of core sectioning. In one instance the core material had to be tapped out of the core barrel and the length of core estimated from the

volume of soil obtained because the shoe could not be removed to open the barrel. Generally the varying lengths of core were proportioned according to the length each was supposed to represent. Fifteen-centimeter depth cores were arbitrarily selected, and in most cases the core divided into four sections. Each section was manually pushed off the end of the split barrel for its separate 0.24-liter (pint) glass jar.

The top of each first core from each sample location had a gray, pasty, and sticky layer from about 0.6 to 1.9 cm thick. The remainder of the cores were mainly sand to coarse sands, with some small rocks or rock fragments. The sands were not consolidated, and they crumbled easily in the handling during sectioning. No effort was made to avoid mixing the sectioned core materials, nor was there any intentional mixing in the handling subsequent to sectioning and prior to aliquoting for analysis for plutonium content.

The laboratory commented on three of the top core sections as "muck," "fine silt," and "clay sample", and this was taken as describing the gray, pasty, and sticky material mentioned above. The "clay sample" had an appreciable radiation reading (10 mR/hour). The "fine silt" and "clay sample" had two of the three reported high plutonium concentrations (see remarks in Table I). Radiation readings were not taken on each individual section or collection of sections. However they were taken on several collections of jars of sections (boxes or jars) with <1 mR/hour readings, except for the box with the sample with the 10 mR/hour reading. The "clay sample" was singled out of this box.

Several unsuccessful attempts were made to sample the number 11 location.

The cores were pushed from the sample pipes in the 1959

set of samples. The entire sections were leached with two batches of 6*M* HNO_3; they were then combined and analyzed. No further leaching was done on the individual sections to determine if all the plutonium was removed.

The pipes with the cores from the 1961 sampling were cut in uniform section lengths (4-cm) before the soil was removed. The entire section of soil was then leached with hot 6*M* HNO_3. As many as six leaches were performed on a single section with various hot reagents, with each leach being analyzed for plutonium. In general the leaching was continued until a factor of 10 reduction in plutonium from the preceding leach was attained. The second leach with hot 6*M* HNO_3 removed significant amounts of plutonium, and in some cases even more than the first leach. When concentrated HNO_3 was used on some of the sections, as much and sometimes more plutonium was removed than in the preceding 6*M* HNO_3 leaches. Some HF (0.25*M*) was added to concentrated HNO_3 for subsequent leaches, and still significant amounts of plutonium were extracted. The sum of the amounts of plutonium removed by each leach of a section was designated as total plutonium content of the section.

Because of problems encountered in extracting the plutonium from the entire section of the 1959 and 1961 samplings, and the larger size of sections from the 1963 sampling, new extraction equipment was fabricated for extraction and analysis for the 1963 sampling. Two- to four-gram aliquots of soil were placed in a test tube equipped with an air sparger. About 10 ml of 10*M* HNO_3 and 0.05*M* HF were added to the test tube and the tube placed in a 60 to 70 °C water bath for four hours with sparging. The samples then were allowed to stand overnight in the leach solution without sparging before the solution was analyzed for

TABLE I

PLUTONIUM CONCENTRATION IN 216-Z-9 TRENCH

Section Number	Zone Depth Centimeters	Pu Concentration--grams/liter of Soil Original	Re-Analysis	Re-Analysis After Mixing	Remarks
5- 1	0 - 30.5	1.73			Had to tap out core. Could not remove shoe.
5- 3	61 - 91.5	0.61			
5- 5	122 -137	0.09			
5- 6	137 -152	0.16			
5- 7	152 -168	0.07			
5- 8	168 -183	0.03			
6- 1	0 - 15.2	25.5	22.5	15.8	"Fine silt".
6- 2	15.2- 30.5	22.5		12.7	
6- 3	30.5- 45.7	1.16			
6- 7	91.5-107	0.24			
6-11	152 -168	0.34			
6-12	168 -183	0.13			
7- 1	0 - 15.2	19.2	21.3	34.5	"Clay sample", 10 mR/hr gamma.
7- 2	15.2- 30.5	23.1		24.1	
7- 3	30.5- 45.7	2.61		12.7	
7- 6	76 - 91.5	0.53			
7- 7	122 -137	1.69	0.19		Rock in barrel; 20-cm core.
8- 1	0 - 15.2	1.43	1.13	0.20	10-cm core.
8- 2	15.2- 30.5	0.70		5.09	
8- 3	30.5- 45.7	19.3	11.9	5.66	
8- 4	45.7- 61	25.4	11.3		
8- 5	61 - 76	1.81			25-cm core.
8- 7	122 -137	0.50			Short core - 12.5 cm.
8- 8	168 -198	0.08			Intentionally driven to 2.5 meters.
8-10	213 -229	0.07			
8-11	229 -244	0.10			
9- 1	0 - 30.5	2.24			A rock blocked the drive shoe. 25-cm core.
9- 2	30.5- 61	0.60			
9- 3	61 - 81.3	0.30			{
9- 4	81.3-102	0.12			{About 36-cm core.
9- 5	102 -122	0.12			{
9- 6	122 -137	0.13			
9- 7	137 -152	0.18			
9- 8	152 -168	0.15			
9- 9	168 -183	0.18			

TABLE I (continued)

Section Number	Zone Depth Centimeters	Pu Concentration--grams/liter of Soil Original	Re-Analysis	Re-Analysis After Mixing	Remarks
10- 1	0 - 15.2	3.62			"Muck" on top.
10- 3	30.5- 45.7	0.35			
10- 5	61 - 76.2	0.23			
10- 7	91.5-107	0.06			30.5-cm core; rocks in core barrel.
10-10	137 -152	0.51			
10-11	152 -168	0.14			
10-12	168 -183	0.08			
11-		Attempted, but no sample obtained.			
12- 1	0 - 15.2	4.33			{
12- 2	15.2- 30.5	1.44			{Rocks in core barrel.
12- 4	45.7 - 61	0.06	0.07		{
12- 5			A cleanout of sampling hole.		
12- 8			A cleanout of sampling hole.		
12-10	76.2- 91.5	0.62			20-cm core.
12-11	122 -137	0.62			25-cm core.
12-12	137 -152	0.41			Rock stuck in drive shoe.

All laboratory results were given in counts/minute/gram of soil (c/m/g).
A factor of 1.23×10^{-11} was used to convert c/m/g to grams Pu/gram of soil.
A soil density of 2.3 grams/cubic centimeter (g/cm^3) was used to convert to grams of Pu/cm^3 soil.

plutonium. The extraction was repeated on the same aliquot of soil to test for the degree of plutonium removal from the soil. The second extraction on the aliquot of soil in practically all cases contained 1/100 or less of the amount of plutonium found in the first.

The maximum plutonium concentration for Sample Location No. 8, shown in Table I, will be noted between 30 and 61 cm rather than the top 30 cm in other locations. It is possible that this core may have been unloaded from the wrong end. Once the end fittings were removed from the split tube core barrel, the core may have been inadvertently reversed.

Although more than a year elapsed between the 1961 sampling (December 1961) and the 1963 sampling (April 1963), the cavern operating time was only a little over three months during that period. [Recuplex ceased operation after April 7, 1962; hence the trench was inactive for one year.] Aside from the damp appearance of all the 1963 sampling cores, no liquids were noted during core handling and sectioning.

DESCRIPTION OF MATERIALS SENT TO Z-9

No simple description of the materials sent to the Z-9 Enclosed Trench is adequate to evaluate the conditions existing in the cavern soil. While it was desirable to make up the Recuplex feed solutions as uniform in composition as possible, the feed materials and their compositions actually varied widely. The solutions all wound up as partially neutralized salt waste in the Z-9 Trench. The organic extractant (15% by volume TBP in CCl_4) degraded in the presence of nitrate ion, HNO_3, radioactivity, and other agents. Organic washing removed some of the products of degradation,

and these were routed to Z-9. The organic itself was occasionally discarded to Z-9 when washes were no longer effective. These materials comprised the major part of the volume discarded to Z-9.

Some of the smaller volumes of materials sent to Z-9 are significant from the standpoint of their possible effect on the soil and the location of the plutonium.

Fabrication oil (fab oil), used as cutting oil in the plutonium metal machining operations, was made up of 25 vol% lard oil (a liquid pig fat) in CCl_4. Fabrication oil was discarded to Z-9 after processing for plutonium recovery. The lard oil by itself contained some congealed fats.

Dibutylbutyl phosphonate (DBBP) in CCl_4 was used in tests and actual production over the last two years of Recuplex processing, and this was discarded to Z-9 after degrading.

Recuplex glove box (hood) gloves deteriorated rapidly in contact with the Recuplex organics and acids. Plastic sleeves and sample bottles also deteriorated. The Recuplex system leaks got mixed with these products of degradation on the hood floors. The liquids from the floors on occasion caused process difficulties and prompted the direct disposal to Z-9 of particularly bad batches.

Undissolved solids were a problem throughout the life of Recuplex. The CA Column accumulated a separate phase of gelatinous-appearing materials (commonly called interface crud) that were periodically disposed of to the Z-9 Trench. The acid salt waste was partially neutralized with NaOH before disposal to Z-9; this neutralization produced some localized precipitation in the salt waste since aluminum, magnesium, calcium, and iron were present in considerable amounts. This would tend to scavenge some of the remaining

amounts. This would tend to scavenge some of the remaining soluble plutonium. The low acidity of the waste tended to precipitate Pu^{+4} polymer (the presence of Pu^{+4} polymer in Z-9 was confirmed by the high-acid concentration necessary to leach the plutonium from the soil). Some sulfate in the original forms of hydroxylamine sulfate, ferrous sulfamate, and in feed material were added to the Recuplex process. Sulfate under certain conditions will precipitate plutonium, and plutonium sulfates were found in some of the Recuplex equipment. The Z-9 soil consists mainly of sand that readily filtered out solid materials.

Uranium was used in the start-up and testing of Recuplex and was discarded to Z-9.

Perchlorethylene and tetrabromoethane were used at different times in combination with CCl_4 as a diluent for TBP or for cleaning agents that came into the process and were subsequently discarded to Z-9.

ESTIMATE OF PLUTONIUM CONTENT

Estimates of the plutonium content of the 216-Z-9 Enclosed Trench were made on the basis of the 1963 sampling and are indicated as follows:

- Trench floor area = 162 square meters (9 meters x 18 meters.
- 4,246 liters of soil in upper 2.5 centimeters of trench.
- 25,470 liters of soil in upper 15 centimeters of trench.

1. <u>Minimum Estimate</u>

   2.0 g Pu/liter x 25,000 liters = 50 kg Pu.

2. Maximum Estimate

2.0 g Pu/liter x 2/3 x 25,000 liters =	33 kg Pu
15.0 g Pu/liter x 1/3 x 25,000 liters =	125 kg Pu
	158 kg Pu

3. Moderate Estimate

2.0 g Pu/liter x 3/4 x 25,000 liters =	37 kg Pu
10.0 g Pu/liter x 1/4 x 25,000 liters =	62 kg Pu
	99 kg Pu

CRITICAL EVALUATION OF 1963 SOIL SAMPLING AND ANALYSIS[2]

A number of items in the above discussion about the 1963 soil sampling and analysis are worthy of discussion. Apparently no effort was made either to mix or not to mix the core contents in each 30- or 15.2-cm section of the larger core sampling. This, combined with the fact a very small sample was taken, means they could have high-graded without intent.

Second, and most disturbing, are the notes on the analytical data. After all of the detail on sampling and leaching, these are the only clues to the method of analysis of the leach solution. "All laboratory results are given in counts/minute/gram of soil (c/m/g). A factor of 1.23×10^{-11} was used to convert c/m/g to grams Pu/gram of soil." These statements are mutually contradictory.

If disintegrations per minute per gram were the units of the laboratory results, the conversion factor would be approximately right. However, as stated and with a 50% alpha counting geometry, which is as high a geometry factor as

[2]Letter, W. H. Zimmer to A. E. Smith, "Sampling of 216-Z-9 (1963)," September 24, 1973.

ever used, the grams plutonium is biased a factor of "two" high. Also, no indication of the method used to separate ^{241}Am from plutonium is mentioned nor is it mentioned what was used to check for completeness of separation. A leach solution is difficult material upon which to perform complete separations; yet there is no allowance stated for the higher specific activity ^{241}Am in the conversion factor.

Finally, a bulk density of 2.3 grams/cm^3 was used for converting the analytical results to grams Pu/cm^3 of soil. The bulk density of the soil was found to be 1.6 g/cm^3 by actual measurements in 1973.

Every item mentioned biases the plutonium value high.

1973 216-Z-9 PLUTONIUM DISTRIBUTION[3]

Attached are the plutonium analyses from the February and March 1973 216-Z-9 core sampling program (Tables II, III, IV, and V). Where comparisons were justified, the data from 1963 analyses were included. The data represent the average plutonium content over a 15-cm interval and are tabulated in grams plutonium per liter of soil as a function of the maximum vertical depth of that 15-cm sample. For example, the analysis listed for a depth of 30 centimeters is the average plutonium concentration between 15 and 30 centimeters. Cross-contaminated samples (caused primarily by backfilling during removal of the core sampler) are reflected as a blank for the corresponding 15-cm interval. A location map, Figure 2, has been included to identify where the samples were taken.

[3] Letter, R. D. Fox to L. M. Knights, "1972-Z-9 Plutonium Distribution," April 23, 1973.

Two independent counting methods were employed to minimize sampling error and assure rapid sample analysis. W. H. Zimmer gamma-counted 25-ml samples, generally in duplicate, using the General Purpose Gamma Energy Analytical System at the 222-S Building. The samples were prepared in the Chemical Technology Laboratory by thoroughly mixing a 2.5-cm diameter section taken from the center of each 15-cm segment. The intent of the second core sample was to minimize potential cross-contamination resulting from vertical smearing along the wall as the 0.61-meter long sampler moved through the soil. The remainder of the 15-cm long sample was placed in a can and counted by D. A. Turner using the 234-5 Building package counter. No americium correction has been incorporated into the package counter, and at times small errors were introduced due to difficulties in defining the sample volume.

Two specific location samples were taken from the surface and bottom (0.69 meters down from the surface) of Angle Sample 4-13, obtained from Access Hole C. A value of 15 grams plutonium per liter of soil was obtained at the top and 0.12 gram plutonium per liter at the bottom. The top layer was of a silty clay consistency a little over 2.5 centimeters thick. This layer consistently represented the maximum plutonium concentration at all sample locations and varied from 0.3 to 3.2 cm thick--the thicker material being at Access Holes B and C. The top 15 cm of Angle Sample 4-2, Access Hole A, and Angle Sample 4-10, Access Hole C, were cored from both ends into two 7.5-cm sections. The top 7.5 cm contained 22 and 2.8 grams per liter, respectively; and the bottom 7.5 cm contained 0.64 and 0.22 gram per liter, respectively.

TABLE II

216-Z-9 PLUTONIUM DISTRIBUTION, SURFACE SAMPLES

ACCESS HOLE A

Depth Centimeters	Angle Sample 4-2 grams/liter		1963 Analyses	Angle Sample 4-3 grams/liter		Vertical Sample 4-6 grams/liter		Angle Sample 4-4 grams/liter	
15.2	{1.4 }	(1.8)	[19]	{1.0 }	[1.0]	{0.57}	(0.48)	{1.3 }	(0.81)
30.5	{0.26}	(0.16)	[23]	{0.26}	[0.14]	{0.25}	(0.25)	{0.15}	(0.20)
45.7	{0.13}	(0.12)	[26]	{0.19}	[0.1]	{0.16}	(0.18)	{0.11}	(0.19)
61.0				{0.17}	[0.1]				(0.17)

ACCESS HOLE C

Depth Centimeters	Angle Sample 4-8 grams/liter		Angle Sample 4-10 grams/liter		Vertical Sample 4-13 grams/liter		1963 Analyses
15.2	{2.93}	(3.4)		(3.8)		(3.9)	[25.0]
30.5	{0.28}	(0.38)	{0.15}	(0.3)	{0.17}	(0.25)	[22.0]
45.7	{0.11}	(0.13)	{0.13}	(0.16)	{0.12}	(0.17)	[1.2]
61.0	{0.11}	(0.12)	{0.12}	(0.14)	{0.13}	(0.16)	

{ } Counted by W. H. Zimmer, 1973.
( ) Counted by D. A. Turner, 1973.
[ ] 1963 analyses.

TABLE III

216-Z-9 PLUTONIUM DISTRIBUTION

ACCESS HOLE A

Depth Centimeters	1973 Analyses Sample Analyses grams/liter		Sample Number	1963 Analyses
15.2	{0.57}	(0.48)		19.0
30.5	{0.25}	(0.25)	4-6	
45.7	{0.16}	(0.20)		2.6
61.0				
76.2	{0.15}	(0.16)		
91.5	{0.06}	(0.17)	4-7	1.0
107	{0.09}	(0.09)		
122				
137				1.7
152	{0.08}	(0.06)	3-1	
168	{0.09}	(0.07)		
183				
198				
213	{0.06}	(0.07)	3-2	
229	{0.05}	(0.06)		

{ } Counted by W. H. Zimmer.
( ) Counted by D. A. Turner

TABLE IV

216-Z-9 PLUTONIUM DISTRIBUTION

ACCESS HOLE B

Depth Centimeters	1973 Analyses Sample Analyses grams/liter		Sample Number	1963 Analyses
15.0		(3.9)		1.4*
30.5	{0.11}	(0.2)		0.7*
45.7	{0.12}	(0.14)	4-1	19.0*
61.0	{0.12}	(0.16)		25.0*
76.2				1.8
91.5	{0.09}	(0.08)	4-9	
107				
122				
137				0.49
152				
168	{0.12}	(0.11)	2.5-1	0.08
183	{0.11}	(0.14)		
198				
213				0.07
229				
244	{0.11}	(0.15)	2-1	0.08

*Probably inverted sample order.

{ } Counted by W. H. Zimmer.
( ) Counted by D. A. Turner.

TABLE V

216-Z-9 PLUTONIUM DISTRIBUTION

ACCESS HOLE C

Depth Centimeters	1973 Analyses: Sample Analyses grams/liter		Sample Number	1963 Analyses
15.2		(3.9)		25.0
30.5	{0.16}	(0.25)	4-13	22.0
45.7	{0.13}	(0.17)		1.2
61.0	{0.13}	(0.15)		
76.2				
91.5	{0.11}	(0.13)	4-12	0.24
107	{0.09}	(0.17)		
122				
137				
152	{0.09}	(0.10)	3-5	0.34
168	{0.05}	(0.[illegible])		
183				0.13
198	{0.04}	(0.13)	2.5-2	
198	{0.04}	(0.13)	2.5-2	
213	{0.02}	(0.06)		
229				
244	{0.04}	(0.46)	2-2	
259	{0.03}	(0.09)		

{ } Counted by W. H. Zimmer.
( ) Counted by D. A. Turner.

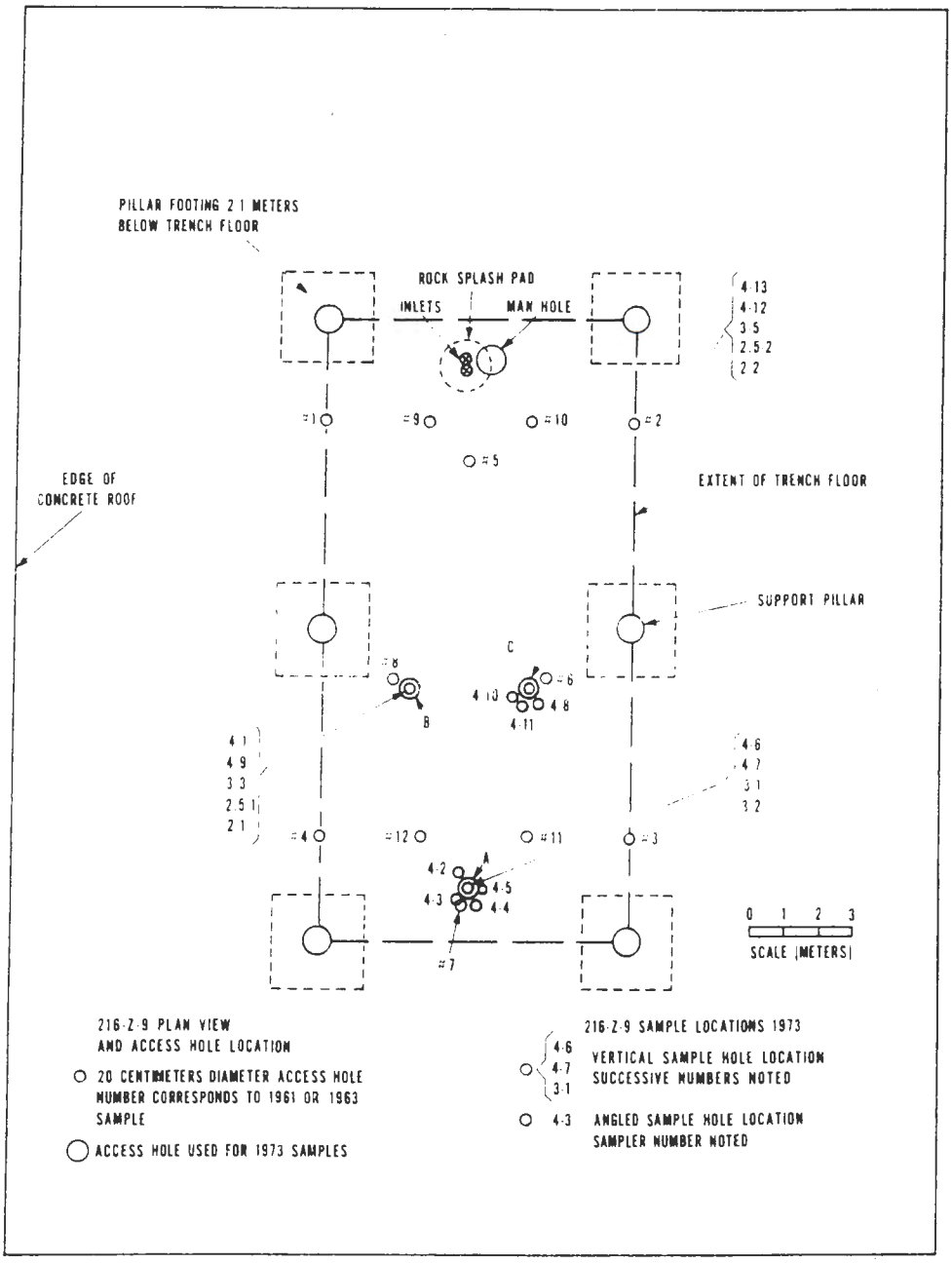


FIGURE 2

216-Z-9 CORE SAMPLING LOCATION MAP

V7312-10.37

APPENDIX M

ESTIMATED PLUTONIUM IN UPPER 30 CENTIMETERS OF 216-Z-9 ENCLOSED TRENCH

T. R. McKenzie

An estimate of the plutonium content in the first 30.5 centimeters of material on the 216-Z-9 Covered Trench floor was made. The samples taken and analyzed thus far do not cover sufficient area of the trench to give a representative distribution of plutonium for the entire trench. Therefore some assumptions were made to allow the development of an estimate of the total plutonium in the first 30.5 centimeters of the trench. For these calculations only analyses from the 1973 sampling were included. The assumption was made that the isodose map[1] compiled from gamma scanning the trench floor truly represents the relative plutonium distribution at the surface of the trench floor. It was further assumed that the relative concentrations shown on the isodose map extend down to 30.5 centimeters although the total plutonium decreases rapidly with depth. These assumptions are justified at this stage of the characterization of 216-Z-9 Trench for the following reasons. During construction the first 2.4 meters of the trench material was backfilled, which should have resulted in general mixing. Thus the selective distribution of plutonium from the surface of the trench down 30.5 centimeters should be expected to be similar anywhere in the trench. The isodose map, upon which these estimates are based, appears to be

[1] W. H. Zimmer, "The Isodose Mapping of the 216-Z-9 Trench Floor," ARH-2815, May 28, 1973, Atlantic Richfield Hanford Company, Richland, Washington. (See Appendix I)

validated by neutron counting (Appendix J) and infrared thermal surveys (Appendix H) made of the trench floor.

FIRST APPROXIMATION

The areas described by the isodose map for each relative plutonium value were determined in terms of cubic feet per inch of depth in the covered trench. The first foot of trench floor was divided into layers corresponding to analysis of samples; for example, 0 to 2.5 centimeters, 2.5 to 7.6 centimeters, 7.6 to 15.2 centimeters, 15.2 to 22.9 centimeters, and 22.9 to 30.5 centimeters. The analytical values for each layer from the "G" area, which apparently contains the highest concentration of plutonium, were ratioed on the basis of the values on the isodose map to determine the total plutonium in each layer and the grand total of 53 kilograms of plutonium.

RANGE OF PLUTONIUM CONTENT AND BEST ESTIMATE

Matrices were prepared giving the concentration of plutonium in each layer down to 30.5 centimeters and in each area, or composite of areas, shown on the isodose map. The lowest values, highest values, and best estimate or average values were used. These three approaches gave values of 68.6 kilograms. 26.35 kilograms, and 38.3 kilograms of plutonium as total amounts in the first 30.5 centimeters of the trench. The latter value of 38.3 kilograms is considered the best estimate based on current available results.

TABLE I

SUMMARY DATA--ISODOSE MAP

Pu Concentration Ratios	Location	Area cm^2	Area $meters^2$	Liters per cm
0.1	NS*	81.4	18.94	189.74
1.0	NS*	153.2	35.71	357.07
2.0	NS*	144.7	33.73	337.33
6.0	A-C	90.5	21.10	210.92
9.0	A-C	50.7	11.82	118.17
12.0	A-C	35.5	8.27	82.74
15.0	A-C	55.1	12.85	128.43
18.0	D	23.4	5.46	54.52
21.0	D	20.9	4.87	48.72
25.0	H-D	53.1	12.38	123.74
28.0	G-B	8.9	2.08	20.74
	TOTALS	717.4	167.21	1672.1

*NS = no samples this area.

TABLE II

216-Z-9 COVERED TRENCH
ESTIMATE: Pu CONTENT 0 TO 30.5-CENTIMETER DEPTH

Location	Ratios *	Pu, g/liter 0-2.5	2.5-7.6	7.6-15.2	15.2-22.9	22.9-30.5	Liters per cm	Total Pu, grams 0-2.5	2.5-7.6	7.6-15.2	15.2-22.9	22.9-30.5
Lowest Range												
G-B	28	15.9	1.63	0.149	0.103	0.103	20.74	837	172	24	16	16
D-H	18-25	13.8	1.20	0.163	0.105	0.100	226.96	7,956	1,384	282	182	173
A-C	6-15	2.40	1.45	0.41	0.195	0.10	540.25	3,293	3,980	1,688	803	416
Remainder	1-2	0.40	0.24	0.10	0.10	0.10	884.15	898	1,078	674	674	674
Total g Pu								12,984	6,614	2,668	1,675	1,279
Grand total								25,200 g Pu minimum				
Highest Range												
G-B	28	19.8	8.25	2.64	0.744	0.336	20.74	1,043	869	417	118	53
D-H	18-25	18.6	5.31	0.229	0.132	0.116	226.98	10,723	6,123	396	332	201
A-C	6-15	15.0	1.60	0.80	0.440	0.260	540.25	20,584	4,391	3,293	1,811	1,070
Remainder	1-2	5.0	0.59	0.27	0.15	0.10	884.15	11,229	2,650	1,819	1,011	671
Total g Pu								43,579	14,033	5,925	3,272	1,993
Grand Total								68,800 g Pu maximum				

*W. H. Zimmer, Chemical Technology Laboratory (Appendix I).

TABLE III

216-Z-9 COVERED TRENCH
ESTIMATE: Pu CONTENT 0 TO 30.5-CENTIMETER DEPTH
Best Estimate

Location	Pu, g/liter (average) 0-2.5 cm	2.5-7.6 cm	7.6-15.2 cm	15.2-22.9 cm	22.9-30.5 cm	Liters per cm	Total Pu, grams 0-2.5 cm	2.5-7.6 cm	7.6-15.2 cm	15.2-22.9 cm	22.9-30.5 cm
G-B	18.95	4.44	0.569	0.243	0.239	20.74	998	468	90	38	38
D-H	16.2	3.26	0.196	0.149	0.108	226.98	9,340	3,759	339	258	187
A-C	4.20	1.53	0.605	0.318	0.20	540.25	5,763	4,199	2,491	1,309	823
Remainder	1.40	0.51	0.200	0.106	0.10	884.15	3,144	2,291	1,347	714	674
Total g Pu							19,245	10,717	4,267	2,319	1,722
Grand total g Pu, 0 to 30.5 centimeters									38,300		

TABLE IV

216-Z-9 COVERED TRENCH
ESTIMATE OF PLUTONIUM CONTENT
0 TO 30.5 CENTIMETER DEPTH
First Approximation

W. H. Zimmer Ratios	Liters[1] per Centimeter	Plutonium g/liter 0-2.5 cm	Plutonium Total Grams 0-2.5 cm	Plutonium, grams per liter (Depth in cm) 2.5-7.6	7.6-15.2	15.2-22.9	22.9-30.5
0.1	189.74	0.07	35				
1.0	357.07	0.71	654				
2.0	337.33	1.45	1,236				
6.0	210.92	4.34	2,319				
9.0	118.17	6.50	1,949				
12.0	82.74	8.65	1,819				
15.0	128.43	10.81	3,530				
18.0	54.54	13.00	1,798				
21.0	48.72	15.15	1,875				
25.0	123.74	18.05	5,669				
28.0	20.74	20.20[2]	1,064				
Totals	1,672.1		21,948	8.698	2.690	0.754	0.386

Depth Centimeters	Total Plutonium Kilograms
0 - 2.5	21.948
2.5- 7.6	$\frac{21,948/2.54}{20.20} \times 8.698 \times 5.08 = 18.901$
7.6-15.2	$\frac{21.948/2.54}{20.20} \times 2.690 \times 7.62 = 8.768$
15.2-22.9	$\frac{21.948/2.54}{20.20} \times 0.754 \times 7.62 = 2.458$
22.9-30.5	$\frac{21.948/2.54}{20.20} \times 0.386 \times 7.62 = 1.258$
	53.333

Grand total (in upper 30.5 cm): 53.3 kg of Pu.

[1] Areas determined from isodose map by W. H. Zimmer.

[2] 20.2 g/liter of Pu is highest analysis of "G" location for 0 to 2.5 cm depth and is equal to 19,066 g/m^2 (572 g/ft^3).

APPENDIX N

CRITICALITY CALCULATIONS

R. D. Carter

The reactivity status of the 216-Z-9 Enclosed Trench prior to the addition ot neutron absorbers has been extensively investigated by the use of electronic computers and has been found to have been very far from critical. The k-effective of the trench has been calculated to have been near 0.5, and probably less, before the addition of cadmium nitrate and it is now even lower. The net result is that the Z-9 Enclosed Trench was never at any time close to critical. It should be realized, however, that these definitive calculations were only made possible by the extensive program of Z-9 soil sampling and characterization which was precipitated by the concern over the high k-effective values and changes indicated by the neutron pulsing measurements. The neutron pulsing measurements have now been shown to be inaccurate for the very large "room" geometries as typified by Z-9.

Electronic computer codes used were GAMTEC II,[1] DTF-IV,[2] GEM4,[3] and KENO-II.[4] GAMTEC II was used to generate 18 energy group cross-section sets for use in the DTF-IV and KENO-II codes. The GAMTEC II cross-sections have been used with several other codes for extensive checking with experimental critical systems and have been found to produce excellent agreement.[5] The GAMTEC II code was also used to calculate infinite multiplication factors (k-infinities) and material bucklings for various parameter studies. The DTF-IV code is a multiregion, multigroup, one-dimensional, transport theory code used to calculate effective multiplication factors (k-effectives) and critical

sizes for simple one-dimensional geometries. GEM4 and KENO-II are Monte Carlo codes used to calculate the values of k-effective for complex three-dimensional geometries. GEM4 utilizes its own built-in cross-section library and has also been extensively checked against experiment and found to give good results. More complete descriptions of the codes may be found in the references.

The Monte Carlo codes are very useful calculational tools since they permit three-dimensional descriptions of problems. In the case of the Z-9 Trench they are the only available method of calculating the system with a complex three-dimensional representation. However, Monte Carlo codes have several drawbacks. The general method requires averaging a number of separate k-effective calculations; hence the solution has a standard deviation associated with it which makes it difficult to do parameter studies or to determine incremental differences. Also the codes tend to be sensitive to initial flux distributions and have a tendency to be sensitive to the boundary conditions, at least in the case of the GEM4 code. On the other hand, the GEM4 code has a method of statistical checking which allows the operator to determine if the solution is reliable. In addition, GEM4 has a restart option which either allows the continuation of a case if the desired reliability has not been achieved or allows the use of flux distribution from a previous case.

Since the k-effective obtained from a Monte Carlo code is affected by the neutron flux distribution, it is essential that the calculated flux distribution be representative of the true flux distribution. Depending on the system, it may take a large number of successive calculational steps before a flux is obtained where the flux of a given

calculational step is relatively independent of a previous calculational step. The GEM4 code uses a statistical checking method called the Mean Squared Successive Difference Test (M.S.S.D.) method on both the core multiplication, "M", and the core multiplication times the reflection factor, "MR", for successive calculational steps. It essentially involves taking the ratio of two estimates of variance. The M.S.S.D. values for both these terms should theoretically be 1.0 if the individual values obtained for "M" and "MR" are based on truly random samples.

In actual practice, M.S.S.D. values between 0.95 and 1.05 are considered sufficient to insure that the k-effective value obtained is a good solution. Mean Squares Successive Difference values down to 0.90 and up to 1.10 are usually considered sufficiently accurate to insure that calculated k-effective values less than 0.90 are not far enough from the true value that the system is unsafe. In a number of problems calculated for the Z-9 study, M.S.S.D. values were even farther than 1.0. In such cases additional calculations to improve the statistical checks were not made because the calculated k-effective values were so small that even with the addition of the extremes of the uncertainty the k-effective values would still be less than 0.9.

After the 1969 neutron pulsing, various infinite homogeneous slabs of soil having a void volume of 30% and a plutonium concentration of 24 g/liter were calculated using the DTF-IV code. Although these calculations gave some indication of critical thicknesses with various water contents and reflectors, they were essentially theoretical studies having little relstionship to reality. The calculations were limited by the analyses that were completed in 1963.

In 1972 the proposal to mine the Z-9 Trench created the

need for a parameter study of plutonium-contaminated Hanford soil for homogeneous systems. This was completed prior to the 1973 neutron pulsing.[6] These calculations were made to provide criticality prevention parameters for plutonium-soil mixtures of two different "void" fractions. The void fraction is that part of the soil not occupied by normal soil materials and therefore available for filling with plutonium-water mixtures. These calculations were performed with the GAMTEC II and DTF-IV codes. The void fractions were 30 and 40% by volume. Both fully saturated and one-third saturated soil parameters were calculated. The soil composition is shown in Table I.

TABLE I

HANFORD SOIL COMPOSITIONS, WEIGHT PERCENT

Component	Dry Soil
SiO_2	81.0
Al_2O_3	6.0
Fe_2O_3	2.0
FeO	2.0
CaO	4.0
MgO	2.0
K_2O	1.0
Na_2O	1.0
H_2O	1.0

Full soil density, no voids: 2.43 g/cm^3

After the initial 1973 neutron pulsing measurement was made and an increasing reactivity was indicated, it was postulated that this could result from a drying-out process. Further parameter studies involving k-infinity and material buckling (B_m^2) were made with the GAMTEC II code to determine whether a significant increase could result from this process. The results are shown in Figures 1 and 2.

As can be seen, the k-infinity of a system up to a

plutonium concentration of at least 15 g/liter will increase with a decreasing hydrogen-to-plutonium (H/Pu) ratio (or water content) between 10 and 30% by volume. This increase is more significant as the plutonium concentration decreases. However two other factors become important. First, below about 1.6 g/liter the k-infinity is always less than one; therefore a homogeneous system cannot be made critical below this value. Second, although the k-infinity increases above 5 g/liter, the material buckling does not. Since the geometry of the system is assumed to be constant, it would appear very unlikely that drying out the system over the limited range possible could cause an increase of 0.07 in k-effective or even any increase at all.

A three-dimensional computational basis for the plutonium distribution was developed from the 1973 chemical analyses and neutron and gamma surveys. The infrared scan was used to determine whether or not other surveys missed locations of relatively high-density plutonium. For calculational purposes, the 9 meters (30 feet) by 18 meters (60 feet) floor of the trench was divided horizontally into squares 1.5 meters (five feet) on a side. This dimension was chosen because it appeared to be somewhat larger than the regions of high-density plutonium and thus tended to over-estimate the reactivity, and yet it was small enough to allow sufficient heterogeneity of the trench floor. The chemical analyses were used to divide the floor vertically into a top layer 2.5 cm thick, second and third layers each 15.2 cm thick, a fourth layer 45.7 cm thick, and the lowest layer 61.0 cm thick. Only the first three layers were assumed homogeneous and were treated as reflectors. Above the core was a void 610 cm thick with a 22.9 cm-thick concrete reflector above that. It should be noted that the direction of these calculations was not so much to find the

actual reactivity of the trench but to find if a reasonable trench configuration or some variation thereof could have a k-effective of 0.9 or greater.

The results of the neutron and gamma surveys are shown in Appendices J and I, respectively. The results of the analytical chemistry analyses are shown in Appendix K. With the preliminary data, the composition of the top layer of the trench was initially deduced to be as shown in Figure 3, the second layer as shown in Figure 4, and the third layer as shown in Figure 5. The plutonium composition of the homogeneous fourth and fifth layers was 0.2 and 0.1 gram per liter, respectively. These plutonium densities and material thicknesses provided the base case.

Using this basis, the total plutonium in these layers is 169 kilograms, somewhat higher than can reasonably be assumed to be there. Variations on the base case are indicated in the summary of the calculations. The composition of the soil is the same as used in the earlier calculations (Table I), with adjustments for the void fractions, of course. The water content used with the various plutonium densities is shown in Table II. Line (a) is the composition used in calculating Cases A and B. In these cases, 30% of the soil was assumed to be voids. The volume percents of water were assumed to be two for the low-plutonium density material (the normal soil moisture content for soil deep enough not to be affected by surface fluctuations) and five for the 1 through 10 g/liter soils (as indicated by the chemical analyses). The high-density plutonium soils were in the top layer and were assumed saturated. The water content in the soil containing 0.5-g plutonium per liter of soil was assumed to be between 2 and 5% by volume. For Case C the composition was changed to Line (b); the optimum

TABLE II

PLUTONIUM-WATER COMBINATIONS USED IN CALCULATIONS

	Material #	1	2	3	4	5	6	7	8	9	10	11	12	13
	Pu, g/liter	0.1	0.2	0.5	1	2	6	8	10	12	15	20	25	28
	30 vol% Void* Soil Cases													
a.	H/Pu	5300	2650	2500	1327	663	265	165	133	662	529	397	317	283
	H_2O, vol%	2	2	4.7	5	5	5	5	5	30	30	30	30	30
b.	H/Pu	600	600	600	600	600	1000	994	795	662	529	397	317	283
	H_2O, vol%	0.23	0.50	1.13	2.26	4.5	18.8	30	30	30	30	30	30	30
	45 vol% Void Soil (Maximum)													
c.	H/Pu	5300	2650	2500	1327	663	265	165	133	994	795	596	476	425
	H_2O, vol%	2	2	4.7	5	5	5	5	5	45	45	45	45	45
	70 vol% Void Soil (Maximum)													
d.	H/Pu	5300	2650	2500	1327	664	1061	664	531	1327	1062	796	-	-
	H_2O, vol%	2	2	4.7	5	5	20	20	20	60	60	60	-	-
	Void, vol%	30	30	30	40	40	40	40	40	70	70	70	-	-

*Non-soil percents; includes water fraction.

H/Pu values as determined from Figure 2. (Those which resulted in H/Pu less than two are probably unrealistic but this should not have a significant effect on the calculation.) Line (c) was used in Case F and similar calculations assuming the voids in the soil in most of the top layer were 45% by volume. Line (d) was used in Case U, increasing the void volume to 40% in the 1 to 10 g/liter range and 70% in the 12 to 20 g/liter soils.

A number of variations on the plutonium distribution were assumed. Examples of the GEM4 geometry printout of the input data are shown in Figures 6, 7, 8, and 9. The calculated k-effective for this case (Case Q) was 0.380 ±0.010. The calculated amount of plutonium for this distribution is 98.6 kg for the first 33 cm plus 10.2 kg for the next 61 cm.

The maximum plutonium density of 28 g/liter used in Case Q was probably somewhat on the high side. Other estimates (Appendix M) use a maximum of 20 g/liter. Case Q was recalculated by reducing the distribution of the three heterogeneous layers in Case Q by the ratio 20:28 (and rounding off to the values shown in Table II). The reflector compositions were held constant. The calculated k-effective for this case (Case R) was 0.347 ±0.016. A somewhat contradictory situation arose in that much of the third layer had a lower plutonium composition than the immediately surrounding reflector region. However this is not considered significant in the light of the minor decrease in k-effective compared with Case Q. The calculated amount of plutonium for this case is 75.9 kg in the first 33 cm plus 10.2 kg for the next 61 cm.

A final variation on the composition was assumed for Case U which was identical with the Case R plutonium distribution but the void content was increased to 70% for

the 12 to 20 grams plutonium per liter materials and to 40% for the 1 to 10 grams plutonium per liter materials. The k-effective was calculated to be 0.430 ±0.009 and may be the most representative value, although it is not significantly greater than Cases Q and R.

The apparent increase in k-effective shown by the neutron pulsing between the 1963, 1969, and 1973 (initial) data is difficult to explain. Certainly the reported absolute values of 0.86 to 0.98 are now shown to be incorrect. The apparent increase in k-effective was possibly real, at least between the 1969 and 1973 data. [Data from 1963 should not be compared with 1969 and 1973 data because of different equipment and calculational bases.] Several computer cases were run to determine if differences in water content could account for the apparent changes.

In all cases it was assumed that the materials with plutonium densities from 12 to 28 g/liter were saturated, and that the materials below 1 g/liter contained 2% water by volume. The materials with plutonium compositions from 1 to 10 g/liter were varied in water content. In Case S, the water content in the 1 to 10 g/liter range was increased to 10% by volume, and in Case T it was increased to 20% by volume. The k-effectiveness was shown to increase about 0.2 over the range from 5 to 20% by volume. However, if anything, the crib was drying out in the 1969 to 1973 period, not getting more moist; the k-effective should have been decreasing, not increasing. The differences in the nuclear characteristics of the trench between 1969 and 1963 also indicated that drying out had occurred.

A second possible explanation for the supposed reactivity changes is in equipment positioning. Some pulsed neutron data obtained in 1973 showed that the k-effective

decreased by 0.02 when the detector was lowered from 1.2 meters off the floor to floor level. This change is only about one-third of the change that was observed between 1969 and 1973 (initial data), and actually the position on both these dates is considered to have been nearly identical.

Neither of the above mechanisms appears to explain the increase in relative k-effective. Of course one can assume that, since the magnitude of the measurement is demonstrably larger than the actual value, there was no real increase. Other mechanisms could be compared; for example, the change in the moisture content of the reflector, the vanishing of carbon tetrachloride, changes in plutonium distribution, etc. However, since there are no relative measurements of these soil compositions, these would be academic exercises only; and, since the true k-effective is so low, it is of no real concern.

The results of the calculations are shown in Table III. Several comments on the data need to be made to clarify these results.

- The apparent drop instead of increase in k-effective between Cases A and B when a better reflector was added is a situation resulting from relatively poor statistics. However, additional running times to improve the answers were not done because the k-effective values were so low.
- The same comment applies to comparative values between Cases C and D.
- Some of the variations were done to determine if there were boundary conditon effects which had caused erroneous k-effective values.

Other cases were run but were either in error or were

inappropriate configurations. Of the cases shown, many consisted of successive calculations where the program was run, stopped for analysis, then continued. Only the final (and most accurate) result is shown. On many cases as many neutron histories may have been run just to determine the initial flux as were used to define the k-effective directly.

The results of the calculations show that the maximum k-effective in any configuration was about 0.8 even with optimum H/Pu values and over-estimated plutonium densities (at least 169 kg versus a more realistic 40 to 90 kg). The value of 0.5 or less is considered to be a much better determination of the true value of k-effective than any of the data obtained by the neutron pulsing data.

The preceding statements on the trench reactivity apply only to the condition of the trench without cadmium. The reactivity of the trench following the cadmium nitrate addition was not calculated (because the distribution of cadmium with depth was not sampled, although Table III, Appendix K, would allow an estimate to be made of the distribution); but it can be assumed to be much less than a k-effective of 0.4. Even prior to the cadmium nitrate addition, the trench contained significant amounts of cadmium. The data from Table IV, Appendix K, shows a cadmium concentration of 0.1 to 0.6 g/liter of soil for the first 2.54 cm and down to about 0.1 g/liter at 60 cm depth. The GAMTEC II code has been used to calculate the effect of this "original" cadmium. Using these calculations as a guide, the maximum cadmium content appears to have been up to 20% of the amount of cadmium required to reduce the k-infinity of the plutonium-soil mixture to 1.0 in the upper layer, up to 40% in the next layer, and up to 100% in the region greater than 15 cm deep. Therefore the "original" cadmium must have

TABLE III

LISTING OF GEM4 COMPUTER CALCULATIONS
[KENO-II Calculations as Indicated]

Case	Description	Neutron History	k-effective	M.S.S.D. Values M	M.S.S.D. Values MR
A	Basic Case, no side reflector (≈169 kg of Pu)	2,500	0.453 ±0.022	1.137	0.964
B	As Case A but add 60.96 cm soil around bottom and sides of system	2,500	0.418 ±0.024	0.582	1.073
C	As Case B but use optimum H_2O in mixtures	5,000	0.733 ±0.015	0.982	0.896
	KENO-II	10,000	0.713 ±0.007		
D	As Case C except extended second reflector region by 60.96 cm at bottom	7,500	0.684 ±0.013	0.905	0.926
E	As Case C except used slightly different densities	12,500	0.665 ±0.15	1.25	1.35
F	As Case E except used 45 vol% for 12 to 28 g/liter mixture at saturated H/Pu	7,500	0.738 ±0.012	0.944	0.885
G	As Case C except 12 to 28 g/liter materials to 45 vol% void soil and saturated H/Pu	2,500	0.761 ±0.017	1.076	1.106
H	As Case C but used 216 individual boxes to get neutron fluxes for each location	10,000	0.750 ±0.011	1.06	1.03
I	As Case H but with 12 to 28 g/liter material at sp. gr. ≈1.56 with 300 g/liter water density	5,000	0.712 ±0.016	0.94	0.83
J	As Case I but with 12 to 28 g/liter material at sp. gr. ≈1.56 with 600 g/liter water density	5,000	0.736 ±0.14	1.13	0.989
K	As Case G except in location 8-D on the third layer used 10 g/liter material	2,500	0.786 ±0.17	0.889	0.779
L	As Case G except lowered the top layer 2.54 cm into the box below in location 8-E	2,500	0.657 ±0.024	0.921	0.824
M	As Case H but increased the entire top layer thickness from 2.54 cm to 3.81 cm	7,500	0.772 ±0.012	0.928	1.13
N	Assumed centerlines of array through D 8-12 and D, E, F 8 with full reflection on north and east faces	2,500	0.789 ±0.038	1.13	1.07
O	As Case H except 12 to 28 g/liter material assumed fully moderated Pu-H_2O solution and no soil	2,500	0.792 ±0.021	1.22	0.85
	KENO-II*	9,800	0.786 ±0.006		

*KENO-II geometry could not be described as individual boxes; some were duplicated.

TABLE III (continued)

Case	Description	Neutron History	k-effective	M.S.S.D. Values M	MR
P	As Case H except third layer mode reflector with constant 0.5 g/liter Pu density	5,000	0.689 ±0.021	1.19	1.04
Q	Updated arrangement, 28 g/liter maximum Pu, 5 vol% H_2O in 1 to 10 g/liter materials	20,000	0.380 ±0.010	0.923	0.985
R	As Case Q except 20 g/liter maximum	10,000	0.347 ±0.016	0.905	0.910
S	As Case Q except 10 vol% H_2O in 1 to 10 g/liter materials	10,000	0.450 ±0.016	1.111	1.107
T	As Case Q except 20 vol% H_2O in 1 to 10 g/liter materials	10,000	0.561 ±0.013	0.929	0.857
U	As Case R except 40 vol% void in 1 to 10 g/liter materials, 70 vol% void in 12 to 20 g/liter materials	20,000	0.430 ±0.009	0.894	0.938

had a significant effect on the reactivity of the crib such that even prior to the cadmium nitrate addition, the reactivity must have been much less than the calculated values which assumed no cadmium.

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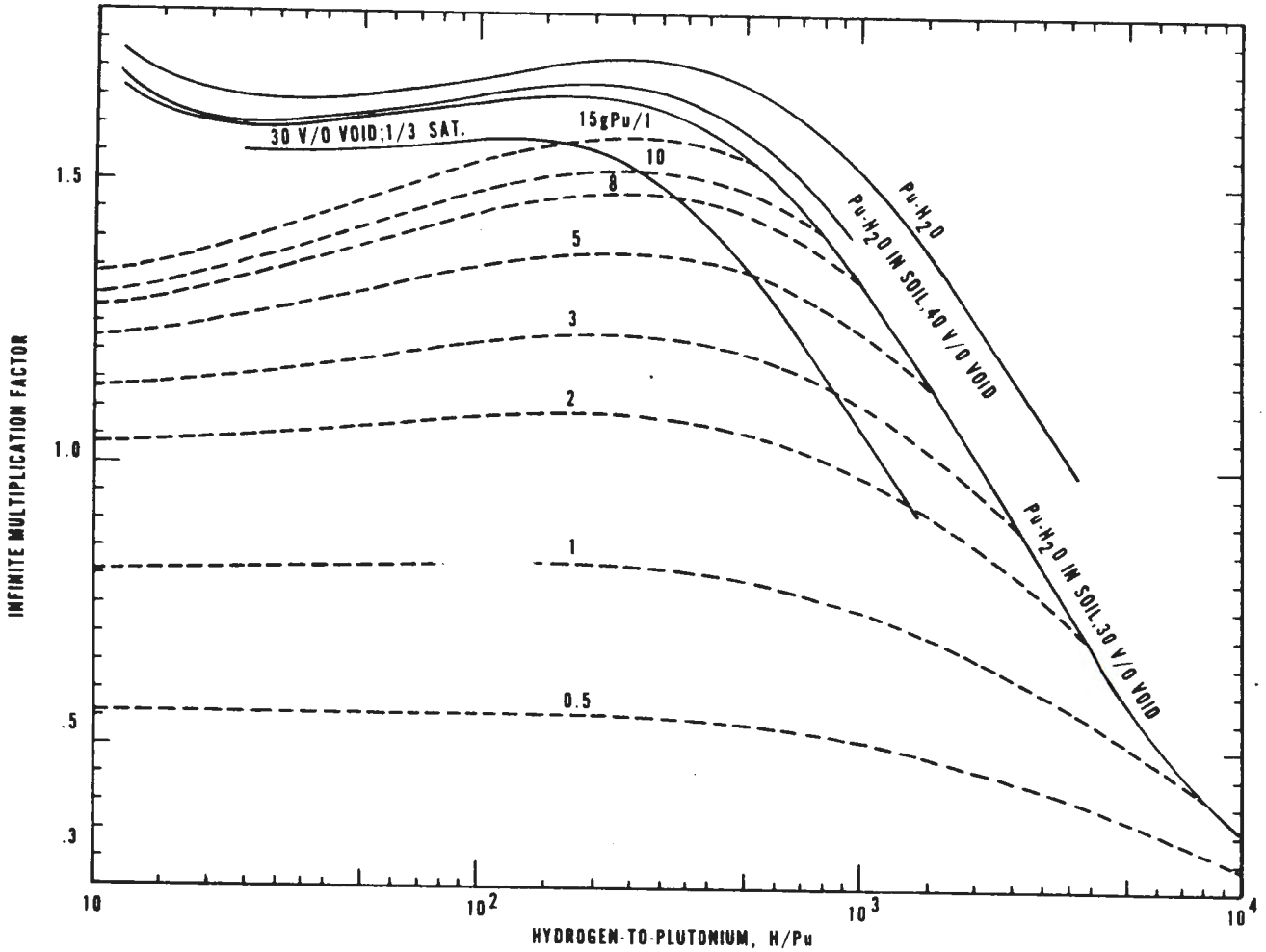


FIGURE 1

k_∞ VERSUS H/Pu

[Pu-H_2O in Soils; 3 wt% ^{240}Pu in Pu; GAMTEC II Calculation]

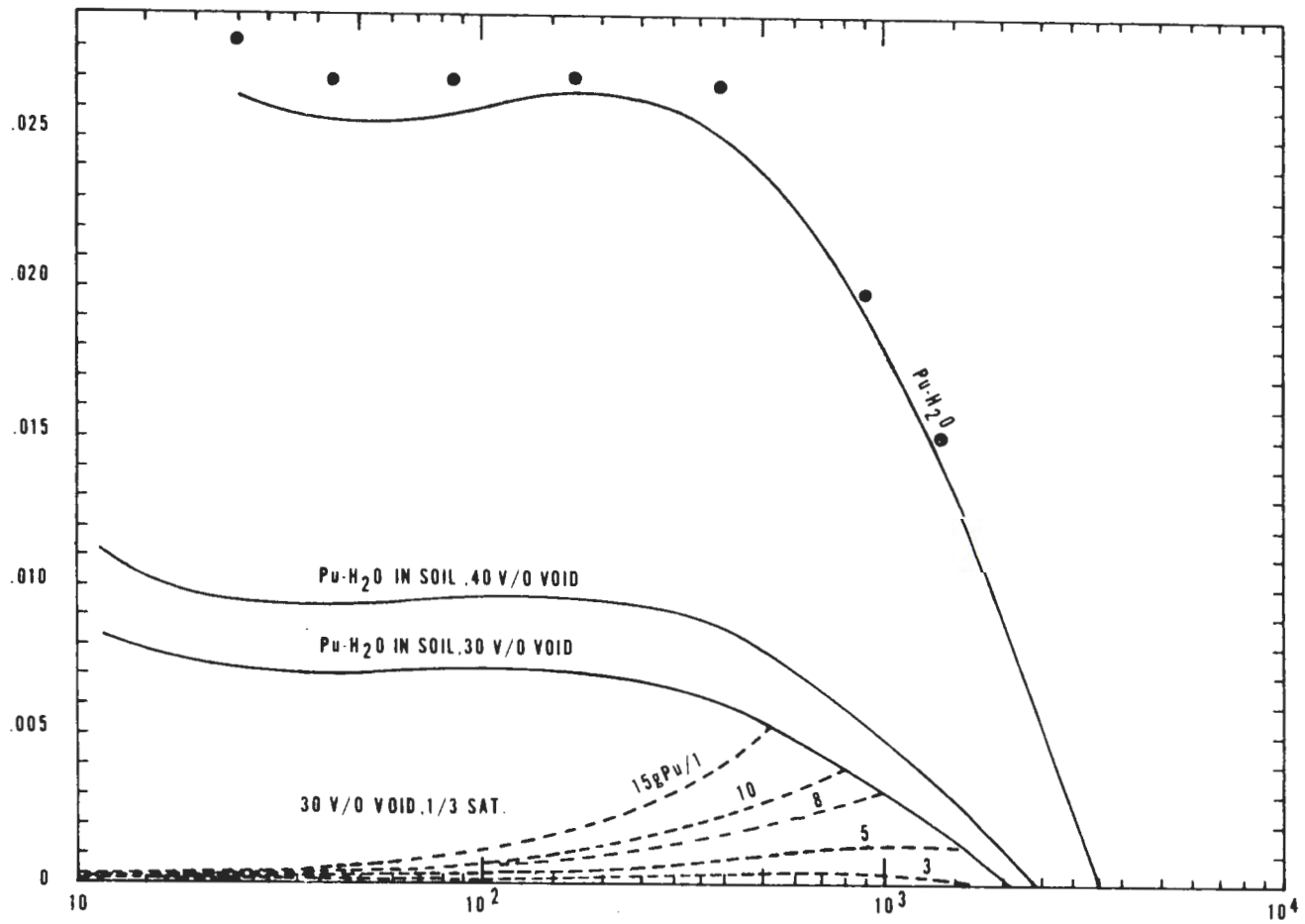


FIGURE 2

MATERIAL BUCKLING VERSUS H/Pu
[Pu-H_2O in Soils; 3 wt% ^{240}Pu in Pu, GAMTEC II Calculation]
(• GAMTEC II - HFN)

← N →

	1	2	3	4	5	6	7	8	9	10	11	12
A	0.1	0.1	0.1	0.1	1	5	5	12	5	2	1	1
B	1	1	2	2	5	12	5	15	12	12	20	2
C	8	8	5	5	2	15	15	15	25	25	20	2
D	8	8	5	5	5	15	25	28	25	25	5	2
E	1	5	1	2	5	12	20	25	12	12	5	1
F	0.1	0.1	1	2	5	12	8	2	1	1	15	1

Layer 1 Thickness 2.54 cm (one inch)

Plutonium concentrations in grams per liter

FIGURE 3

216-Z-9 TRENCH IN 1.524-METER (5-FOOT) INCREMENTS

← N →

	1	2	3	4	5	6	7	8	9	10	11	12
A	0.1	0.1	0.1	0.1	1	2	2	5	2	1	0.5	0.5
B	0.5	0.5	1	1	2	5	2	8	5	5	10	1
C	8	8	5	5	1	8	8	8	10	10	10	1
D	8	8	5	5	2	8	10	10	10	10	2	1
E	0.1	2	0.5	1	2	5	10	10	5	5	2	0.5
F	0.1	0.1	0.5	1	2	5	5	1	0.5	5	8	0.5

Layer 2 Thickness 7.62 cm (6 inches)

Plutonium concentrations in grams per liter

FIGURE 4

216-Z-9 TRENCH in 1.524-METER (5-FOOT) INCREMENTS

← N

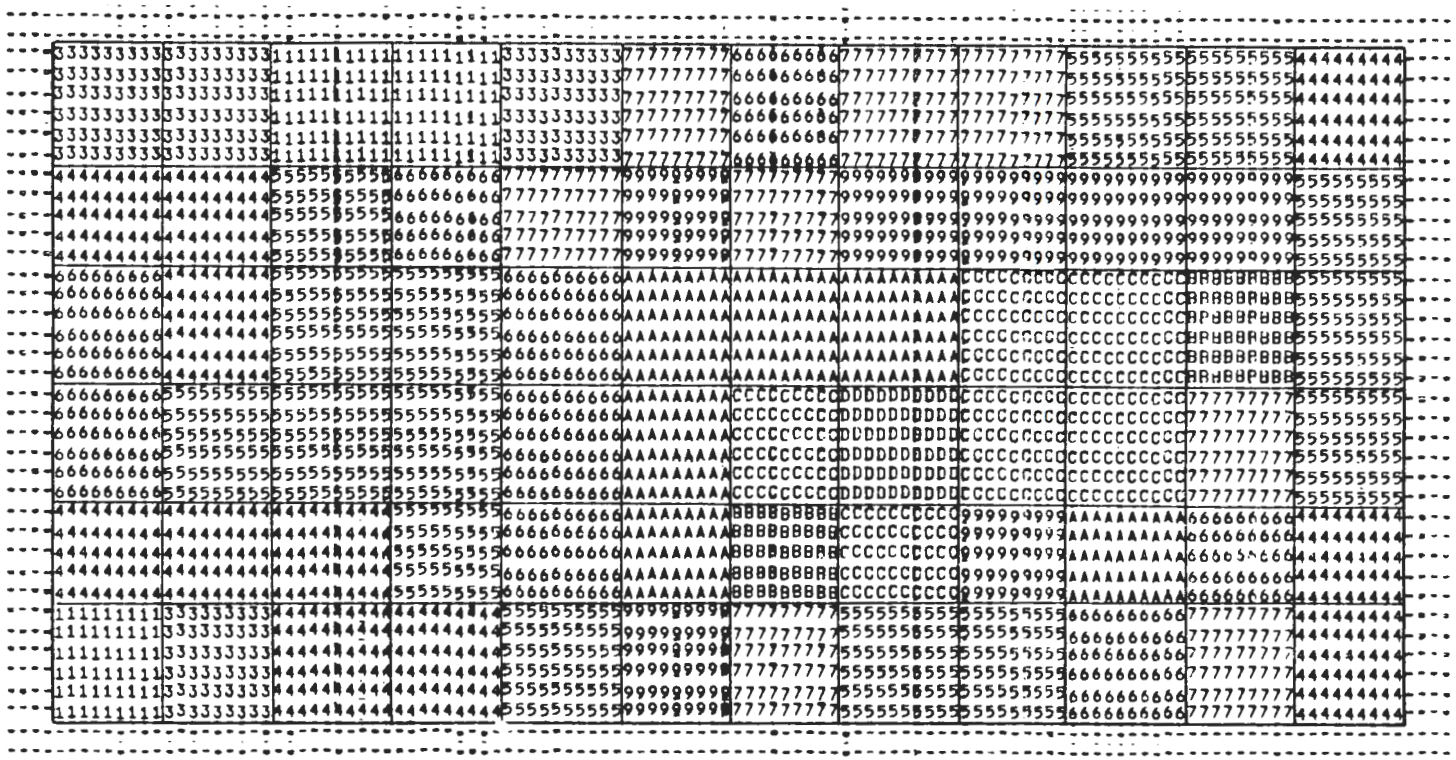
	1	2	3	4	5	6	7	8	9	10	11	12
A	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.5	0.2	0.2	0.2	0.2
B	0.2	0.2	0.2	0.2	0.2	0.5	0.2	0.5	0.5	0.5	0.5	0.2
C	0.2	0.2	0.2	0.2	0.2	0.5	0.5	0.5	0.5	0.5	0.5	0.2
D	0.2	0.2	0.2	0.2	0.2	0.5	0.5	0.5	0.5	0.5	0.2	0.2
E	0.1	0.2	0.2	0.2	0.2	0.5	0.5	0.5	0.5	0.5	0.2	0.2
F	0.1	0.1		0.2	0.2	0.5	0.2	0.2	0.2	0.2	0.5	0.2

Layer 3 Thickness 7.62 cm (6 inches)

Plutonium concentrations in grams per liter

FIGURE 5

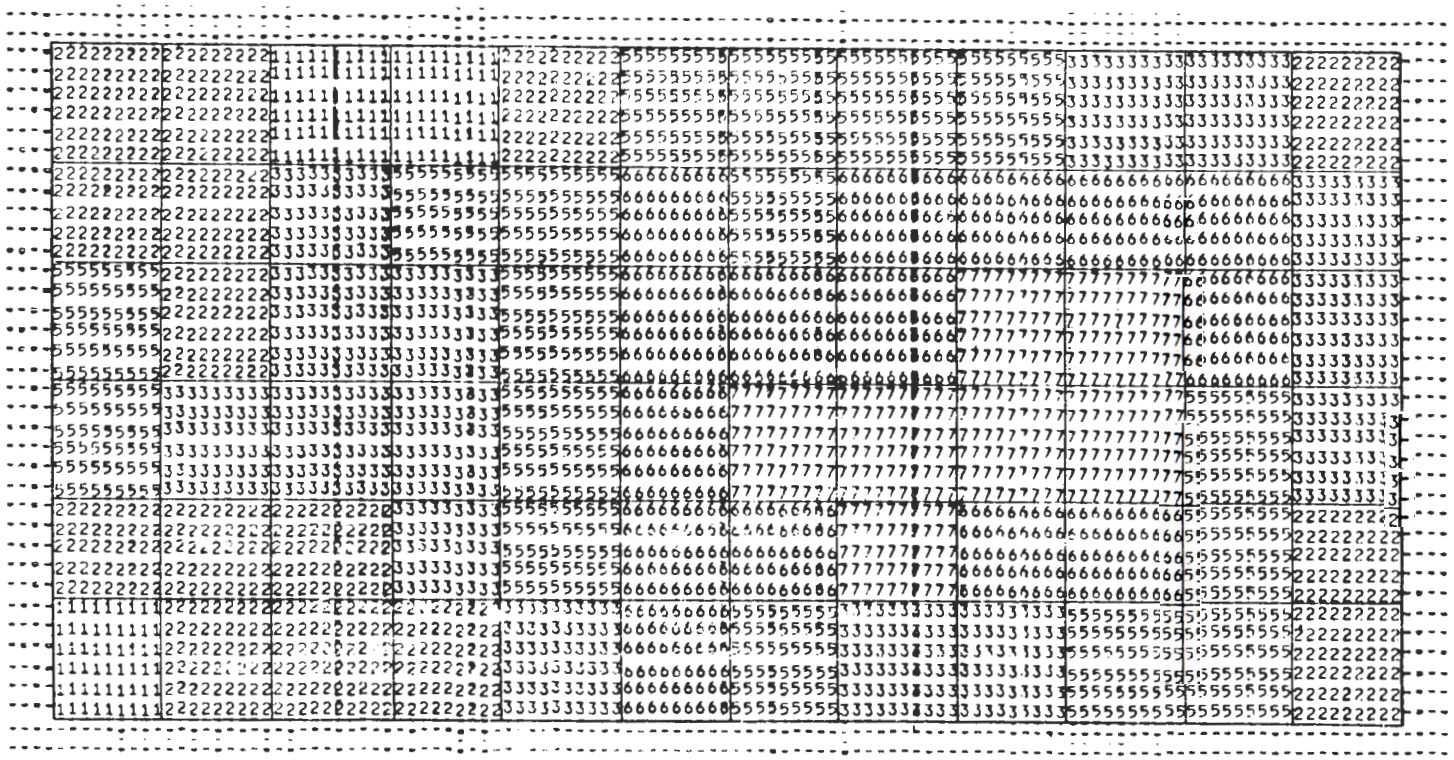
216-Z-9 TRENCH IN 1.524-METER (5-FOOT) INCREMENTS



Legand:
- 1 = 0.1 g Pu/liter, 30 vol% void soil
- 3 = 0.5 g Pu/liter, 30 vol% void soil
- 4 = 1.0 g Pu/liter, 30 vol% void soil
- 5 = 2.0 g Pu/liter, 30 vol% void soil
- 6 = 5.0 g Pu/liter, 30 vol% void soil
- 7 = 8.0 g Pu/liter, 30 vol% void soil
- 9 = 12 g Pu/liter, 45 vol% void soil
- A = 15 g Pu/liter, 45 vol% void soil
- B = 20 g Pu/liter, 45 vol% void soil
- C = 25 g Pu/liter, 45 vol% void soil
- D = 28 g Pu/liter, 45 vol% void soil
- - = Soil
- * = Concrete

FIGURE 6

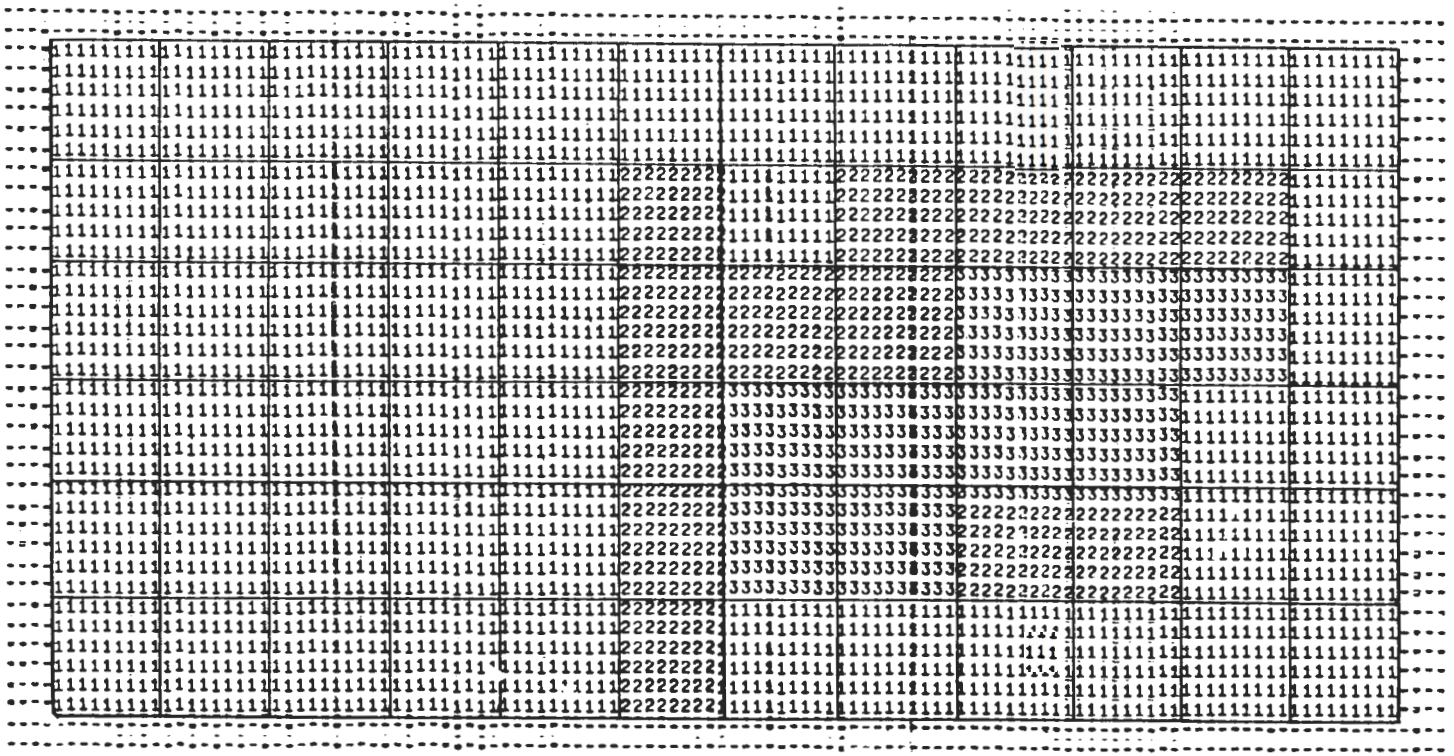
PLAN ELEVATION OF 216-Z-9 TRENCH TOP 2.54 cm PLUTONIUM DISTRIBUTION (GEM4 PRINTOUT)



Legand: 1 = 0.1 g Pu/liter, 30 vol% void soil 5 = 2.0 g Pu/liter, 30 vol% void soil
2 = 0.5 g Pu/liter, 30 vol% void soil 6 = 5.0 g Pu/liter, 30 vol% void soil
3 = 1.0 g Pu/liter, 30 vol% void soil 7 = 8.0 g Pu/liter, 30 vol% void soil

FIGURE 7

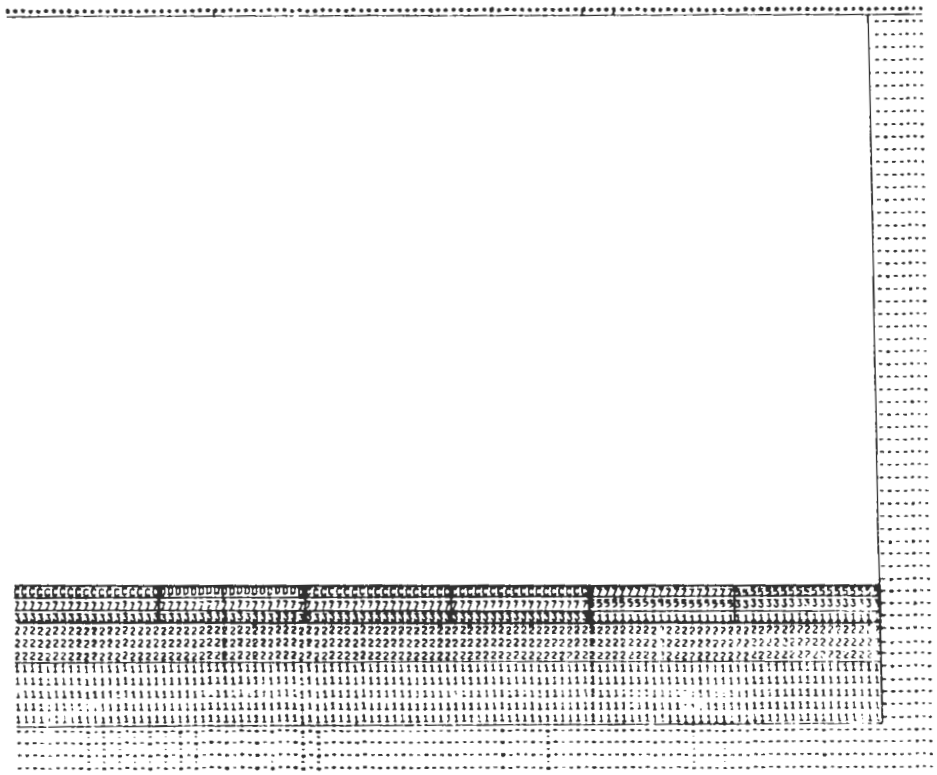
PLAN ELEVATION OF 216-Z-9 TRENCH, 2.54 TO 17.78 cm Pu DISTRIBUTION (GEM4 PRINTOUT)



Legand: 1 = 0.1 g Pu/liter, 30 vol% void soil
2 = 0.5 g Pu/liter, 30 vol% void soil
3 = 1.0 g Pu/liter, 30 vol% void soil

FIGURE 8

PLAN ELEVATION OF 216-Z-9 TRENCH 17.78 cm TO 33.02 cm Pu DISTRIBUTION (GEM4 PRINTOUT)



Legand:
1 = 0.1 g Pu/liter, 30 vol% void soil
3 = 0.5 g Pu/liter, 30 vol% void soil
4 = 1.0 g Pu/liter, 30 vol% void soil
5 = 2.0 g Pu/liter, 30 vol% void soil
6 = 5.0 g Pu/liter, 30 vol% void soil
7 = 8.0 g Pu/liter, 30 vol% void soil
9 = 12 g Pu/liter, 45 vol% void soil
A = 15 g Pu/liter, 45 vol% void soil
B = 20 g Pu/liter, 45 vol% void soil
C = 25 g Pu/liter, 45 vol% void soil
D = 28 g Pu/liter, 45 vol% void soil
- = Soil
* = Concrete

FIGURE 9

ONE-HALF OF SIDE ELEVATION OF 216-Z-9 TRENCH (GEM4 PRINTOUT)

APPENDIX O

BATTELLE PACIFIC NORTHWEST LABORATORIES' PULSED NEUTRON ANALYSIS OF 216-Z-9 ENCLOSED TRENCH

S. R. Bierman
E. D. Clayton

INTRODUCTION

The 216-Z-9 crib is a 6-meter deep excavation covered with a 27- by 37-meter concrete slab approximately 23 centimeters thick. The active, or level, floor area of the crib is about 9 by 18 meters. Prior to June 1962, liquid process wastes containing trace quantities of plutonium were discharged into this crib for slow percolation into the floor soil. Since 1962 the crib has been inactive, and pulsed neutron source measurements have been periodically made in the crib to monitor its degree of subcriticality and to observe any changes in its reactivity.

PULSED NEUTRON THEORY AND MEASUREMENT TECHNIQUES

In theory, a pulsed neutron measurement is made by injecting a burst of neutrons into a system in a fraction of a microsecond and observing, at some point in the system, the effect these neutrons and their progeny have on the neutron population as a function of time following the burst. In actual practice, the measurements are made by repetitively injecting bursts of neutrons into the system and accumulating the observed time behavior, following each burst, by means of a suitable detector properly positioned in or near the system and a series of scalers. The repetition rate and number of neutron bursts required depends on

the statistics of the accumulated data--which, in turn, are dependent on the particular system.

To determine the degree of subcriticality of a system, the raw data obtained from a pulsed neutron source measurement should, ideally, look something like that shown in Figure 1. Each data point shown represents the total number of neutrons counted during a time interval positioned at that point in time between the neutron bursts. Since the neutron detector generally used is primarily sensitive to thermal neutrons, the count rate may be seen to increase immediately following the neutron burst. As the fast neutrons slow down and become thermalized, the count rate will reach a maximum and then begin to decrease expotentially. Once an asymptotic distribution of neutrons is reached in the system, the count rate, as a function of time following the neutron burst, can be described as the sum of the exponential terms:

$$n(t) = A_1 e^{-\alpha_1 t} + A_2 e^{-\alpha_2 t} \tag{1}$$

One term describes the time behavior of the prompt neutrons and the other describes the time behavior of the delayed neutrons. Since the decay of the delayed neutrons is very slow compared with that of the prompt neutrons, Equation 1 is generally written as:

$$n(t) = A_1 e^{-\alpha_1 t} + N_D, \tag{2}$$

where N_D is a constant equal to the averaged delayed neutron contribution and

$$A_1 e^{-\alpha_1 t}$$

is the prompt neutron contribution.

After a period of time the prompt neutron portion of the

total population that is due to the neutron burst will approach the background level preceding the burst, and only the delayed neutrons will remain. Since the prompt neutrons must all decay away before the delayed neutron contribution can be determined, the prompt neutron decay rate is a limiting factor in determining the pulse repetition rates and counting time intervals to be used. This rate of decay is dependent upon the system on which the measurements are being made. However, the faster the neutron spectrum is, the faster the decay rate will be. Also, the further subcritical a system is, the faster the decay rate will be. It is this ambiguous feature of the prompt neutron decay rate which prevents its being used as a direct measurement of activity, although it is directly related to the reactivity of the given system. The rate of decay of the prompt neutrons can, however, be used to obtain an effective multiplication constant, k_{eff}, for the system by the following relationship:

$$\alpha_0 = \frac{1 - k_{eff}(1 - \beta_{eff})}{\ell}, \tag{3}$$

where α_0 is the decay rate $-\alpha_1$, β_{eff} the effective delayed neutron fraction, and ℓ the neutron lifetime in the system. However, this requires a knowledge of ℓ and β_{eff} and ℓ is as difficult to calculate as k_{eff}. Also, Equation 3 and the definition for reactivity,

$$\rho \equiv \frac{k - 1}{k}, \tag{4}$$

can be combined to obtain an expression for the reactivity of the system in units of β; *i.e.*, dollars

$$\frac{\rho}{\beta} = \frac{\alpha_0 - k\beta/\ell}{k\beta/\ell} \tag{5}$$

If the neutron generation time is assumed to be constant,

then Equation 5 reduces to:

$$\frac{\rho}{\beta} = \frac{\alpha_0 - \alpha_C}{\alpha_C} \tag{6}$$

where α_C is the prompt neutron decay rate at delayed critical (k = 1). However, the generation time does vary significantly with the degree of subcriticality.

Three methods have been developed whereby the reactivity of a system can be determined directly from raw data such as that shown in Figure 1. All three methods are similar in that, in each case, the reactivity of the system is related to the area under the curve generated by the pulsed neutron source measurement. The earliest technique was suggested by Sjöstrand[1] who simply separated the data into a prompt neutron component and a delayed neutron component, as implied by Equations 1 and 2, and then approximated the reactivity by taking the ratio of the area under the prompt neutron curve to the area under the delayed neutron curve,

$$\left(\frac{\rho}{\beta}\right)_{SJ} = - \frac{\text{Prompt Neutron Area}}{\text{Delayed Neutron Area}}. \tag{7}$$

Gozani[2] improved on this by extrapolating the prompt neutron fundamental mode of decay back to time zero following the burst of neutrons, and taking the reactivity as:

$$\left(\frac{\rho}{\beta}\right)_{GO} = - \frac{\text{Prompt Neutron Fundamental Mode Area}}{\text{Delayed Neutron Area}}. \tag{8}$$

Garelis and Russell[3] developed a more rigorous theoretical model and showed that the prompt neutron count rates multiplied by a factor involving the reactivity of the system must equal the total area under the pulsed neutron source curve between time zero and 1/R following the burst of neutrons.

$$\int_0^{1/R} N_P \, e^{\frac{k\beta t}{\ell}} \, dt = \int_0^{1/R} N_D \, dt + \frac{N_D}{R}, \qquad (9)$$

where N_P is the prompt neutron count rate at time t following the burst, N_D is the averaged delayed neutron count rate, and R is the pulse repetition rate.

All the information needed to solve Equation 9 for $k\beta/\ell$ is available in the data obtained from the pulsed neutron source measurement. Consequently, all the data needed to solve Equation 5 for the reactivity of the system is provided by the pulsed neutron source data in the Garelis-Russell model. No other information is needed about the system.

All three methods of data analysis, Sjöstrand, Gozani, and Garelis-Russell, require that the delayed neutron density achieve a quasi-equilibrium condition and that a pure delayed neutron component be established above the background. In addition, the Gozani and the Garelis-Russell methods require that the measurements be made in such a way that the fundamental mode of decay for the prompt neutrons can be determined.

MEASUREMENTS PRIOR TO 1973

Pulsed neutron source measurements were initially made in the 216-Z-9 crib in October 1963, in an effort to evaluate the degree of reactivity as the result of the plutonium buildup in the soil. At the time of these measurements the theory had not been developed to the point where a direct measurement could be made of the reactivity. As a result, the value of k_{eff} was dependent on a calculated neutron

lifetime, which, in turn, depended on knowledge of the Pu content and distribution in the soil. This was the first time the pulsed neutron source technique had ever been applied to this type system, but since no other alternative was available, this method had to be used. It was also known that the result could be expected to be biased on the high side. Thus, the value for k_{eff} would, in any event, represent an upper limit which, for the purposes of evaluating safety, is to be preferred. That is, it is much more important to determine the fact that k_{eff} does not exceed a certain value rather than to establish a lower limit. Because of the equipment limitations, the 1963 measurements were made and analyzed by the technique associated with Equation 3. The results of these measurements, associated calculations, and correlating measurements in plutonium-free soil are analyzed and presented in HW-80913.[4] Briefly, however, the prompt neutron decay rate was measured to be 4350 sec^{-1} and the neutron lifetime was calculated to be 33 microseconds for a resultant k_{eff} , from Equation 3, of 0.86.

Pulsed neutron source measurements were again made in 1969 after the analytical techniques of Garelis-Russel[3] and Gozani[2] had been developed and a pulsed neutron source built that permitted such reactivity measurements to be made in such systems as the 216-Z-9 crib. These measurements were made with a Kaman-Nuclear A808 pulsed neutron source and a 23-cm long, 1.3-cm diameter BF_3 tube. A diagram of the pulsed neutron source and data acquisition system is shown in Figure 2.

Since the measurements in 1963 had indicated no difference in the prompt neutron decay rate between Locations 6, 7, or 8, shown in Figure 3, the measurements taken in 1969 were

limited to Location 7. Both the pulsed neutron source and the BF_3 tube were located just above the crib floor in 1963 and in 1969. Measurement data from 1969 are plotted in Figure 4 and show the prompt neutron decay rate in the vicinity of Location 7 to be 7550 sec^{-1} and the reactivity, as determined by the Garelis-Russell method, to be at least \$43 subcritical (a k_{eff} of 0.92 for a β_{eff} value of 0.0021). This increase in the decay rate coupled with the apparent increase in reactivity indicated that a faster neutron energy spectrum existed in 1969 than in 1963. Subsequent moisture determinations of the crib soil showed that the crib had dried out between 1963 and 1969 (10 vol% water in 1963 as compared with 3.3 vol% in 1969). Consequently, the neutron energy spectrum would be expected to be faster. [Dead-time corrections of 1.0 microsecond have not been made.]

MEASUREMENTS IN 1973

Pulsed neutron source measurements were repeated in the 216-Z-9 crib during April 1973 with the same source and detector used in the 1969 measurements. These measurements, made in the same region of the crib as in 1969, showed that the prompt neutron decay rate had decreased to 3550 sec^{-1} and that the crib could possibly be within about \$7 of critical; based on a Garelis-Russell analysis of the data, and a value of 0.0021 for β_{eff}, an upper limit of 0.98 was placed on k_{eff}. Measurement data are shown in Figure 5 along with the analytical results. Tabulated values of the data plotted in Figure 5 are presented on page O-21 as PNSZ9 4373-5 (dead time corrections of 1.0 microsecond have not been made to either the plotted or tabulated data).

As a result of neutron and gamma surveys made of the crib floor during May 1972, the pulsed neutron source and

the BF_3 tube were moved to the center region of the crib where both these surveys indicated the highest concentration of plutonium existed. The pulsed neutron source was positioned on the floor of the crib through Hole H, shown in Figure 3. The BF_3 tube was positioned about 76 cm away through Hole G. In an attempt to minimize spatial effects and room return neutrons, the BF_3 tube was lowered into a 10-cm diameter hole in the crib floor such that the top of the 23-cm long active region of the BF_3 tube was approximately level with the crib floor. Measurement data with the source and detector in this location are shown in Figure 6. Tabulated values of this data, without dead-time corrections, are presented on O-22 as PNSZ9 72673-1.

Based on data such as that shown in Figures 4 and 5, it was believed that the required delayed neutron quasi-equilibrium level had been attained in the measurements and that a constant delayed neutron level was observable in the accumulated data. However, after reviewing the measurement data, an independent AEC consultant suggested that the data accumulation period of 0.00512 second being used between pulses of neutrons was not sufficiently long to fully establish the decay pattern in the time domain where the delayed neutrons (essential for reactivity determination) were expected to dominate. However, due to limitations on the 256 channel analyzer being used, it was not practical to cover a greater time span, and at the same time, obtain sufficient definition on the prompt neutron decay initially. Consequently, the Technical Measurement Corporation (TMC) channel analyzer having only 256 channels and a minimum channel width of effectively 20 microseconds was replaced by a Nuclear Data 4096 channel analyzer. The data shown in Figure 6 were accumulated using this analyzer, which had the capability of good data resolution for any period greater than 0.00256

seconds.

The data shown in Figure 6 were obtained at a pulse repetition rate of 39.44 pulses per second, which corresponds to a pulse period of 0.025355 seconds. The Nuclear Data channel analyzer was operated as a 512 channel analyzer, with each channel having a 40-microsecond width, to obtain a data accumulation period (0.020480 second) slightly shorter than the pulsing period.

In the data shown in Figure 6, the neutron population over at least the last 40% of the data accumulation period is essentially constant and is above the nonpulsing background by 29%. Consequently, since the pulse repetition rate is relatively high at 39.44 sec^{-1}, a delayed neutron equilibrium condition is established in the measurements and is observable. However, this level is about a factor of 3 lower than would have been observed if the data had been accumulated during only the first 0.00512 second (128 channels in Figure 6) following each neutron pulse, as was the case for measurements with the TMC analyzer. This factor of 3 lower in the delayed neutron level does not have a significant effect on the decay rate determined for the prompt neutrons, but it does significantly affect the reactivity determination. The decay rate of 3250 sec^{-1} is essentially the same as in the previous measurement at Location 7; however, the Garelis-Russell reactivity value of \$7 subcritical has decreased to \$198 subcritical (k_{eff} of 0.98 versus 0.71 using a β_{eff} value of 0.0021). If only that portion of the data accumulated within 0.00512 second of the neutron pulse is used, the prompt neutron decay rate is 3500 sec^{-1} and the Garelis-Russell determined k_{eff} is 0.97, which does not differ significantly from that obtained from the measurement data accumulated with the TMC analyzer and

shown in Figure 5.

There are some indications, in the measurement data shown in Figure 6, of some kind of suppression in the prompt neutron dominated portion of the data. There also appears to be a slow mode of decay predominating during the time interval immediately following the prompt neutron time region, which may be contaminating the delayed neutron level out beyond Channel 300. Either phenomenon, if real, would result in a high value being determined for the reactivity. That is, the Garelis-Russell k_{eff} would be less than 0.71 and the region in the vicinity of Hole G would be further subcritical if either the prompt neutron data were suppressed or the delayed neutron tail were unaccountably being supported by another mode of decay. The effect of the latter has been minimized in the analysis by forcing the delayed neutron level to be equal to the average of the last few channels of data accumulated in the measurement. This procedure, however, has the adverse effect of considering everything else as prompt neutrons in the Garelis-Russell analysis. As a consequence, the Garelis-Russel reactivity is artifically low.

For these particular measurements in the 216-Z-9 crib, it would appear that the Gozani technique of analysis would be the most appropriate. The prompt neutron suppression, if any, does not occur during the prompt fundamental mode of decay nor does it appear to affect its value. Also, the Gozani technique does not make use of the data immediately following the prompt mode of decay. It will be affected by these data only to the extent some of it still persists during the last few channels of data accumulation. By applying the Gozani method of analysis to the data shown in Figure 6, a reactivity of $132 subcritical is obtained for

the crib floor region below Entry Hole G. This corresponds to a k_{eff} of 0.79 (β_{eff} = 0.0021) and should be used as the more accurate value for criticality safety purposes.

After 1100 ±30 liters of aqueous cadmium nitrate solution had been added to the 216-Z-9 soil in August 1973, another pulsed neutron source measurement was made. The measurement data are shown in Figure 7 and were obtained with the source and detector in the same position as when the data in Figure 6 were obtained. Tabulated data, without dead-time corrections, are presented in O-25 as PNSZ9 81773-2.

After addition of the cadmium nitrate, the prumpt neutron decay rate was observed to increase to 3825 sec^{-1}. Using the Garelis-Russell method of analysis, as before, the value determined for the reactivity decreased to $1950 subcritical ($k_{eff}$ = 0.2 using a β_{eff} value of 0.0021). A reactivity of $760 subcritical is obtained using the Gozani method of analysis (k_{eff} = 0.39). However, because of the extreme sensitivity of the analysis to the delayed neutron level, and since the delayed plus background level for this poisoned system is only 7% above the background, k_{eff} values as low as 0.23 can be obtained from the data. Consequently, a nominal k_{eff} value of 0.3 is probably more appropriate for this very subcritical system.

REACTIVITY OF 216-Z-9 CRIB

Because of the 216-Z-9 crib's size and complexity, the pulsed neutron source measurements cannot preclude the existence of isolated regions of high reactivity in the crib. However, a direct analysis of the most recent measurement data, as taken, and without benefit of interpretive corrections, results in a maximum k_{eff} value of 0.79

preceding the addition of cadmium nitrate to the crib. Following the addition of cadmium nitrate, this value decreased to about 0.3. Since these values were determined from measurement data taken in the region indicated by gamma and neutron scans to have the highest plutonium concentration, k_{eff}, for at least the surface layers of the crib floor, should not exceed 0.79 and 0.3, respectively, prior to and after the cadmium nitrate addition.

It is possible to interpret the data on the neutron dieaway in such fasion as to imply lower values of k_{eff}. Such interpretation has merit on the basis that room-return neutrons are distorting the time decay in the region where the delayed neutrons would be expected to reach equilibrium--and there is evidence that this is the case. However, it would not be considered prudent to place such merit on the presence of these room-return neutrons, which, in any event, cannot be fully substantiated in the crib itself. Where nuclear criticality and safety are a matter of concern, any bias in the data, and interpretation thereof, must always be toward the higher value, not the lower, unless the numbers (and the assumptions on which the numbers were deduced) can be established with absolute certainty. This is especially so in the case of this particular underground waste cavern, which constitutes the only system of its type ever pulsed--and a system that is not feasible to mock up in the laboratory.

In concluding, it should be mentioned that there is no question whatever concerning the validity of reactivity measurements to the types of systems (critical assemblies) that have been investigated in the Plutonium Critical Mass Laboratory. Against known systems, the results are quite accurate.

REFERENCES

1. N. G. Sjostrand, "Measurements on a Subcritical Reactor Using a Pulsed Neutron Source," *Arkiv Fysik*, *11*, 233 (1956).

2. T. Gozani, "A Modified Procedure for the Evaluation of Pulsed Source Experiments in Subcritical Reactors," *Nukleonik*, *4*, 238 (1962).

3. E. Garelis and J. L. Russell, "Theory of Pulsed Neutron Source Measurements," *Nucl. Sci. Eng.*, *16*, 265 (1963).

4. S. R. Bierman, *Pulsed Neutron Source Measurements of the Z-9 Crib*, HW-80913, General Electric Company, Richland, Washington, March 1964.

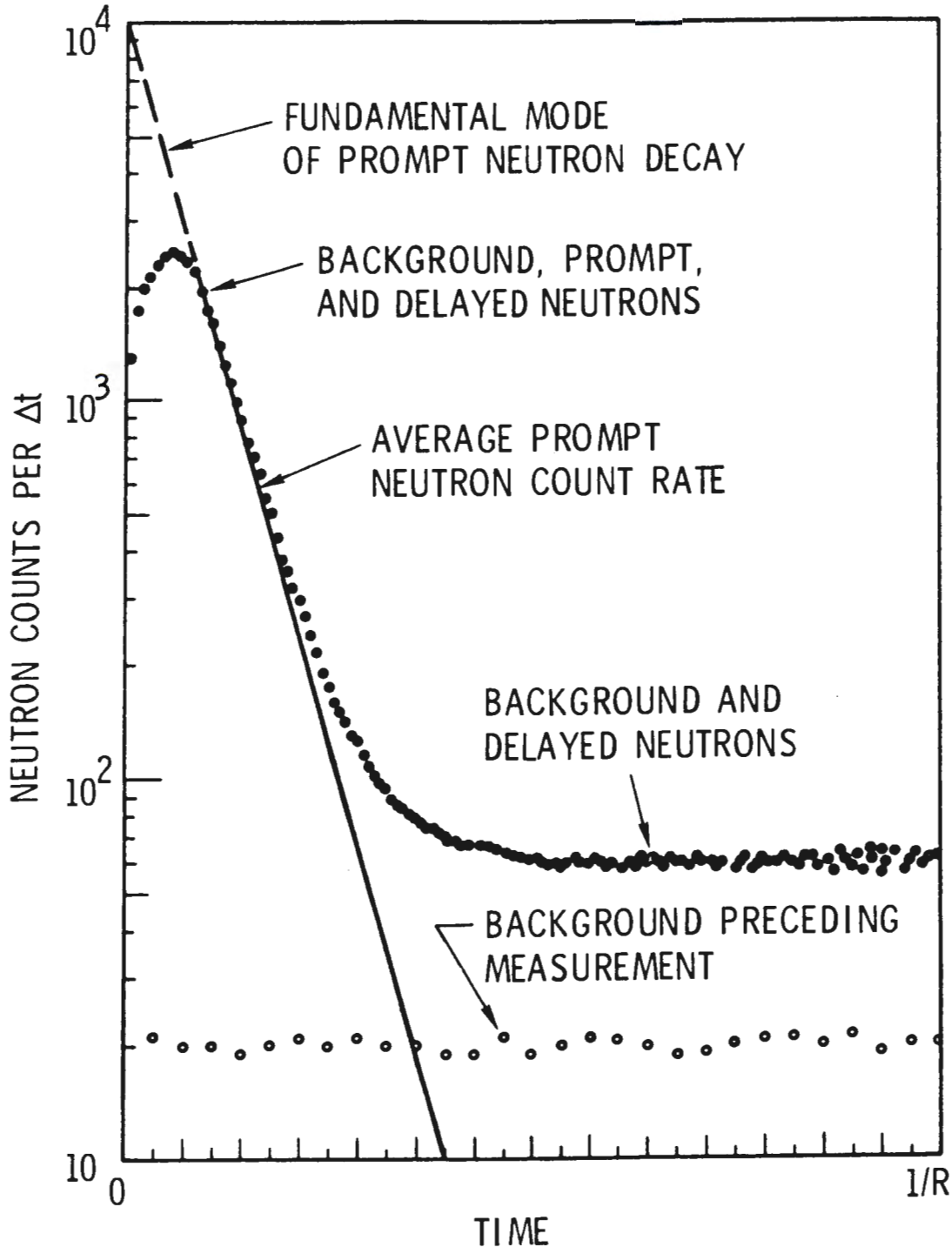


FIGURE 1

TYPICAL TYPE DATA OBTAINED
IN A PULSED NEUTRON SOURCE MEASUREMENT

V7312-10.44

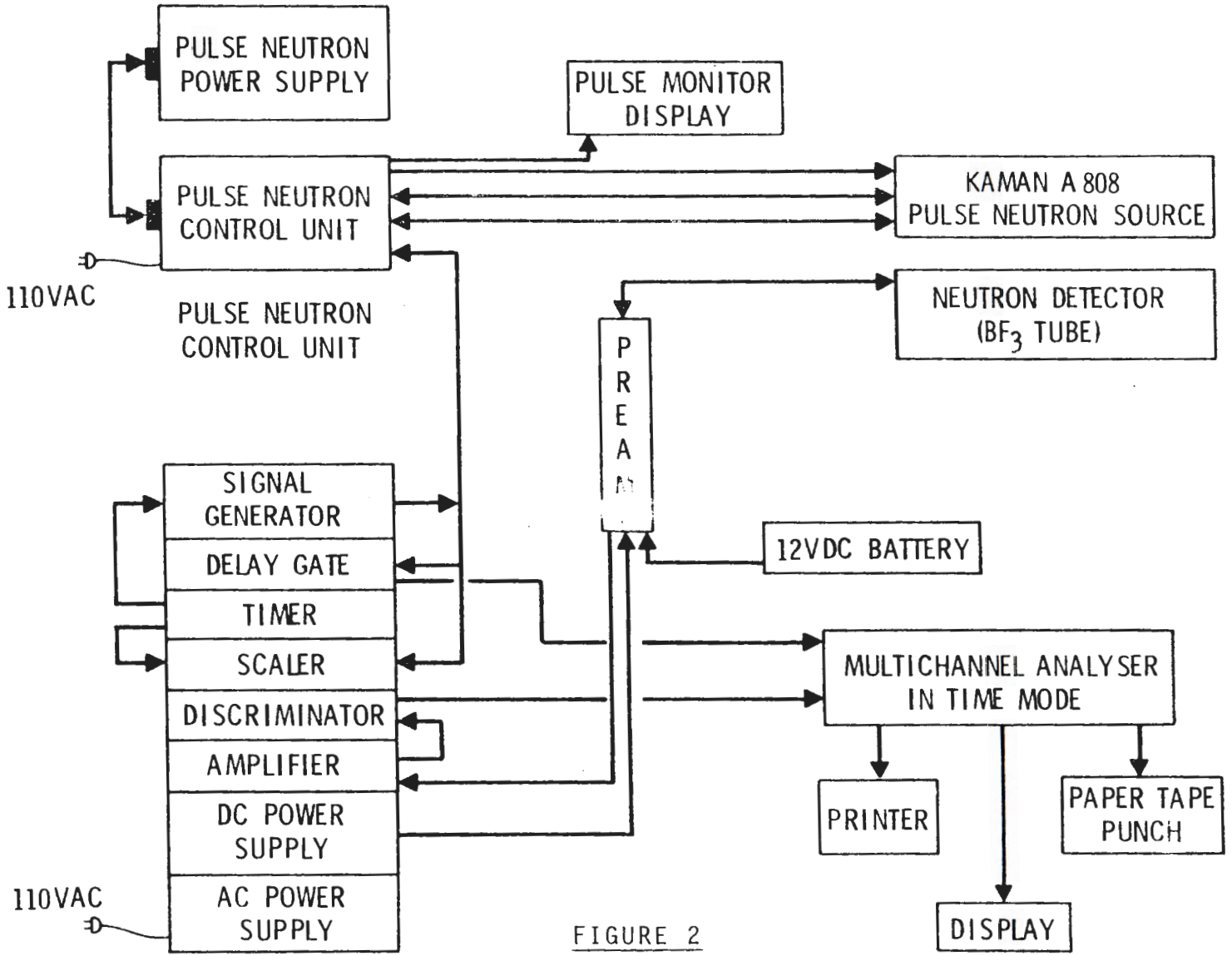


FIGURE 2

PULSE NEUTRON SOURCE AND DATA ACQUISITION SYSTEM

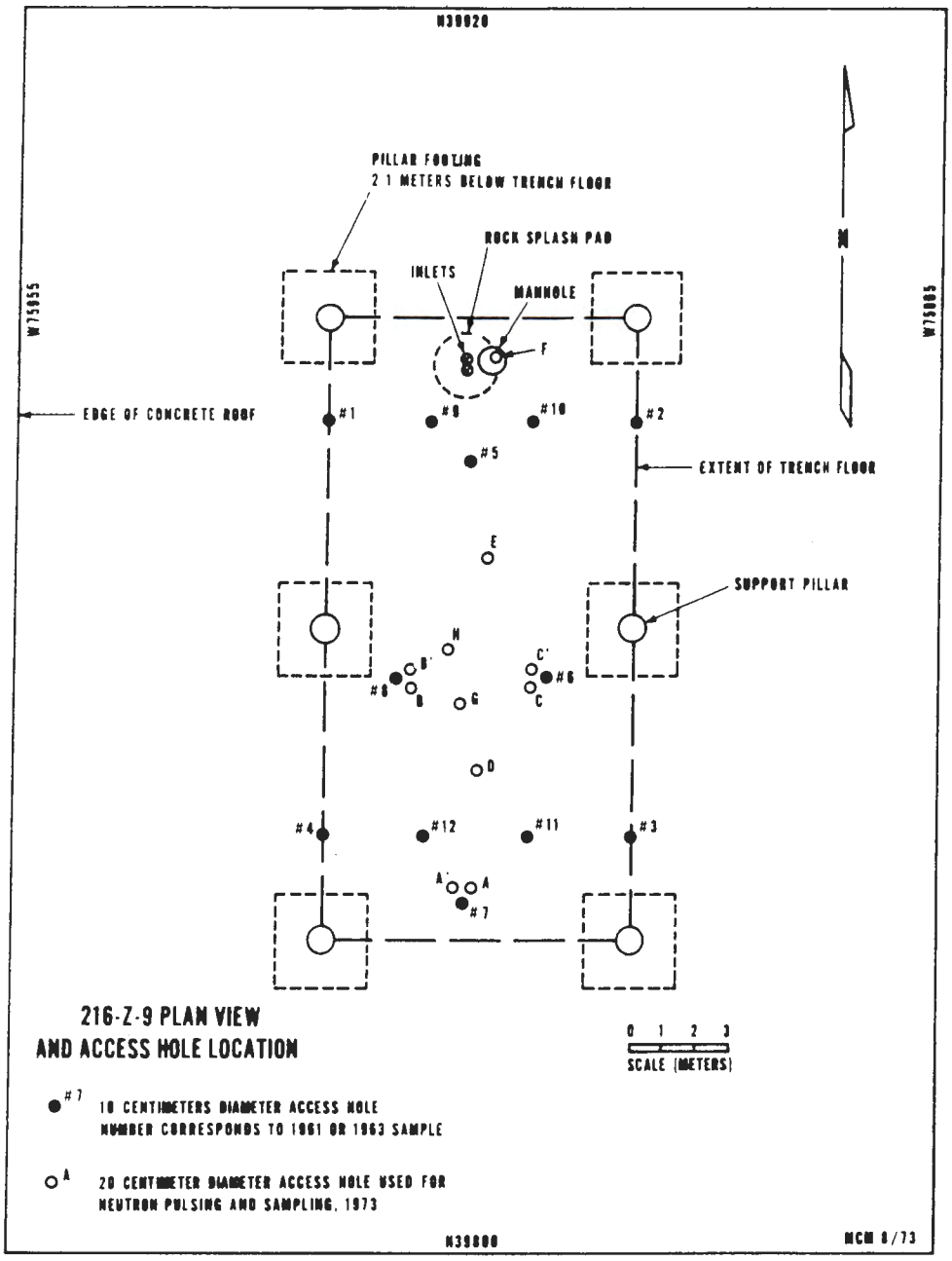


FIGURE 3

216-Z-9 PLAN VIEW

V7312-10.46

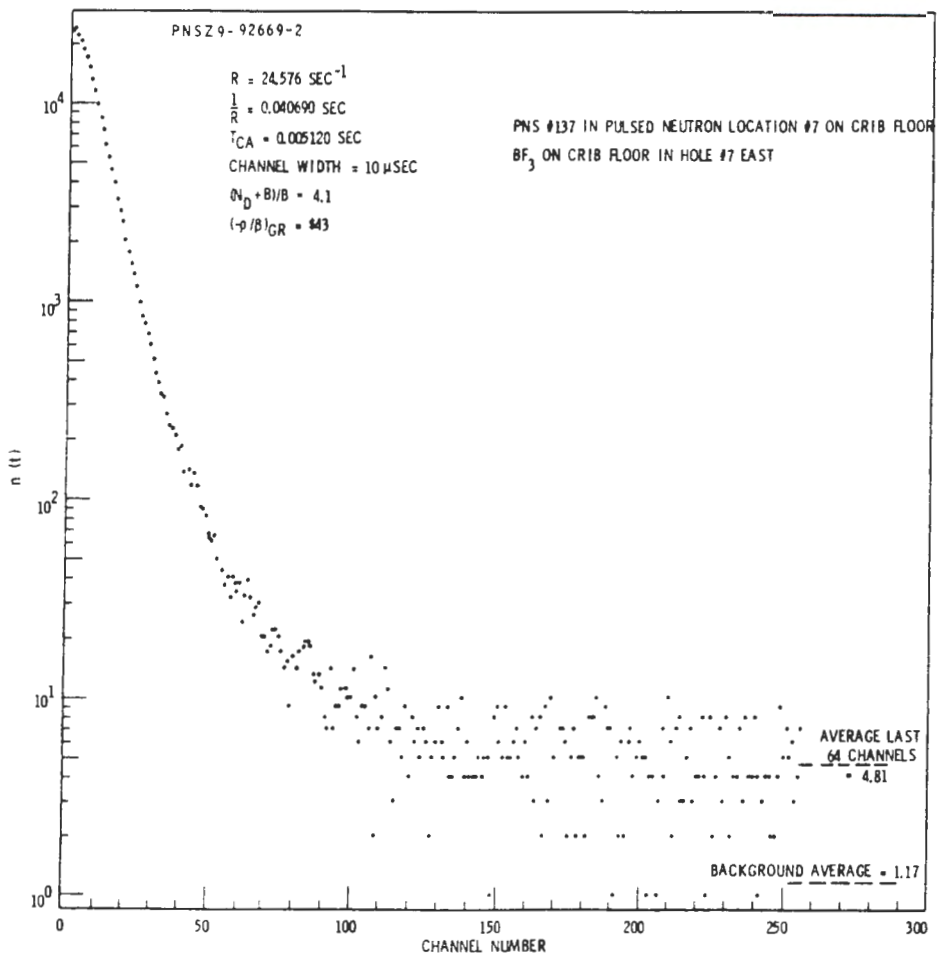


FIGURE 4

216-Z-9 PULSED NEUTRON MEASUREMENT - 1969

V7312-10.47

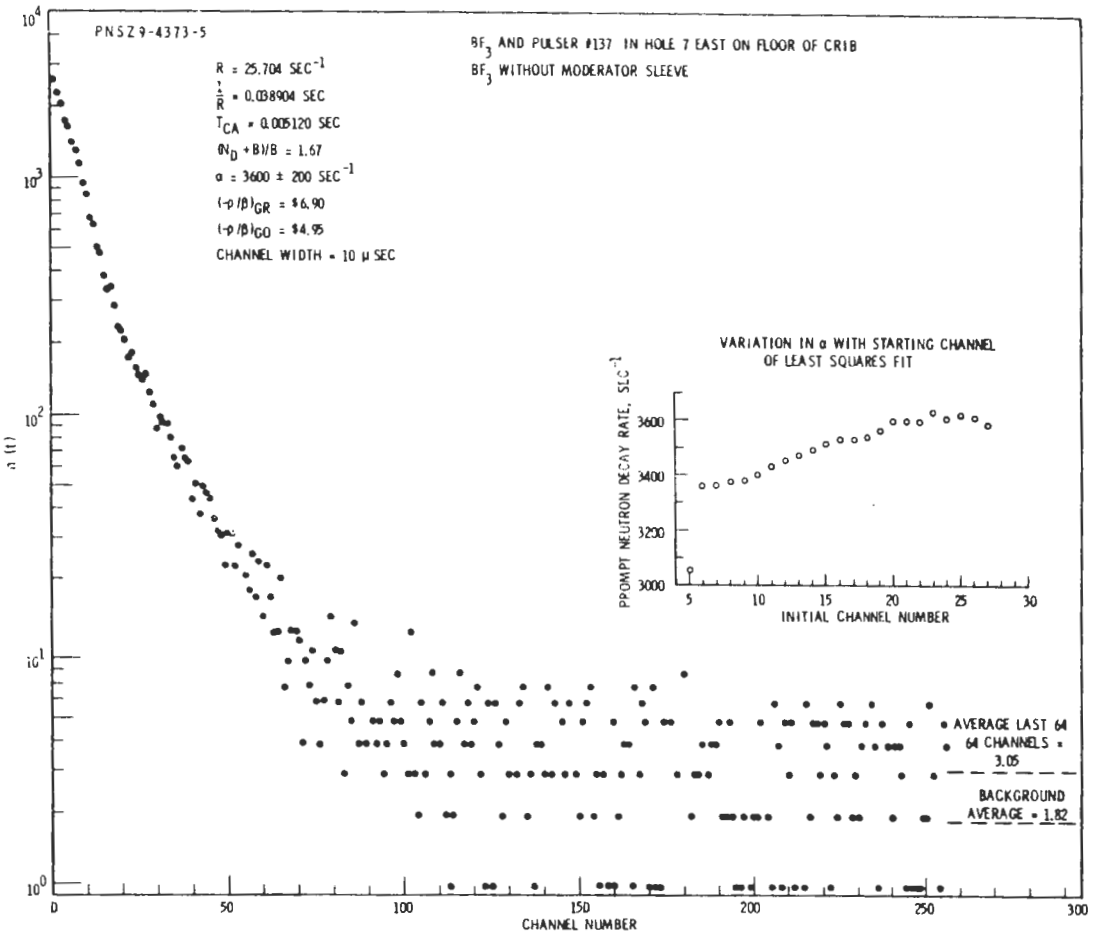


FIGURE 5

216-Z-9 PULSED NEUTRON MEASUREMENT - 1973

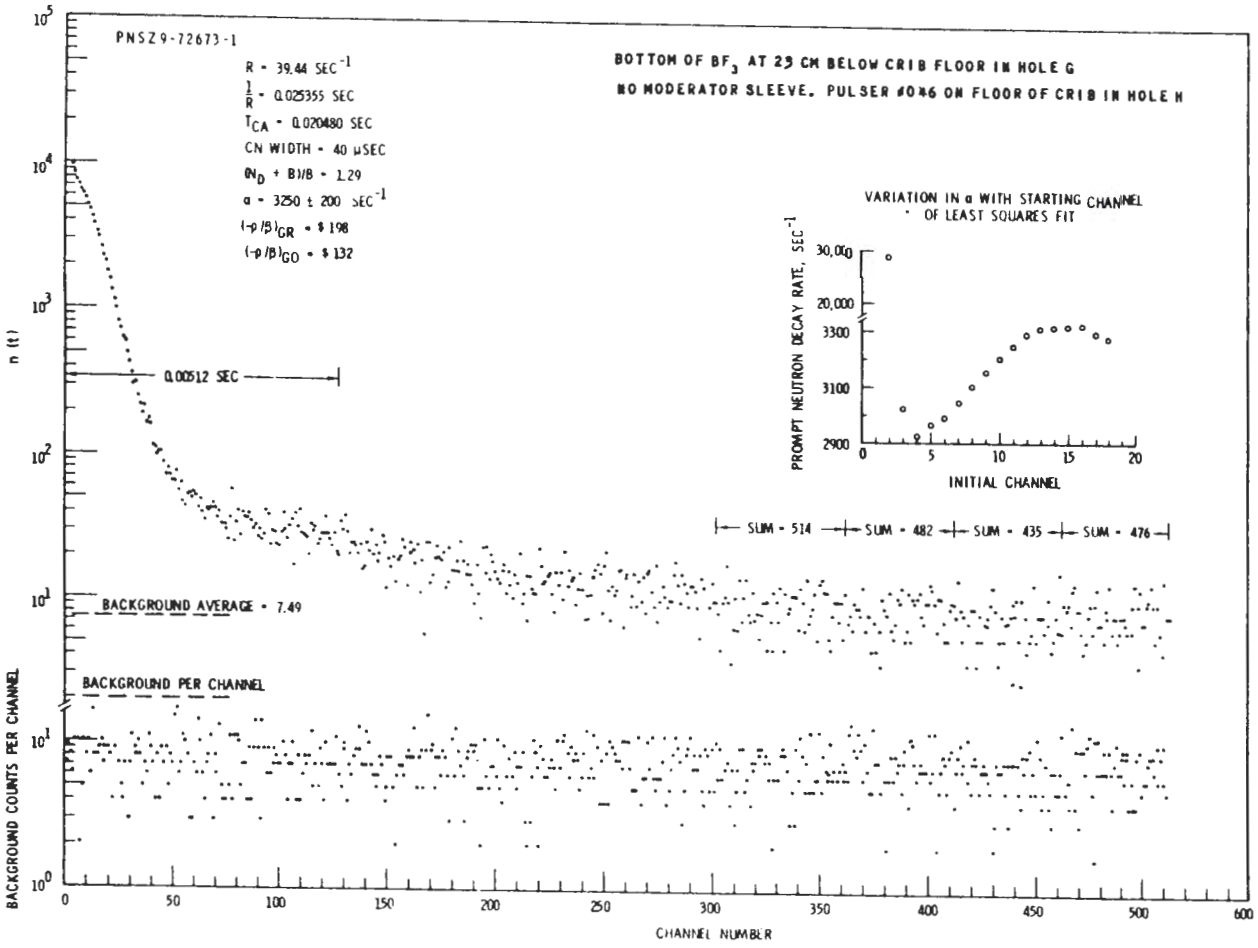


FIGURE 6

216-Z-9 PULSED NEUTRON MEASUREMENT - 1973

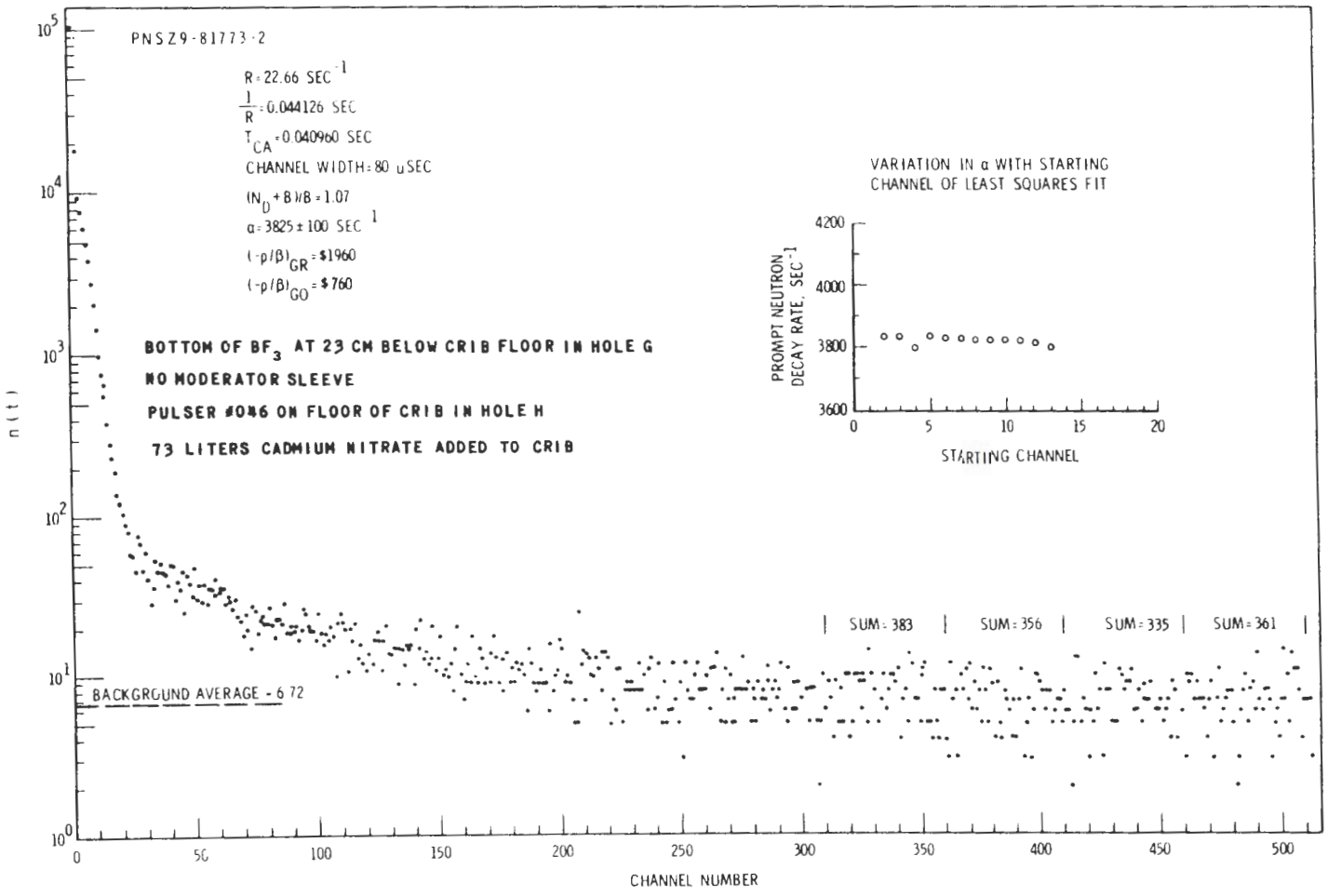


FIGURE 7

216-Z-9 PULSED NEUTRON MEASUREMENT - 1973

PNS79 4373-5
* BOTTOM OF BF3 TUBE IS ABOUT 30 CM. ABOVE FLOOR IN HOLE 7 EAST, NO MODERATOR ON BF3.
* PULSER #137 ON CRIB FLOOR IN HOLE 7 EAST
* TECHNICAL MEASUREMENTS CORPORATION, TMC-256, CHANNEL ANALYSER USED.
* RESOLVING TIME OF DATA ACQUISITION SYSTEM IS 1.0+, -0.5 MICROSEC.
* CHANNEL WIDTHS: 10 MICROSEC + 10 MICROSEC DEADTIME BETWEEN CHANNELS.
* TOTAL MEASUREMENT TIME: 603.1 SEC.
* BUILDUP TIME PRECEDING DATA ACCUMULATION: 200 SEC. (MIN.)
* TOTAL NUMBER OF NEUTRON BURSTS: 15502
* TOTAL NUMBER OF ANALYSER CYCLES: 10242

0									
2630	2295	2073	1774	1671	1416	1307	1154	959	848
685	626	509	476	383	339	341	285	233	227
209	174	188	158	148	144	150	127	111	87
99	93	93	80	67	60	72	65	64	44
51	38	50	47	44	36	32	31	23	32
32	23	28	21	18	26	17	24	14	23
17	12	12	20	7	9	12	12	11	4
9	6	10	6	4	6	9	14	10	6
10	3	7	5	13	4	6	6	4	1
5	4	5	3	4	6	5	8	5	4
100									
3	12	3	2	6	3	5	8	4	4
6	2	3	2	5	8	4	6	4	5
7	3	1	6	1	6	4	2	5	3
0	3	6	7	2	3	1	4	4	3
7	3	6	0	5	3	6	0	3	2
5	6	7	2	3	1	3	1	1	5
2	3	4	4	1	7	3	6	5	1
7	1	1	5	5	5	3	0	4	8
0	2	3	3	4	0	3	4	4	5
2	2	5	2	1	1	3	3	1	2
200									
2	5	0	2	1	6	4	1	5	3
5	1	1	1	6	2	5	5	3	5
4	1	3	2	6	5	5	2	3	2
7	4	5	0	6	4	1	5	4	2
4	4	3	1	5	1	1	1	2	2
6	3	0	1	5	4				

BACKGROUND
---
* BACKGROUND TAKEN WITH CHANNEL ANALYSER AT SAME REPETITION RATE AND CHANNEL WIDTHS AS USED IN PULSE MEASUREMENTS.
* TOTAL MEASUREMENT TIME: -
* TOTAL NUMBER OF ANALYSER CYCLES: 10633

SUM ALL CHANNELS: 485

PNSZ9 72673-1
* BOTTOM OF BF3 TUBE 23 CM. BELOW CRIB FLOOR IN HOLE G
NO MODERATOR ON BF3
* PULSER #046 ON CRIB FLOOR IN HOLE H
* NUCLEAR DATA, MODEL 2400, CHANNEL ANALYSER USED WITH
NUCLEAR DATA ZERO DEAD TIME MODULE.
* RESOLVING TIME OF DATA ACQUISITION SYSTEM IS
1.0+, -0.5 MICROSEC.
* CHANNEL ONE IS NOT A DATA CHANNEL.
* CHANNEL WIDTHS: 40 MICROSEC.
* TOTAL MEASUREMENT TIME: 636.8 SEC.
* BUILDUP TIME PRECEDING DATA ACCUMULATION: 180 SEC.(MIN.)
* TOTAL NUMBER OF NEUTRON BURSTS: 25115
* TOTAL NUMBER OF ANALYSER CYCLES: 18013
SUM ALL CHANNELS: 263544

0									
5	128762	30529	9792	8584	7628	7119	6574	6157	5641
5080	4776	4240	3805	3352	3078	2621	2299	2062	1775
1557	1313	1116	1004	811	701	636	591	498	422
363	305	308	251	217	191	212	161	176	160
118	115	100	106	107	88	73	80	73	66
65	78	57	63	47	44	53	54	50	55
52	43	49	40	35	42	41	42	46	42
37	40	34	34	30	26	37	57	25	34
41	28	40	37	37	39	35	31	33	27
31	26	28	41	39	24	30	34	29	23
100									
29	40	30	26	33	36	17	40	32	42
29	28	27	20	34	30	32	24	26	29
29	38	29	26	24	29	22	20	35	31
39	30	21	25	25	24	21	24	16	17
25	22	30	21	24	18	21	28	25	12
19	17	21	14	20	21	28	24	13	22
27	24	19	26	12	20	6	27	27	14
16	21	26	16	20	23	13	14	25	17
17	20	17	28	20	16	19	16	14	10
14	12	8	25	17	25	15	22	20	17
200									
15	14	17	19	12	17	14	11	16	14
23	10	12	16	8	16	13	12	12	25
19	14	15	16	17	12	9	17	14	17
11	24	14	18	15	16	10	13	17	13
8	12	8	12	16	18	20	17	9	19
24	13	8	14	12	13	18	18	7	16
17	10	12	17	10	15	11	16	9	17
18	13	10	20	8	11	14	12	10	11
11	17	21	14	11	17	15	13	10	14
14	13	10	6	16	14	22	11	10	15
300									
11	11	9	5	11	12	20	12	4	7
12	7	16	8	12	16	9	8	13	8
9	6	9	11	5	11	8	5	13	11
8	14	5	13	9	10	13	13	13	7
14	11	7	16	8	9	10	13	6	15

PNS Z9 72673-1

350									
16	13	13	6	5	9	11	11	8	11
6	13	8	9	7	11	10	10	9	14
7	9	9	5	8	5	7	4	12	10
9	13	7	6	8	12	11	14	6	7
8	14	9	12	12	10	8	9	8	11
400									
13	6	12	11	12	13	9	8	11	10
15	14	11	7	12	10	8	6	6	10
11	11	9	16	10	6	9	4	8	14
10	4	6	9	6	8	8	9	11	9
12	6	3	12	9	5	6	7	15	6
9	9	9	7	8	12	5	6	9	7
18	7	11	10	11	8	14	15	10	10
7	5	6	9	11	7	11	14	8	8
6	10	9	15	7	9	9	6	7	9
9	8	7	7	11	15	4	11	14	8
500									
8	11	12	15	11	6	11	7	5	16
9	9								

PRE-PULSE BACKGROUND CPM: 636 @ 112VAC LINE VOLTAGE
POST-PULSE BACKGROUND CPM: 630 @ 112 " "

BACKGROUND
---

* BACKGROUND TAKEN WITH CHANNEL ANALYSER AT SAME REPETITION RATE AND CHANNEL WIDTHS AS USED IN PULSE MEASUREMENTS.
* TOTAL MEASUREMENT TIME: 457.4 SEC.
* TOTAL NUMBER OF ANALYSER CYCLES: 18050

SUM ALL CHANNELS: 3833

0									
7	9	8	6	10	10	2	5	10	8
10	6	16	8	8	9	10	7	9	9
8	4	9	1	7	5	4	7	3	7
11	9	8	10	8	5	7	6	11	9
7	4	8	4	9	7	9	5	8	7
15	17	6	7	11	10	8	3	3	7
6	14	10	6	4	7	8	11	3	8
6	13	5	4	4	5	11	4	11	11
10	5	7	7	4	9	4	9	14	9
3	14	9	6	9	6	9	7	8	7
100									
7	10	8	4	7	7	10	4	8	4
6	8	7	8	12	5	7	5	9	7
4	10	7	7	7	7	11	6	5	9
10	4	7	6	8	9	13	9	7	7
12	7	10	6	5	6	8	7	4	5

PNS Z9 72673-1

150									
8	8	5	2	6	7	7	6	8	9
8	8	13	5	8	9	5	9	16	9
10	5	8	8	6	9	8	6	3	11
6	13	9	7	6	3	8	9	10	9
10	5	2	5	11	6	5	7	7	6
200									
11	5	4	10	6	6	8	6	9	5
7	7	9	3	2	3	6	11	9	2
10	8	6	6	7	8	7	5	11	7
11	12	9	6	10	8	9	8	5	6
9	13	6	7	6	12	10	4	8	4
9	4	11	10	9	8	8	11	7	11
11	7	5	5	5	12	4	6	6	11
7	12	6	5	6	6	8	12	4	5
7	9	12	10	8	3	5	9	10	12
9	7	7	9	5	4	10	5	9	10
300									
5	11	6	10	6	7	8	4	7	3
5	7	10	10	5	6	4	8	7	8
10	9	10	8	9	6	8	2	6	6
6	9	10	9	7	3	5	3	10	6
12	9	5	8	5	13	5	6	6	13
5	9	7	6	11	6	7	6	7	8
6	7	6	13	15	10	9	13	10	6
11	7	5	5	14	8	8	5	1	6
2	6	9	6	9	7	8	5	10	8
4	12	11	8	6	7	8	7	7	13
400									
6	7	13	2	5	7	9	8	5	9
10	4	7	9	11	7	8	6	12	5
8	9	8	5	7	8	7	6	5	2
3	8	7	7	8	5	3	8	8	8
8	5	4	9	7	9	10	5	7	5
12	9	4	5	8	4	3	7	7	5
5	7	13	5	6	4	15	4	10	3
10	10	7	11	13	5	12	12	7	7
10	7	7	10	7	4	8	11	7	7
9	6	9	4	6	4	4	9	10	5
500									
6	6	8	9	9	7	11	6	9	6
11	5								

CHI SQUARE 1ST. 100 BACKGROUND CHANNELS: 119.2
CHI SQUARE 2ND. 100 BACKGROUND CHANNELS: 81.62
CHI SQUARE 3RD. 100 BACKGROUND CHANNELS: 90.81
CHI SQUARE 4TH. 100 BACKGROUND CHANNELS: 99.0
CHI SQUARE 5TH. 100 BACKGROUND CHANNELS: 98.16

PNSZ9 81773-2
* BOTTOM OF BF3 TUBE 23 CM. BELOW CRIB FLOOR IN HOLE G
NO MODERATOR ON BF3
* PULSER #046 ON CRIB FLOOR IN HOLE H
* NUCLEAR DATA, MODEL 2400, CHANNEL ANALYSER USED WITH
NUCLEAR DATA ZERO DEAD TIME MODULE.
* RESOLVING TIME OF DATA ACQUISITION SYSTEM IS
1.0+, -0.5 MICROSEC.
* CHANNEL ONE IS NOT A DATA CHANNEL.
* CHANNEL WIDTHS: 40 MICROSEC.
* TOTAL MEASUREMENT TIME: 700.2 SEC.
* BUILDUP TIME PRECEDING DATA ACCUMULATION: 180 SEC. (MIN.)
* TOTAL NUMBER OF NEUTRON BURSTS: 15868
* TOTAL NUMBER OF ANALYSER CYCLES: 11806
SUM ALL CHANNELS: 171788

0									
5	104723	18575	9422	7667	6139	4972	3844	2768	2004
1423	993	771	565	381	287	236	191	139	124
106	92	81	59	57	46	77	69	47	60
42	29	37	54	47	51	46	44	38	50
50	31	40	36	46	26	44	39	33	49
31	38	30	38	29	36	36	33	41	34
36	36	29	32	30	27	31	24	33	18
25	20	15	28	27	19	23	24	22	22
28	21	18	23	23	22	29	19	19	21
20	21	17	20	27	25	21	20	20	17
100									
25	19	16	19	17	21	18	10	17	25
17	15	11	20	17	22	13	16	12	11
14	14	12	17	19	17	11	17	21	14
14	15	9	15	15	12	16	15	16	9
20	15	23	13	14	12	13	21	11	13
18	10	11	10	12	8	15	21	10	7
9	12	9	18	10	9	15	13	9	11
9	14	18	13	9	8	13	14	9	11
9	12	11	12	10	6	15	12	9	8
9	12	9	9	6	16	8	10	11	17
200									
15	9	10	9	7	5	5	26	12	7
14	13	10	10	13	11	8	14	14	13
5	7	6	11	11	5	8	9	8	9
8	8	12	8	10	6	11	13	6	7
12	6	5	9	5	6	6	12	5	9
3	12	8	7	7	10	12	8	8	8
10	6	12	12	14	5	8	5	11	7
10	5	8	8	8	13	8	9	5	8
5	9	7	8	7	9	6	8	9	7
8	12	6	5	11	5	9	6	9	7
300									
3	8	5	8	8	5	2	5	10	6
9	7	4	9	5	8	5	10	10	4
5	10	10	9	6	9	5	15	10	8
7	5	7	10	6	8	10	10	9	11
4	7	8	5	14	12	7	7	5	10

PNS z9 81773-2

350									
12	5	5	4	8	5	4	8	8	4
3	12	7	8	3	10	8	11	7	12
6	9	6	8	5	11	8	5	11	9
4	9	5	4	8	7	6	4	7	4
7	11	3	5	7	3	6	10	10	9
400									
8	6	8	8	5	6	7	7	5	8
6	6	2	5	13	13	5	7	6	3
6	5	10	6	8	3	12	8	8	5
5	5	11	10	8	9	9	11	6	6
8	5	7	7	7	9	1	6	6	7
5	6	7	4	9	8	4	6	3	3
10	9	10	7	9	7	7	6	4	7
9	3	7	11	5	6	7	8	8	5
2	3	6	8	10	5	8	9	6	14
7	6	8	8	7	3	5	6	4	7
500									
7	10	5	14	11	11	8	4	7	7
7	3								

PRE-PULSE BACKGROUND CPM: 431 @ 112VAC LINE VOLTAGE
POST-PULSE BACKGROUND CPM: 430 @ 112VAC LINE VOLTAGE

BACKGROUND
---

* BACKGROUND TAKEN WITH CHANNEL ANALYSER AT SAME REPETITION RATE AND CHANNEL WIDTHS AS USED IN PULSE MEASUREMENTS.
* TOTAL MEASUREMENT TIME: 519.4 SEC
* TOTAL NUMBER OF ANALYSER CYCLES: 11802

SUM ALL CHANNELS: 3437

0									
8	10	2	11	11	3	8	11	5	5
7	8	3	3	6	15	6	8	4	7
3	5	3	5	7	7	7	10	7	7
7	7	4	4	3	6	8	9	10	8
4	8	4	10	4	9	6	6	5	4
7	5	6	7	6	3	6	12	6	7
2	9	8	5	4	2	4	6	3	6
4	6	6	8	5	7	6	7	9	10
5	3	6	8	9	12	10	6	5	7
6	10	4	9	7	4	4	4	8	3
100									
3	4	2	5	7	8	11	10	3	3
5	5	3	4	6	6	6	6	10	4
6	5	8	11	11	6	6	3	10	3
5	5	8	6	9	7	9	6	5	7
14	9	5	13	10	4	9	8	6	4
8	4	4	8	5	4	6	6	4	6
5	11	4	4	9	7	8	7	9	5
1	7	4	10	6	3	3	5	6	5
7	9	5	7	3	10	5	3	2	6
9	6	4	9	3	2	8	4	9	4
200									

PNS Z9 81773-2

200									
9	8	7	4	6	8	3	8	12	7
5	3	7	6	11	5	9	10	5	3
1	7	5	8	5	7	7	5	10	4
12	9	8	6	5	9	3	10	13	7
10	6	9	8	3	9	7	9	6	6
6	2	5	7	6	9	13	5	5	5
1	3	7	9	8	8	7	5	10	6
7	4	6	3	4	6	15	6	10	10
8	6	10	6	8	6	8	7	12	6
10	10	10	2	8	9	9	7	5	3
300									
6	2	8	5	9	7	6	5	8	4
5	8	8	9	11	11	4	6	5	6
2	5	6	17	6	10	10	11	3	1
10	5	7	11	7	9	9	10	10	8
8	4	2	4	8	10	11	12	7	7
8	5	7	3	3	7	9	8	5	13
9	9	6	8	7	4	5	8	4	8
8	6	9	10	9	9	8	7	8	7
5	4	6	4	9	9	8	7	10	8
2	8	4	3	7	7	6	10	10	10
400									
4	5	7	9	8	4	12	4	3	6
8	11	10	3	7	7	10	6	6	3
7	4	5	4	10	9	5	13	5	4
7	6	8	9	6	4	7	9	4	9
11	7	13	10	2	5	7	11	8	8
7	5	5	5	7	9	6	9	4	8
6	5	7	6	8	6	9	4	4	7
6	7	6	6	5	13	4	11	9	10
7	10	7	3	13	6	8	6	3	11
4	4	7	4	7	7	7	5	8	7
500									
5	5	3	9	6	5	5	6	8	11
7	6								

APPENDIX P

SAVANNAH RIVER LABORATORY ANALYSIS OF BATTELLE PACIFIC NORTHWEST LABORATORIES' 216-Z-9 ENCLOSED TRENCH PULSED NEUTRON MEASUREMENTS

P. B. Parks
M. P. Baumann

INTRODUCTION

The Richland Operations Office of the USAEC requested an independent analysis of pulsed neutron data from the Z-9 Crib. These data were taken from experiments performed by Battelle-Northwest Laboratory personnel. The physical description of these experiments has been detailed in the main body of this report.

The first experiment was performed on July 26, 1973, with the crib in an unpoisoned state; *i.e.*, before the $Cd(NO_3)_2$ solution was added. The second experiment was performed on August 17, 1973, after the addition of the $Cd(NO_3)_2$ solution. The physical location of the detector and the pulsed source was the same in the two experiments.

SUMMARY

The SRL analysis shows the k_{eff} of the unpoisoned crib to be about 0.48 and of the poisoned crib to be about 0.22. An assumption concerning the origin of a "background" component was required as discussed in the following paragraph. These values were derived from the assumption most likely to be correct. A second assumption, considered less likely to be correct, led to k_{eff} values of 0.80 for the unpoisoned crib and 0.25 for the poisoned crib. Values are summarized in Table I.

TABLE I

COMPARISON OF Z-9 CRIB MEASUREMENTS

	$-\lambda$ Decay Constant	$-\beta$ (Gozani)	k_{eff}
Before flooding with $Cd(NO_3)_2$ (7/26/73)	0.35×10^4 sec^{-1}	525. with room return extrapolation	0.48
		117. without room extrapolation	0.80
After flooding with $Cd(NO_3)_2$ (7/26/73)	0.41×10^4 sec^{-1}	1650. with room return extrapolation	0.22
		1432. without room extrapolation	0.25

The analyses would have been straightforward and have admitted only single values except for a distortion in the data apparently due to the phenomenon of "room return". It was not possible to accurately assess the impact of the room return problem on derived values of k_{eff} on the basis of the supplied data alone. The first set of k_{eff} values correspond to an assessment of the room return considered most reasonable and the second set corresponds to a less reasonable assessment. Nevertheless, the second set is conservative and can be used as upper limits to k_{eff}.

The analysis method used to derive these numbers was Gozani's "Extrapolated Area Method".[1] This technique has been previously tested at Savannah River and at other laboratories and has been found to be generally accurate at k_{eff} values approaching unity (critical). The accuracy of the technique at the reported low k_{eff} values of Table I is

[1] T. Gozani, "The Theory of the Modified Pulsed Source Technique," EIR Bericht Nr. 79 (1965).

somewhat uncertain. However, for purposes of nuclear criticality safety, it is only necessary to be able to infer from a measurement whether criticality is or is not being closely approached. The pulsed neutron technique with Gozani analysis is suitable for that purpose.

DISCUSSION

RAW DATA FROM THE UNPOISONED CRIB MEASUREMENT (7/26/73)

The raw data supplied by BNW for the unpoisoned crib is shown in Figure 1. The raw data can be characterized in four rather distinct time domains. Before about 0.6 msec elapsed time, a pronounced positive harmonic distortion in the prompt neutron decay exists. There is also evidence of some negative distorting mechanism. This distortion looks much like a preamp-amplifier disabling effect that has been observed in other pulsed experiments at SRL with similar source and detector systems. If this is evidence of disabling, the analyzed k values will be high because some of the prompt neutron response will not be counted.

In the second time domain, between 0.6 and about 1.4 msec, a reasonably exponential decay exists. Ordinarily one would expect this decay to be the prompt neutron fundamental mode of decay and to tail off into a sum of the background and delayed neutron level. This identification is complicated by the existence of a third time domain which consists of a much longer lived but low amplitude decay superimposed on the background and delayed neutrons. This region extends out to about 12 msec. The decay constant in this region is much greater than the well known decay constants for delayed neutrons and thus must originate from some other source. Finally, the fourth time domain beyond 12 msec seems to be a

relatively cleanly defined sum of the background and delayed neutrons. However, the long-lived decay could also extend into the fourth domain but be masked by the large scatter.

EXPLANATION OF TIME DOMAIN III AS "ROOM RETURN"

In principle, the room return problem arises whenever the object to be pulsed is enclosed in a space surrounded by neutron-reflecting walls. In the case of the Z-9 crib the neutron-reflecting walls would be the concrete roof slab and the sloping earthen walls of the crib. A rough estimate of the decay characteristics one would expect for the room return of the crib is obtained as follows:

The average distance from the source-detector region to the walls of the crib is about 10 meters. The transit time of the 14 MeV source neutrons to the walls is essentially zero. The thermalization and escape of the neutrons from the nonmultiplying walls and ceiling is also accomplished in a time interval small compared with the time scale of time domain III. Hence, it can be assumed that a Maxwellian distribution of thermal neutrons with a most probable velocity of 2200 m/sec exists at the average wall 10 meters away from the detector at time t = 0.

It can easily be shown that the detector would record neutrons from this distribution with a time variation given as

$$N(t) + C_1 \, t^{-2} \, e^{-\left(\frac{4.55 \times 10^{-3}}{t}\right)^2}$$

where C_1 is a constant. If this function is plotted, the variation in the region from 4 milliseconds to 12 milliseconds looks very much like a simple exponential function with time variance given by

$$N(t) \approx C_2 \, e^{-(0.16 \times 10^3)t}$$

where C_2 is another constant. That is, the decay constant is about -0.16×10^3 sec^{-1}.

The data of time domain III has been analyzed to extract an average decay constant assuming that it consists of an exponential decay superimposed on a constant sum of background and delayed neutrons from the crib floor. The experimental decay constant thus determined is about -0.24×10^3 sec^{-1}. When the crudeness of the theoretical arguments leading to the -0.16×10^3 sec^{-1} value is considered, the agreement with the experimental value of -0.24×10^3 sec^{-1} provides reasonable evidence that time domain III is indeed displaying the room return phenomenon.

The magnitude of the room return neutrons relative to the prompt neutrons from the fissionable material in the crib floor can also be roughly estimated. From geometrical considerations and an estimate of the number of thermal neutrons leaving the walls as thermally moderated neutrons, one would expect the ratio of the total (integrated) number of room return neutrons to the total number of prompt neutrons seen by the detector to be about 10^{-3}. From the measured data the ratio appears to be about 10^{-2}. The total discrepancy of a factor 10 remains unexplained. Part of the explanation would appear to be due to a loss of measured prompt neutrons caused by detector disabling. Further experimental studies and more sophisticated calculations would be required to satisfactorily resolve the discrepancy.

k_{eff} VALUES DERIVED FROM THE UNPOISONED CRIB DATA (7/26/73)

The PULSUB code was used to reduce and analyze the data. This code presupposes the existence of a source-induced

prompt neutron buildup and decay superimposed on a constant sum of background and delayed neutrons. The analysis was complicated by the existence of the long-lived decay beyond what appeared to be the prompt neutron response of the plutonium-containing soil. If this long-lived decay is considered to be a "room return", two different characterizations of the return lead to two different reactivity results.

1. Room Return Abruptly Ending by Channel 300

The analysis used the data between Channels 16 and 40 to find the fundamental mode prompt neutron decay constant (by Peierl's method[2]). The data beyond Channel 300 was assumed to consist only of a constant background and delayed neutrons and was used to establish the delayed neutron level. The $\$$ value was

$$\$ \text{ Gozani}^1 = -117$$

and the prompt neutron decay constant was $\lambda = -0.35 \times 10^4 \text{ sec}^{-1}$.

Under the assumption that the room return has abruptly ended at Channel 300, the subcritical reactivity was

$$\rho = \$ * \beta = -0.246 \text{ where } \beta = 0.0021.$$

$$\therefore k_{eff} \simeq \frac{1}{1-\rho} = 0.80.$$

2. Room Return Exponentially Extrapolating into Time Domain IV

We consider the above assumption to be an unlikely characterization of the room return. A more likely characterization is that the decay is nearly exponential as

[2] R. Peierls, "The Statistical Error in Counting Experiments," Proc. Roy. Soc., A149,467 (1955).

discussed in the Section "Explanation of Time Domain III as 'Room Return'". Time domain IV would then have three types of contributions: background, a small room return, and an even smaller delayed neutron level. Without extrapolating the room return data into time domain IV, as in section (1), the delayed neutron level appeared to be about 2.2 counts per channel above the background. With extrapolation of the room return, the delayed neutron level was reduced to about 0.5 counts per channel. The ∅ Gozani value is inversely proportional to the delayed neutron level. Hence the ∅ Gozani value whould be corrected in the ratio of 2.2/0.05 to

$$\text{∅ Gozani} = -525.$$

$$\therefore k_{eff} \simeq 0.48$$

RAW DATA FROM THE POISONED CRIB MEASUREMENTS (8/17/73)

Figure 2 shows a plot of the poisoned crib pulsed data. Again before 0.6 msec there is strong evidence of both prompt harmonics and some other unexplained distortion (probably detector saturation effects). Between 0.6 and 1.4 msec a reasonably exponential decay exists and these data are considered to be the prompt neutron decay. What would appear to be room return exists out to the neighborhood of 20 msec. Beyond that time, the data appear to be relatively flat.

k_{eff} DERIVED FROM POISONED CRIB DATA (8/17/73)

1. Room Return Abruptly Ending in Channel 300

The PULSUB analysis used the data between Channels 8 and 18 to find the decay constant. Under the assumption that room return was ended by Channel 300 (24 msec), the Gozani analysis showed

$$\not{\delta}\ \text{Gozani} = -1432$$

and

$$\lambda = -0.41 \times 10^{4}\ \text{sec}^{-1}.$$

Uncorrected for room return extrapolation beyond Channel 00, the reactivity is

$$k_{eff} = 0.25$$

2. Room Return Exponentially Extrapolating into Time Domain IV

With exponential extrapolation of room return beyond Channel 300 the delayed neutron level is reduced from 0.12 counts per channel to 0.10 counts per channel. The corrected reactivity value is

$$k_{eff} = 0.22.$$

The assumption of section (1) about the nature of time domain IV has not led to much error in this analysis. The reason is that the channel width has been doubled, thus twice as much time has elapsed by Channel 300 in the poisoned crib experiment as in the unposoned crib experiment. Thus, the room return contribution is smaller under the exponential extrapolation assumption.

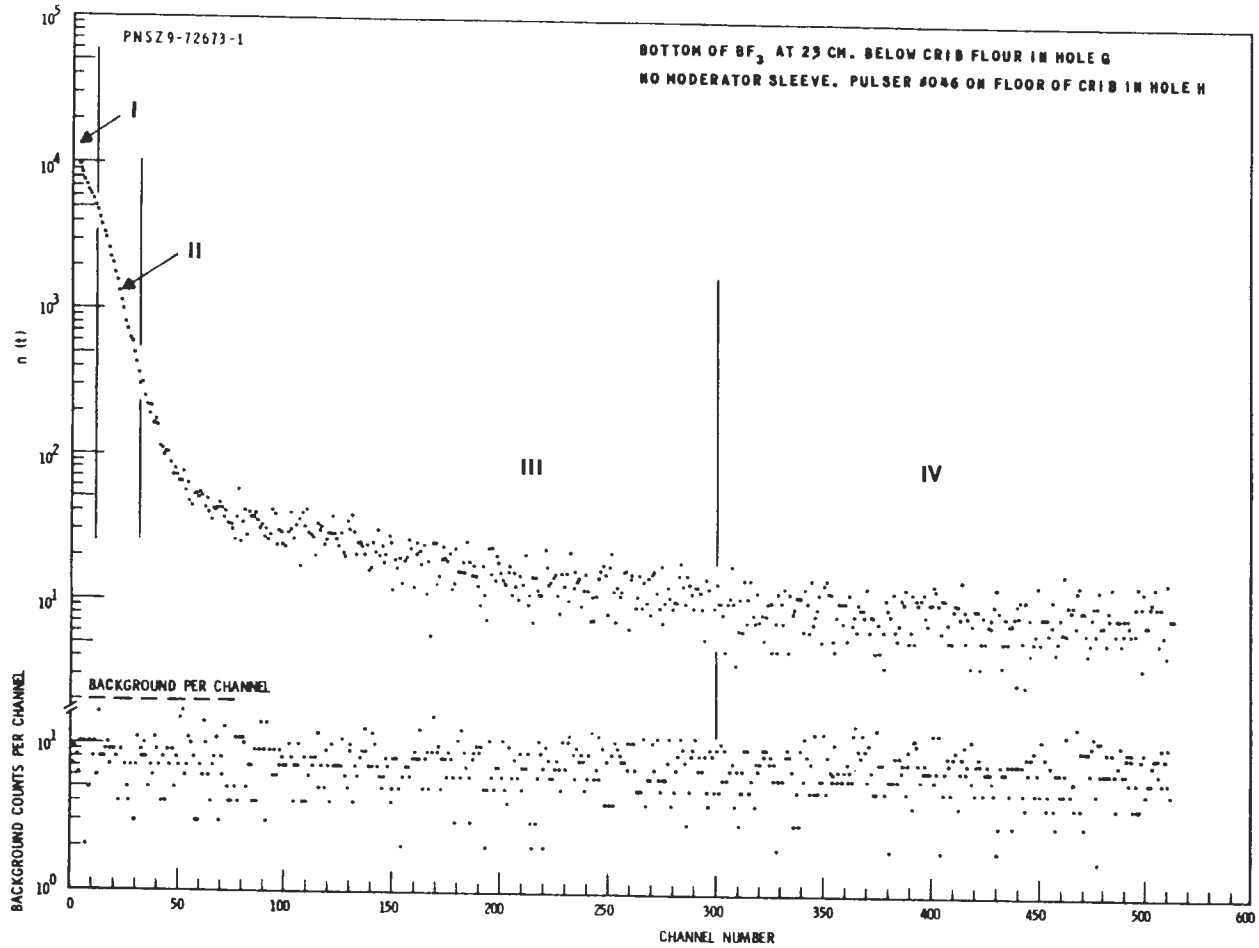


FIGURE 1

PULSED NEUTRON MEASUREMENT OF UNPOISONED 216-Z-9 TRENCH

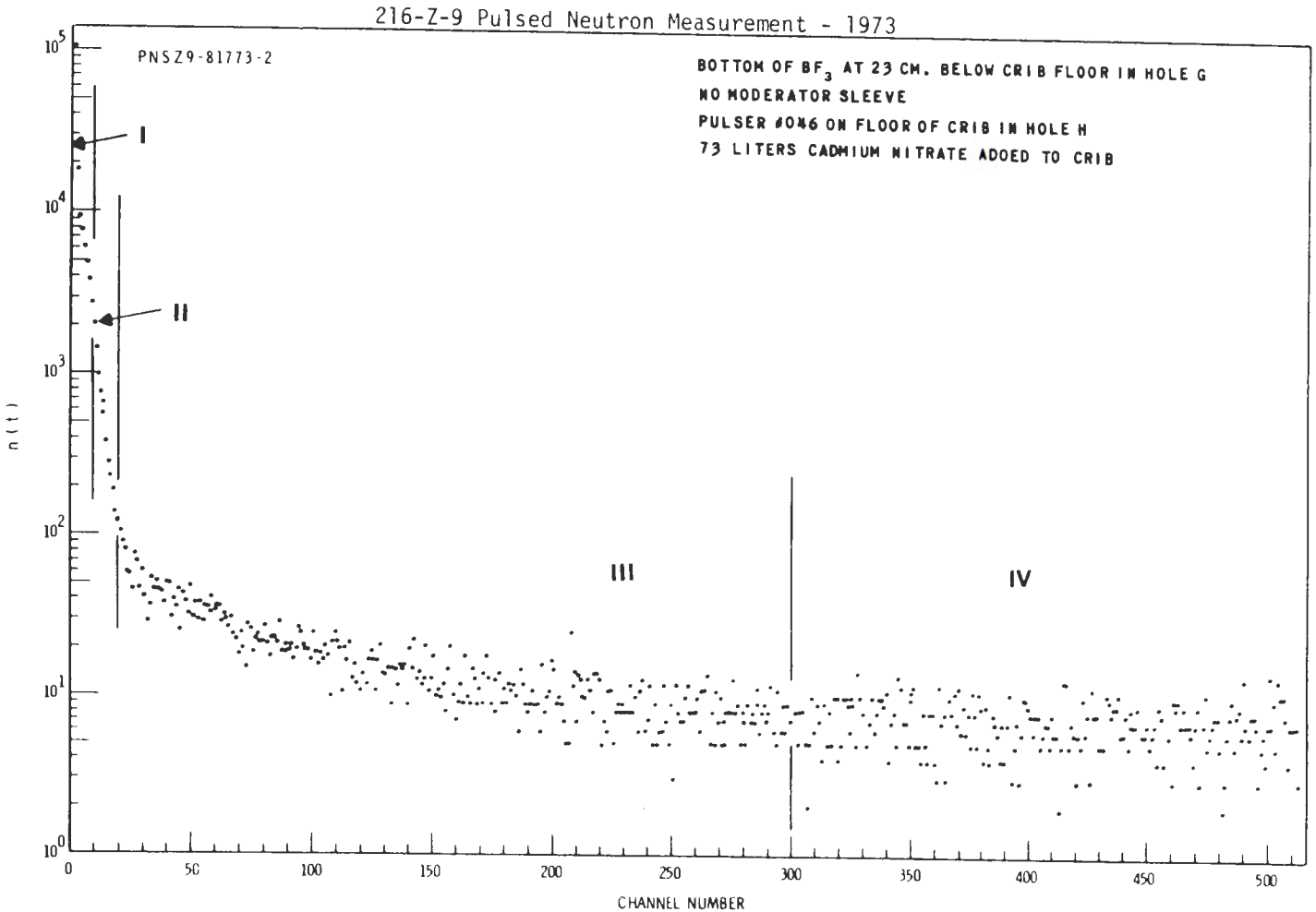


FIGURE 2

PULSED NEUTRON MEASUREMENT OF POISONED 216-Z-9 TRENCH

APPENDIX Q

LOS ALAMOS SCIENTIFIC LABORATORY ANALYSIS OF BATTELLE PACIFIC NORTHWEST LABORATORIES' 216-Z-9 ENCLOSED TRENCH PULSED NEUTRON MEASUREMENTS

D. R. Smith

COPY

UNIVERSITY OF CALIFORNIA
LOS ALAMOS SCIENTIFIC LABORATORY
(CONTRACT W-7405-ENG-36)
P. O. Box 1663
Los Alamos, New Mexico 87544

IN REPLY
REFER TO: P-5-110 October 2, 1973

Mr. Oscar J. Elgert
U. S. Atonic Energy Commission
Richland Operations Office
P. O. Box 550
Richland, WA 99352

Dear Mr. Elgert:

The pulsed neutron data obtained by Battelle at the Z-9 trench have been reviewed. We do not believe these data support any definitive statement as to the value of the neutron multiplication factor (k_{eff}) associated with this trench. The tail of the curve obtained might be interpreted as representing delayed neutrons, but we believe a significant portion of the neutrons involved are attributable to die-away of the pulses. This view is supported by the observation of similar die-away in pulsed data obtained in one of our facilities and reported in the attached memorandum.

We concur with an interpretation which concludes that the value of k_{eff} prior to introduction of cadmium nitrate did not exceed 0.5, and that after cadmium was added the value was less than 0.3. Although we are unable to assign a lower limit to either of these values, the data are

COPY

still useful for demonstrating that no nuclear criticality safety problem exists.

Sincerely,

G. E. Hansen (signed)

G. E. Hansen

H. H. Helmick (signed)

H. H. Helmick

David R. Smith (signed)

D. R. Smith

DRS:af

Enclosure: Memo dated 10/2/73, Pulsed Neutron Die-Away Measurment

C: R. D. Baker, CMB-DO
H. C. Donnaly
F. P. Baranowski
H. J. Blackwell
G. E. Hansen, P-5
H. H. Helmick, P-5
D. R. Smith, P-5
Mail & Records, 2
P-DO file

COPY

LOS ALAMOS SCIENTIFIC LABORATORY
UNIVERSITY OF CALIFORNIA
LOS ALAMOS, NEW MEXICO 87544

OFFICE MEMORANDUM

LASL-AEC-OFFICIAL

TO : D. R. Smith, P-5 Date: October 2, 1973

Geh/af (signed) HHH (signed)
FROM : G. E. Hansen and H. H. Helmick, P-5

SUBJECT: Pulsed Neutron Die-Away Measurement

SYMBOL : P-5-118

As a result of our earlier discussion with you concerning your interest in the Hanford Z-9 crib we have performed a neutron die-away measurement that may be of some help to you in assessing the data obtained at Hanford.

Our measurement was simply a standard die-away observation performed by placing an array of ten BF_3 counters one meter from a three-surface concrete reflector, producing a short pulse of 14 MeV neutrons in the vicinity and observing the neutron count rate as a function of time after the pulse. The concrete reflector was the corner of a room whose walls are 18 inches thick and floor is 8 inches thick. The room is 36 feet by 78 feet and 34 feet high. The pulsed neutron source is a commercial device utilizing the D-T reaction and produces about 10^7 neutrons in a pulse of 4 μsec duration.

A 512-channel time analyzer was used to record counts from the ten BF_3 counters connected in parallel. The width of the time channels was 512 μsec and the first time channel opened 0.1 μsec after the end of the neutron pulse. At the end of the time sweep (262 milliseconds) the neutron pulse generator was triggered again and the data storage sequence repeated. This process was repeated until 9234 counts were obtained in the first time channel, the first point plotted on the accompanying graph. Error bars have been applied to the sixth point and the last point to indicate the degree of statistical uncertainty across the plot.

COPY

Although points are only plotted out to 17.93 milliseconds, data was averaged over the interval from 102.4 ms to 204.8 ms and the bar at 32 counts/512 μsec shows the equilibrium background rate obtained.

We would be most happy to discuss details of this measurement further if this would be of additional benefit to you.

GEH:HHH:af

Enclosure for P-5-110

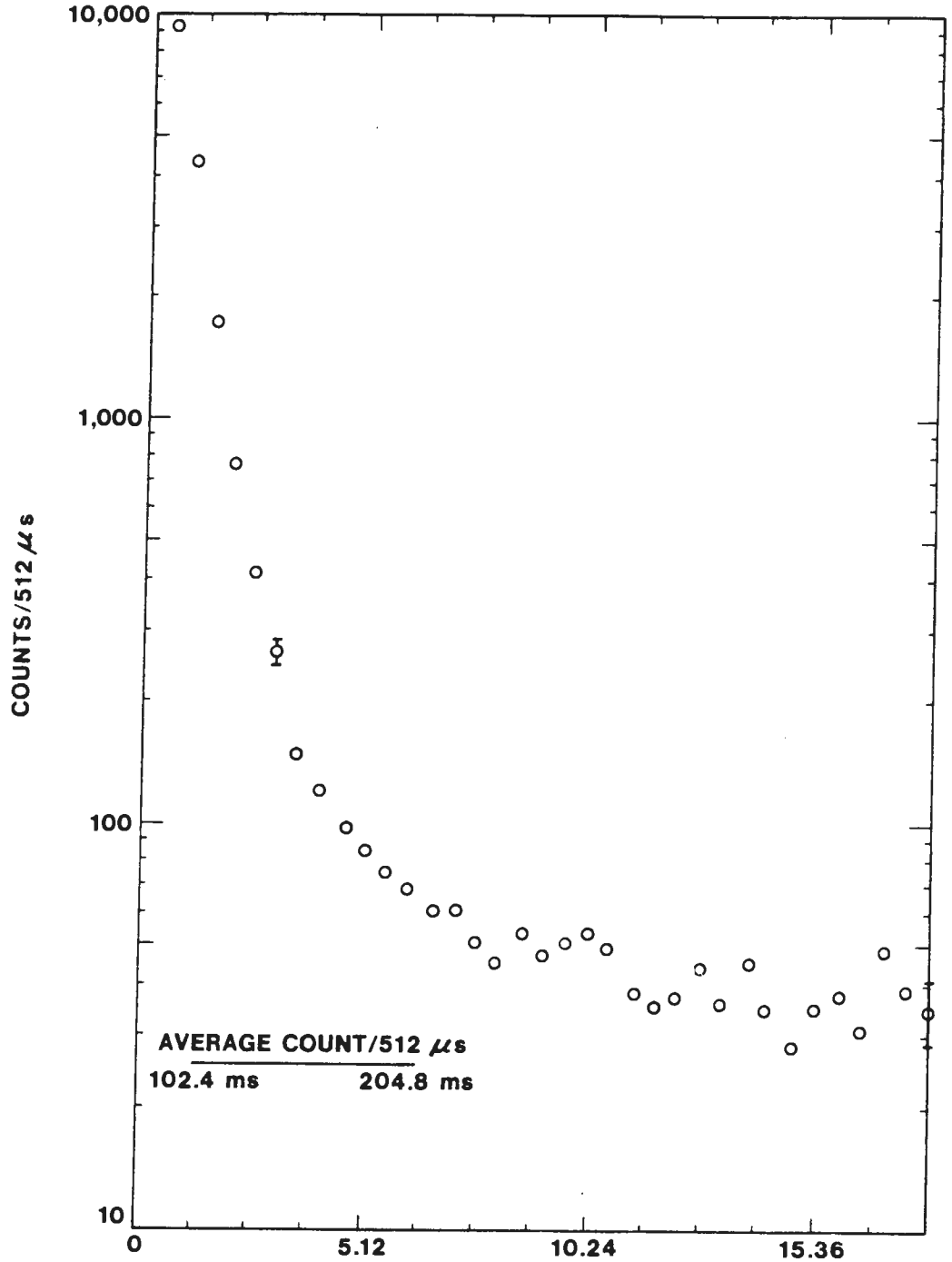


FIGURE 1

NEUTRON COUNT RATE DIE-
AWAY VERSUS TIME AFTER NEUTRON PULSE

V7312-10.60

APPENDIX R

SAVANNAH RIVER LABORATORY EVALUATION OF 216-Z-9 ENCLOSED TRENCH CHARACTERIZATION STUDIES OF 1973

R. M. Wallace

USR 24-A116
REV 1-72

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
ATOMIC ENERGY DIVISION
SAVANNAH RIVER LABORATORY
AIKEN, SOUTH CAROLINA 29801
TWX 810 771 2670 TEL 803 824 6131 WU AUGUSTA, GA.

CC: N. Stetson, SROO

September 28, 1973

Mr. O. J. Elgert, Director
Production and Waste Management
Programs Division
Richland Operations Office
U. S. Atomic Energy Commission
P. O. Box 550
Richland, Washington 99352

Dear Mr. Elgert:

Enclosed are copies of a report by P. B. Parks and N. P. Baumann, and one by myself, giving our evaluations of activities related to the Hanford Z-9 trench in CY 1973. These reports were requested in a teletype message from Alex G. Fremling to N. Stetson on September 21, 1973.

Very truly yours,

Richard M. Wallace

Richard M. Wallace, Research Associate
Separations Chemistry Division

RMW:jc
Encl.

INTRODUCTION

The Richland Operations Office of the USAEC requested an evaluation of the efforts of personnel from Atlantic Richfield Hanford Company and Battelle-Northwest Laboratory to characterize the 216-Z-9 Trench. This is a report of that evaluation.

The present characterization studies began as a result of pulsed neutron experiments that indicated the trench to be nearly critical. The purpose of the study was to obtain information by techniques other than pulsed neutron experiments to determine whether the trench was nearly critical. The primary concern was to obtain an accurate picture of the distribution of ^{239}Pu in the trench; however, analysis for other materials that might affect the moderation or absorption of neutrons was also considered important.

SUMMARY

The plutonium distribution in the top two feet (*61 centimeters*) is now known as well as it needs to be known for criticality considerations. Additional work on plutonium distribution in the upper two feet (*61 centimeters*) would be of marginal value; a study of the cadmium distribution after poisoning the crib would be of interest.

DISCUSSION

TECHNIQUES EMPLOYED

The techniques employed to estimate the distribution of plutonium in trench were:

- Infrared scan.
- Gamma ray survey.
- Neutron survey.
- Core sampling followed by analyses for plutonium.

Of these methods, the gamma survey and the core sampling gave the most detailed picture. A detailed map of the plutonium concentration within a few centimeters of the surface of the trench was derived from the gamma survey while the core sampling gave the vertical distribution of plutonium at a number of isolated points.

The infrared scan and the neutron survey yielded less detailed information about the plutonium distribution near the surface of the trench than did the gamma survey. These techniques, however, complement the gamma survey because they would indicate the existence of high concentrations of plutonium at greater depths.

A qualitative disagreement among these techniques would indicate that the gamma survey did not give a true representation of the distribution of total plutonium in the trench; agreement among the survey methods, on the other hand, would indicate that gamma survey and the core samples yielded an accurate picture of the horizontal and vertical distribution.

Core samples were analyzed for moisture, nitrate, chloride, cadmium, and TBP content, in addition to plutonium content. The pH, ion exchange capacity, and mineralogy were also studied as a function of depth. The moisture content is important because it affects the moderation of neutrons and is necessary for criticality calculations. Similarly, the measurement of cadmium content and ion exchange capacity are important because they reflect the amount of poison present before, or the amount that may be sorbed by the soil

after the trench was poisoned with cadmium nitrate. The other analyses are principally of interest because they might shed light on the mechanisms of plutonium sorption on the soil.

EVALUATION OF TECHNIQUES

The infrared scan should give qualitative information about the distribution of plutonium because the principal source of heat in the trench is ^{239}Pu, which generates heat at the rate of about 0.002 watt/gram. It is doubtful that an accurate concentration map of plutonium can be derived from the heat fluxes obtained by this technique because of difficulties in calibrating the scanner in the trench.

The gamma ray survey was performed with a sodium iodide detector. Since the trench contains considerable quantities of ^{241}Am in addition to ^{239}Pu, it is probable that the detector measures some of the gamma rays from the former in spite of efforts to discriminate against them. Nevertheless, the gamma scan should still give an accurate representation of the plutonium distribution because analysis of the core samples showed that the ratio of americium-to-plutonium was nearly constant in all samples.

The neutron survey was performed with ^{3}He and BF_3 counters, which should give an accurate measure of the neutron field at the counters. The neutrons in the trench are produced primarily by the spontaneous fission of ^{240}Pu and by an α,n reaction with ^{18}O contained in minerals in the trench; the α particles are, in turn, generated by plutonium isotopes. A survey of the neutron flux in the trench should therefore reveal the location of plutonium.

In the present study, neutron measurements were not made at a sufficient number of points to obtain as detailed a map

of the plutonium as was obtained with the gamma survey. Sufficient information was obtained in the neutron survey, however, to show the general location of the plutonium within the trench.

The core sampling of the trench was performed very carefully and extreme pains were taken to prevent cross-contamination of the samples. These samples therefore probably represent reliably the conditions actually existing in the trench.

The analyses for ^{239}Pu and ^{241}Am in the core samples were performed by gamma ray counting with lithium-drifted germanium detectors. These high resolution detectors are easily capable of distinguishing between ^{239}Pu and ^{241}Am, and when properly calibrated, as they were in the present experiments, are capable of analyzing each of them accurately.

Other analyses were performed by standard methods.

EVALUATION OF RESULTS

The maximum plutonium accumulation was found in the south half of the trench where surface concentrations varied from about 15 to 30 grams Pu/liter of soil. Most of the south half was in the range 15 to 25 grams Pu/liter of soil. Most of the north half of the trench was in the 1 to 5 grams Pu/liter of soil range.

Soil taken from the south half of the trench contained 0.3 to 3 grams Pu/liter of soil in the top six inches (*15 centimeters*) and 0.1 to 0.3 gram Pu/liter of soil at the 7- to 12-inch (*17.5- to 30-centimeter*) depth. The deeper samples near 8 feet (*2.4 meters*) contained 0.03 to 0.1 gram Pu/liter of soil. A more detailed study of the area of maximum concentration revealed the following vertical

distribution.

Depth	Gram ^{239}Pu/liter of Soil
0- 1 inch (0 - 2.5 cm)	13 -20
2- 3 inch (5 - 7.5 cm)	1 - 9
4- 6 inch (10 -15 cm)	0.1- 3
7- 9 inch (17.5-22.5 cm)	0.1- 0.8
10-15 inch (25 -30 cm)	0.1- 0.3

The infrared scan, the gamma survey, the neutron survey, and the core samples all showed that the bulk of the plutonium is in the south half of the Z-9 Trench. There seems to be no reason to doubt that the gamma survey gives the correct horizontal distribution and the core sample the correct vertical distribution of plutonium. Furthermore, the total amount of plutonium in the trench, calculated from these distributions, agrees fairly well with other estimates based on the amount of plutonium known to have been added to the trench.

Core samples collected and analyzed in 1963 appeared to contain higher concentrations of plutonium to a greater depth than samples taken from nearly the same location in the present study. The reason for this discrepancy is not yet clear. However, because of the larger number of samples taken in the 1973 study and the care taken in obtaining and handling them, the 1973 analyses are probably more reliable than those obtained in 1963.

ADDITIONAL COMMENTS

The few core samples that extended to eight feet (2.4

meters) indicated that after a depth of about one foot (*30 centimeters*), the plutonium concentration remained constant at about 0.1 gram/liter to the eight-foot (*2.4-meter*) depth. While this concentration is of no concern from a criticality standpoint, it is of environmental concern. Future programs should be directed toward finding how far plutonium extends under the trench.

APPENDIX S

LOS ALAMOS SCIENTIFIC LABORATORY EVALUATION OF 216-Z-9 ENCLOSED TRENCH CHARACTERIZATION STUDIES OF 1973

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IN REPLY REFER TO: CMB-11-9962

September 27, 1973

Mr. O. J. Elgert, Director
Production Programs Division
Richland Operations Office
United States Atomic Energy Commission
P. O. Box 550
Richland, Washington 99352

Dear Mr. Elgert:

In May, 1973, I was given a detailed briefing on the history of the Z-9 trench and the neutron pulse and sample data that indicated that a nuclear chain reaction might occur under certain conditions. At the same meeting Atlantic Richfield Hanford Company detailed the steps they had taken to evaluate the situation and the techniques that they planned to utilize to fully characterize the Z-9 trench. The final data were accumulated during the period May through August, 1973 and supplied to me at a meeting in September, 1973.

I have evaluated the chemical data and have arrived at the following conclusions:

1. In my opinion the techniques employed in taking and analyzing the 1963 samples would lead to erratic and erroneous results. My main objection was to the analysis of only a minute fraction of what was obviously a heterogeneous sample.

AN EQUAL OPPORTUNITY EMPLOYER

2. I believe that the later samples (those taken after the neutron pulse data had indicated a high K^{eff}) were not only taken more carefully, but were analyzed more accurately, section by section, by non-destructive techniques capable of an accuracy of at least ± 10 percent. The data from these soil samples indicated to me that the amount of plutonium in the trench was much nearer the value obtained from accountability records than the amount indicated by the data from the combination of neutron pulse measurements and the earlier soil samples.

3. It is my opinion that ARHCO personnel then used all feasible techniques, including additional soil samples, infrared photographs and gamma dose measurements of the entire trench floor, neutron scan of selected areas, and detailed examination of soil samples in an attempt to more accurately determine the actual amount and location of the plutonium in the trench. Further, that these measurements, photographs and analyses supported my conclusion that the total amount of plutonium present was much less than what ARCHO told me was indicated by the combination of neutron pulse data and the data from analyses of the 1963 soil samples.

4. It is my belief that the addition of the cadmium nitrate was unnecessary, based on what I concluded was the amount and distribution of the plutonium present, but it should do no harm as far as trench characteristics are concerned.

5. I believe that ARHCO has ample data to assess the situation as to whether or not it is "possible to conceive of conditions which could result in a nuclear chain reaction" but that additional work must be done for general trench characterization for the sole purpose of waste management considerations. It is my understanding that ARHCO has also concluded that the amount of plutonium and the distribution of the

plutonium are such that a chain reaction could not occur with the plutonium in the existing configuration.

I hope these comments will aid you in evaluating the situation. Please let me know if you have any questions.

Very truly yours,

Eldon L. Christensen,
Supervisor
Plutonium Recycle Facility

ELC:arm

cc: R. D. Baker, CMB-DO
H. C. Donnelly, ALO
F. P. Baranowski, DPMM
H. J. Blackwell, LAAO
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