GEOLOGIC, CHEMICAL, RADIOMETRIC AND GEOTECHNICAL STUDIES OF SAMPLES FROM ELEVEN DRILLHOLES IN SURFICIAL MATERIALS, SAXTON NUCLEAR FACILITY, SAXTON, PENNSYLVANIA

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EXECUTIVE SUMMARY

This report presents the results of investigations conducted on material from 11 holes drilled to 24 inches depth at the SNEC Nuclear Facility near Saxton, PA using a split spoon auger drill. Five holes are within the fence of the Saxton Exclusion Area, and 6 are outside, the most distant being about 300 ft. northeast from this fence. The texture, color, lithology, mineralogy and other characteristics of the unconsolidated materials recovered by the drill were described at the site and each hole was divided into either three or four intervals of relatively homogeneous material. These 34 samples have been investigated by gamma spectrometry and particle size distribution. Selected samples were also analyzed chemically and mineralogically and subjected to a sequential selective extraction procedure and autoradiography. The goal of these analyses was to determine the distribution and chemical form of radionuclides in the surficial materials within and adjacent to the facility.

At most drill sites, the surficial layer is composed predominantly of fly ash, underlain by coal, bottom ash, crushed limestone or red clay in areas disturbed during activities related to the power plant, and by sand, silt and gravel in undisturbed areas. Of the two man-made radionuclides detected, ^{137}Cs was detected in 20 samples but ^{60}Co was detected in only 8 samples. Also detected in these samples were natural radionuclides (^{40}K and the U and Th series). In a few surface-layer samples ^{7}Be, formed by cosmic rays in the upper atmosphere, was seen. The ^{137}Cs is strongly concentrated in the top few inches in nearly all drill holes, and is undetectable at the bottom of the holes outside the Saxton Exclusion Area fence. In surface samples outside this fence ^{137}Cs does not exceed 1.0 pCi/g, with a median value of about 0.5 pCi/g. In these samples the ^{137}Cs may have originated almost completely from regional atmospheric fallout from nuclear weapons tests and the Chernobyl incident, although a component from the nuclear facility is not precluded. Activities of ^{137}Cs in these samples are far lower than activities of the natural radionuclides.

Activities of ^{137}Cs in surface layers from drillholes inside the fence all exceed 1.0 pCi/g, and reach 25, 8, and 4 pCi/g in holes FC-5, -1, and -6, respectively. Activities decrease downward but are still detectable in the bottom samples. In the three samples for which size fractions were counted, the activity of ^{137}Cs consistently increases with decreasing particle size, reaching a value of 13 pCi/g in the fraction finer than 0.1 mm in sample FC-1, which consists mainly of fly ash. However, because of the larger amount of mass in the fine sand-size fraction for this sample, 39 to 57% of the total ^{137}Cs activity was found to be in the fine sand-size fraction (composed mainly of fly ash particles but with subordinate particles of natural materials). Selective extractions for two fly ash-rich samples from within the fence show only 12 to 14% of the ^{137}Cs is in the exchangable, organic and Fe-oxide fractions, and only an additional 11 to 34% is extracted by concentrated nitric acid. The remaining 53 to 75% of the ^{137}Cs remains in the residual fly ash-rich solids in the sand and silt/clay fractions. Autoradiographs for several samples show no obvious highly radioactive grains.

Based on this data the ^{137}Cs could be in the following possible forms:

1. Strongly adsorbed in the edge or wedge sites of the clay mineral illite, which occurs as a minor component of the fly ash-rich surficial material. Illite is known from investigations in other localities to concentrate and strongly bind cesium.

2. Strongly adsorbed in the devitrified glass of the fly ash particles making up the bulk of the more ^{137}Cs-rich samples.

It is very likely that some Cs occurs in both these forms, but the relative proportions are not known. The low ^{137}Cs in fly ash from sites just outside the fence is not consistent with the hypothesis that Cs was incorporated in the fly ash by burning radioactive material in the coal-fired plant.

INTRODUCTION

GPU Nuclear, the operator of the SNEC Experimental Station at Saxton, PA, is assessing the station for eventual decontamination and decommissioning. The surfical material covering many areas of the site appears to be fly ash, and was found to contain low levels of radioactivity. The main purpose of the work reported here is to evaluate the nature, distribution and origin of the radioactivity in this surficial material.

Previous tests had suggested that the radioactivity was confined to the site and that the radionuclides were very strongly bonded to the fly-ash material. The work reported here was intended to answer the following questions:

1. What radionuclides are present in fly ash, soils and unconsolidated materials of the Saxton Facility and vicinity?

2. What is the concentration and areal distribution of fission-generated radionuclides in surficial materials of the Saxton site and immediate vicinity?

3. What is the depth distribution of the radionuclides?

4. In what type of material (fly ash, soil, alluvium, etc.) do the radionuclides occur?

5. In what chemical and mineralogical form do the radionuclides occur in the surficial materials?

6. What is the distribution of radionuclides among particle size fractions?

7. What is the composition and nature of the fly ash?

8. What are the geotechnical properties of the materials?

In order to evaluate these questions, 11 two-foot holes (FC-series) were drilled with a split-spoon auger. The material from each hole has been described in terms of type and character of material. The material has been divided into 3 or 4 units with depth and analyzed for radionuclides by gamma spectrometry. Grain size has been determined, and gamma spectra have been accumulated on size fractions for 3 samples. Six samples have been analyzed chemically for major elements. For two samples, the form of radionuclides has been investigated by a series of selective chemical extractions. Finally, autoradiographs have been made for several samples, to identify the types of particles that are radioactive.

At the same time as the above-described FC-series of holes was drilled, six deeper holes (T-series) were drilled to investigate deeper materials. The results of these deeper holes have been discussed in a separate report (Rose and Jester, 1988), but the results have been incorporated into this report where relevant, as has the earlier drilling by Ground/Water Technology (1981) and verbal reports by GPU personnel.

HISTORY AND DESCRIPTION OF SITE

The Saxton location was originally the site of a coal-fired power plant. The Saxton Nuclear Experiment Facility (SNEC) was inaugurated in 1962. A small (7 MW) nuclear reactor and associated facilities was constructed and used to test various procedures planned for large-scale nuclear power plants. Steam from the nuclear plant was used to power a turbine in the coal-fired plant. The SNEC facility operated until April 1972, when it was deactivated. The facility was partially decommissioned in 1973-74; the decomissioning included removal of the spent resin and liquid waste tanks and other major sources of radioactivity outside the containment building. In October 1974, the coal-fired plant was closed and later completely dismantled. The coal plant operated only during periods of heavy electrical demand from 1970 to 1974.

Within the past two years, the nuclear facility has been further decontaminated with the intent of eventual complete decommissioning of the site and cessation of its nuclear status. Radioactivity in the buildings and ground has been surveyed and largely removed. A preliminary ground water study was conducted in 1981 by Ground/Water Technology, Inc. of Denville, N.J.

The site is located on a gently sloping area 0.8 mile north of Saxton on the flood plain of the Raystown Branch of the Juniata River (Figure 1). A small tributary stream, Shoup Run, forms the south boundary of the area used for the coal-fired plant, and the Raystown Branch approximately limits the west and north sides. Steeper slopes define the east edge. This area of 1800 x 1200 ft. was cleared prior to 1951 and has been used for coal storage, ash storage and plant construction. Air photos taken in 1951, 1958, 1966, 1967, 1977 and 1981 show a complex history of coal and ash storage and redistribution at the site. During this sequence of events, surface materials were redistributed and disturbed in many localities.

Two substantial buildings remain outside the Nuclear Facility, used by regional maintenance crews of GPU. Within this area, a fenced area of 260 x 210 ft. encloses the SNEC Facility (Figure 2,3), and an additional fence separates the containment area from the larger part of the SNEC Facility.

The Saxton area receives precipitation averaging 37.9 in. per year (Environmental Data Service, 1987). The most common wind direction for the region is from the west (Climate Atlas of the U.S., 1968). Natural vegetation is deciduous forest, but the site has been cleared and now supports grass and locally small trees. The fenced containment area and some other parts of the Nuclear Site have been seeded in vetch.

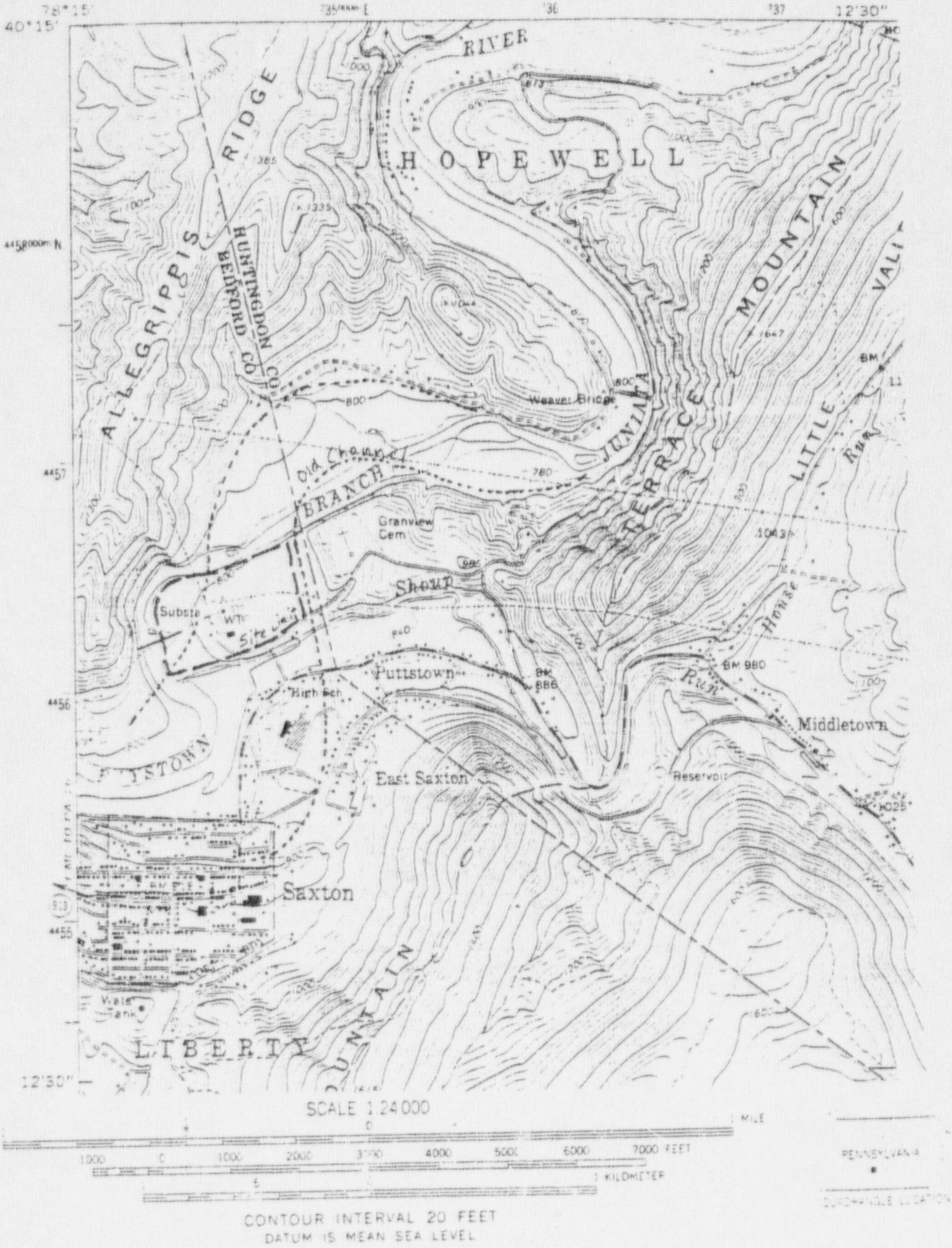


Figure 1. Section of U.S.G.S. topographic map (Saxton Quadrangle, 1:24,000 scale, 1968) showing site and former channel of Raystown Branch.

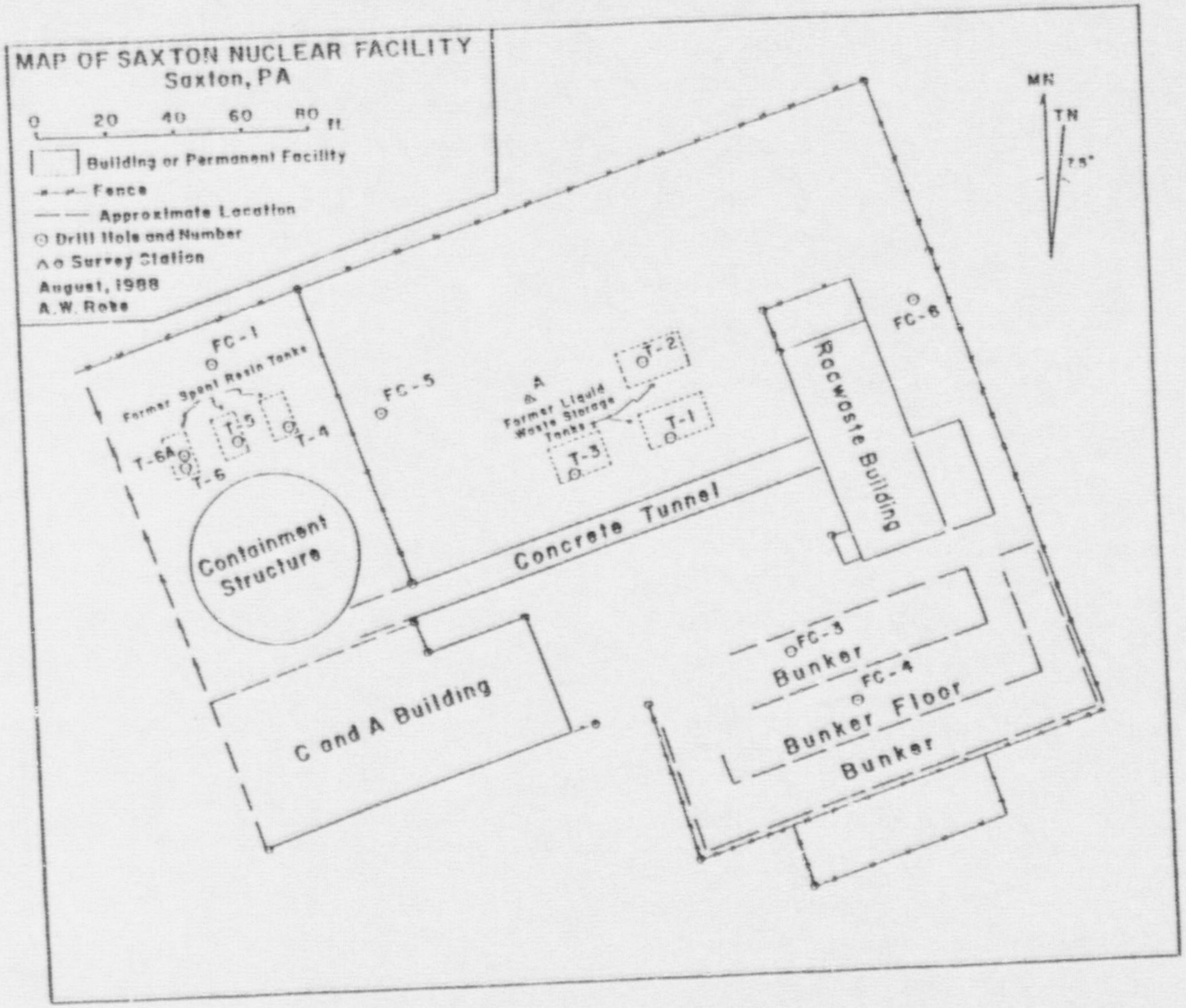
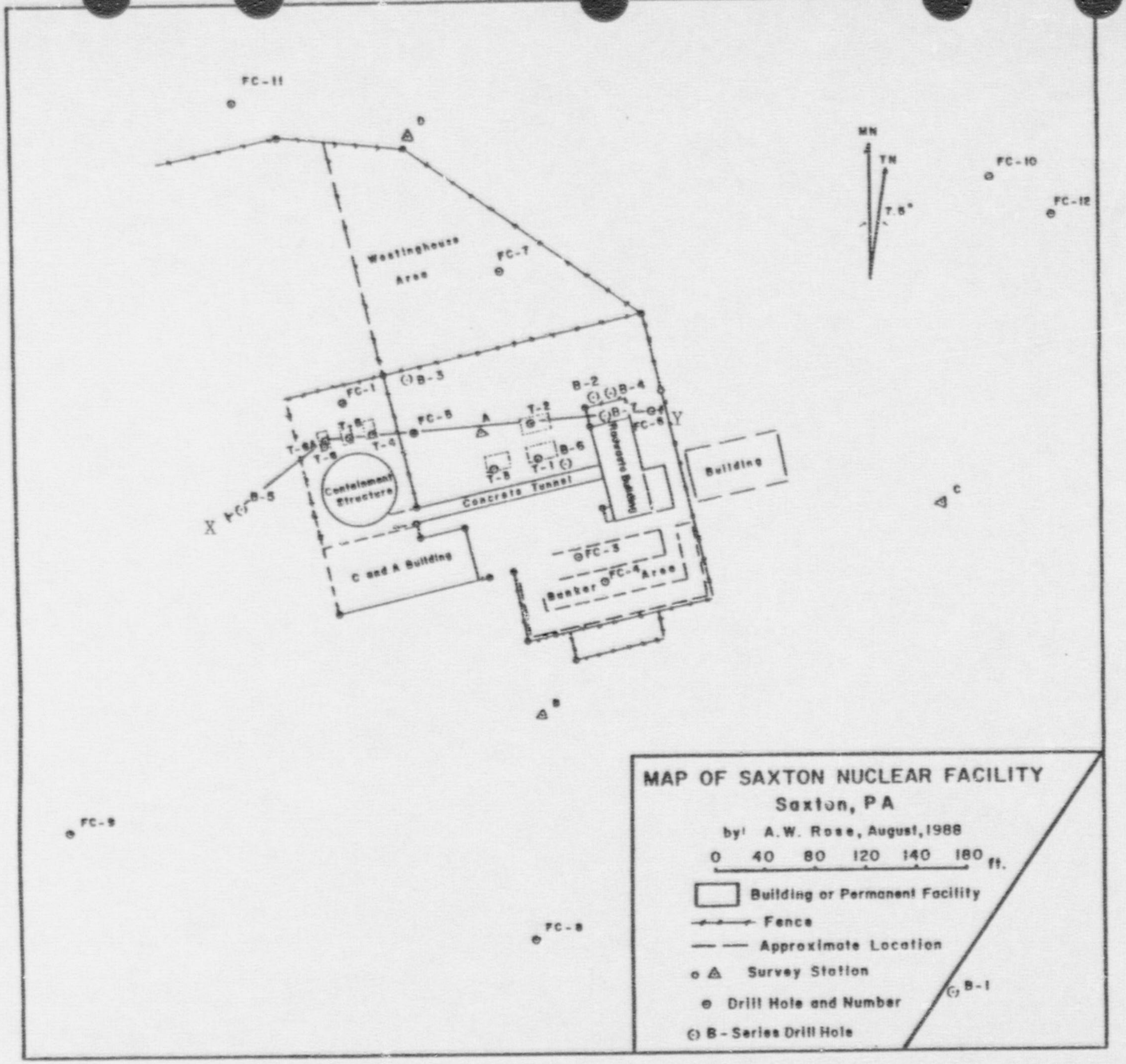


Figure 2. Reduction of plane table map of Saxton Nuclear Facility, showing drill holes within the site.



3. Reduced map of Saxton Nuclear Facility and vicinity, showing drillholes of the T-series, B-series, and F.C.-series. Locations of B-series holes are approximate.

GEOLOGY AND NATURAL SURFICIAL MATERIALS AT THE SITE

Devonian Catskill and Foreknobs Formations

The bedrock underlying the site is assigned by the Pennsylvania Geological Survey to the Devonian Foreknobs Formation (Figure 4). This unit has also been called a lower member of the Devonian Catskill Formation (Williams and Slingerland, 1986), and will be denoted as Catskill Formation in this report. The Foreknobs/Catskill Formation is characterized by interlayered red, gray and green sandstones, siltstones and mudstones. The rocks are generally resistant and well lithified.

The Foreknobs or lowermost Catskill Formation has been described as follows by Williams and Slingerland (1986):

"After the first establishment of nonmarine conditions, the sedimentary pattern of the Irish Valley Member of the Catskill Formation (upper Foreknobs Formation) in the southern and central part of the study area is characterized by many (about 15-20) cycles consisting of repeated alternations from marine sandstone and shale to nonmarine siltstone and silty sandstone which were produced by repeated lateral shifting of the shoreline. The thickness of each cycle varies from 2 to about 27 m. These cycles begin with greenish-gray, fossilferous, clean, sub-parallel laminates overlain by bioturbated, fine-grained sandstone of variable thickness representing a marine transgression, pass upward through a marine shoaling phase and an intertidal transitional phase, and finally grade into a nonmarine phase representing coastal-plain aggradation (Figure 37). The marine shoaling phase of each cycle commonly starts with gray-green to olive-green, fossiliferous shale and silty shale which grades upward to thin-bedded olive-green and chocolate-brown, fossiliferous and bioturbated shaly siltstone occasionally interlayered with thin layers of gray-green, very fine-grained, fossiliferous, micro-cross-ripple-laminated sandstone. The shoreline of this marine shoaling phase is

Figure 4. Geological map of Saxton quadrangle (after PA Geol. Survey).

represented by usually thin (1-2m), olive-green, fine-grained moderately sorted, sub-parallel to flaser- and lenticular-laminated, fossiliferous, quartzitic sandstone. The transitional part of each cycle usually consists of interlayers of green, chocolate-brown, and red siltstone, shaly siltstone, and thin (1.5-3 m), fine-grained, clean, well-sorted, quartzitic sandstone."

Rocks at the eastern edge of the Saxton coal-fired facility are underlain by the Sherman Creek member of the Catskill, described as follows by Slingerland and Williams (1986):

"Upward-fining cyclicity of fluvial origin is the common characteristic of the other 2 members of the Catskill Formation (the Sherman Creek and Duncannon Members). An ideal cycle consists of a basal brownish-gray to red, fine- to very fine-grained, micaceous, crossbedded sandstone with occasional plant fragments at its base and lenses of carbonate nodules and shale chips. This sandstone occupies a channel or irregular erosional surface cut into the underlying cycle. This sand body grades upward to red to reddish-gray, very fine-grained, silty sandstone, red siltstone, and silty shale which represents the levee-overbank portion of a meandering-channel facies."

Red siltstone-mudstone from this unit appears to have been quarried for use as fill at the SNEC site.

The minerals comprising the sandstones and shales of the Catskill Formation are quartz, illite (clay), hematite (in red units), chlorite (most abundant in gray and green units) and possibly minor feldspar. The hematite, illite and chlorite would be moderately adsorptive for many dissolved heavy elements, and would tend to inhibit dispersion of radionuclides. The grains of sand, silt and clay are poorly sorted, the sand grains being set in a matrix of clay-sized material. As a result, permeability of these rocks is generally low unless well fractured. Ground/Water Technology (1981) obtained permeabilities ranging from 1×10^{-3} cm/sec to 6×10^{-5}cm/sec in this bedrock. Such values are low but would allow some flow.

The rocks of the area occupy the northwest limb of the Broad Top Synclinorium. They strike about N 30°E and dip 20 to 40°SE. The rocks are cut by a moderate number of fractures both parallel to and across bedding.

Mississippian and Pennsylvanian Rocks

To the east of the Saxton site, the ridge of Saxton and Terrace Mts. is held up by the Mississippian Rockwell and Pocono Formations, predominantly sandstones. Above these are sandstones and shales of the Mauch Chunk and Pottsville Formations, and the coal-bearing Allegheny and Conemaugh Series. Detritus from these units has been carried down Shoup Run and the Raystown Branch to form (along with detritus from the Catskill Fm.) the unconsolidated gravels, sands and silts along the flood plain of the Raystown Branch, and the alluvial fan of Shoup Run. Mineralogy of these rocks and detrital materials is generally similar to the Catskill Fm.

Older Alluvial Deposits Along Raystown Branch

Inspection of the topographic map (Figure 1) in conjunction with drilling results of this investigation and that of Ground/Water Technology suggests that at some time in the past, probably in the Pleistocene, Raystown Branch occupied a different position that cut across the Saxton site (see Figure 1). During and after this time, the river deposited "boulder clay" overlain by silty sandstone and local gravel. Based on logs of holes reported by Ground/Water Technology, about 10 ft. of this alluvium is present, the lower 2 to 5 ft. being sandstone boulders in a clay matrix, and the upper 5 to 8 ft. being various combinations of gravel, silty sand, and sand (Figure 5). This material was evidently excavated, along with some bedrock, down to depths of about 15 to 20 ft. at the localities drilled in this study, where tanks for radioactive waste storage were emplaced.

The deposits at the natural surface in the area of the nuclear site (i.e., holes FC-7, 10, 12, Figure 3) are very sandy and do not appear to have undergone much soil development, other than accumulation of an organic-rich A horizon.

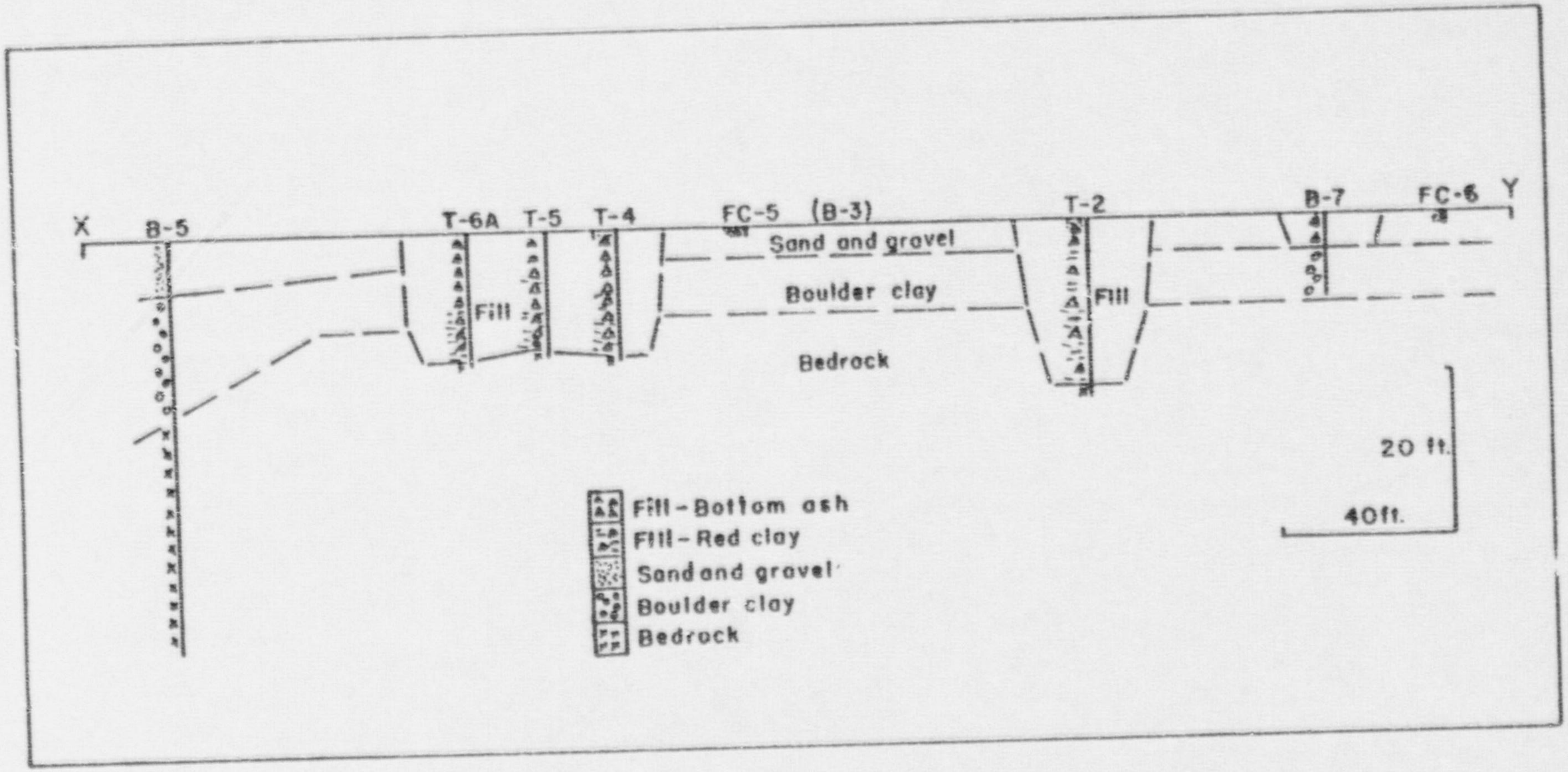


Figure 5. Cross-section showing inferred relations of surficial materials at the Saxton Nuclear Site, based on drillholes.

MATERIALS ORIGINATING FROM COAL-FIRED AND NUCLEAR POWER PLANT ACTIVITIES

Coal

During the operation of the coal-fired plant, coal, probably mainly from the Broad Top Field just to the east, was stored in piles at various locations on the site. The coal of the Broad Top Field is a relatively high-rank bituminous coal. Based on air photos of various dates, the coal was evidently dumped into piles, then picked up and moved to the coal-fired plant. Subsequently, parts of the site were smoothed with a dozer, so that patches of coal near the surface are probably common at the site.

Bottom Ash

Bottom ash and slag are the incombustible products of coal combustion that accumulate in the firebox and must be periodically removed. Particle sizes are typically a few millimeters to about 10 cm. Most of the bottom ash has a rounded to clinkery appearance, and is glassy on fractures, but some is evidently relatively unfused shaly partings and other naturally refractory materials. The ash is typically a silicate material, derived from the clay and other mineral impurities in the coal.

At least some bottom ash at Saxton appears to have been temporarily stored at the NE corner of site, based on the aerial photos. Considerable areas of the site near the former coal plant have a surface layer of bottom ash, evidently spread out after closure of the coal-fired plant.

Red Siltstone and Clay Fill

The T-series drillholes of this investigation indicate that a layer of fill composed of red siltstone and red clay was placed on top of bedrock in the areas where the spent resin and waste tanks were located. This fill was probably obtained from a small quarry in the Catskill Fm at the northeast edge of the site.

The material typically contains 50 to 90% red silty clay, probably originally red mudstone that has softened as a result of weathering, excavation, packing and exposure to moisture. From a few percent to 50% is harder fragments of red siltstone and occasionally buff sandstone, rarely larger than a centimeter in size. The fill is soft and easily drilled. Permeability appears to be low.

Fly Ash

Fly ash is the portion of ash that is small enough, in terms of particle size, to be entrained in the flue gas and carried away from the site of combustion (Roy et al, 1981). Fly ash particles are typically derived from the melting of mineral matter or the partial combustion of coal. In general, 70 to 80% of the solid waste derived from combustion of coal is fly ash. Fly ash is typically silt sized (2 to 62 μm) with a floury to fine granular texture but some fly ash at Saxton has a particle size of 1 mm or more. A wide range of particle shapes and types is reported, from spherical to angular, and translucent to opaque.

At present-day powerplants the fly ash is generally collected from the flue gases, but evidently during operation of the Saxton Plant, this was not done, because fly ash covers most of the less disturbed surface in and around the Nuclear Facility, to a depth of 1 to 4 inches. The fly ash at this site is generally black and covers the surface, but in a few holes (FC-6, FC-8. FC-9, T-2, T-3) layers of fly ash were covered with fill of various types.

Fly ash at Saxton is described in more detail later in this report.

Concrete and Crushed Stone

In two drillholes (T-4, T-5) a layer of concrete several inches thick lay on top of the bedrock and was covered by red clay fill. In one of these holes, reinforcing bars were cut in the concrete. Sand and crushed limestone accompanied the concrete and/or formed aggregate within it.

At sites T-1 to T-3, and FC-6, crushed limestone was present at or near the surface, possibly intended as a surface coating for a roadway or parking lot.

SELECTION OF DRILLSITES

Holes FC-1 to FC-12 were drilled mainly to investigate the fly ash, but also to test for contamination in other types of materials. Locations (Figure 2,3) and reasons for each hole are as follows:

FC-1. Located within the fenced containment area, north of the former site of the spent resin tanks. The intent was to sample a well-developed area of fly ash that might be contaminated.

FC-2. Not drilled.

FC-3. Located about half way up the north slope of the northern earthen bunker wall. This wall is about 10 ft. wide at the base and was constructed as a shield for temporary storage of drums of radioactive waste. The top few inches of this earthen bunker had already been removed because of detectable contamination. The hole was drilled to test for deeper contamination.

FC-4. Drilled in the center of the bunker area. An asphalt pavement was present. This pavement was largely dug out before starting drilling. The intent was to check for contamination beneath the bunker.

FC-5. Located near a drain along the fence separating the containment area from the rest of the Nuclear Facility. Slightly elevated radioactivity was reported near this drain. The intent was to test the possible extent of this contamination with depth, as well as to investigate the fly ash at this site.

FC-6. This site is to the northeast of the Radwaste Building, in a location appearing relatively undisturbed by activities since operation of the nuclear facility.

FC-7. Located about 100 ft. NE of the containment, outside the Nuclear Facility Fence, but within the "Westinghouse Area" fence. This area was evidently used on an intermittent basis for storage of supplies. The intent was to sample a relatively undisturbed layer of fly ash at a short distance from the Nuclear Facility.

FC-8. Located about 200 ft. south of the Nuclear Facility, outside its fence, about 25 ft. from a building now used for power line maintenance activities. This spot was detected as being slightly radioactive during a gamma survey of the area by GPU Nuclear Personnel (Gary Baker, pers. comm.) The intent of the drilling was to investigate the depth extent of the radioactivity.

FC-9. Located within the area of the coal-fired power plant. This plant was dismantled and the site has evidently been graded to a flat surface composed largely of bottom ash. The intent was to check the radioactivity level.

FC-10. Located 300 ft. NE of the Nuclear Facility, in an area that was probably used for storage of coal and/or ash, and which accumulated fly ash. The intent was to investigate the fly ash outside the Nuclear Facility.

FC-11. Located about 25 ft. north of the fence around the coal fired plant, about 200 ft. north of the Nuclear Facility. The intent was to investigate fly ash at this site outside the fence.

FC-12. Located near FC-10, and intended to investigate local variability and reproducibility of the surficial materials.

METHODS OF INVESTIGATION

Drilling

Drilling was done August 10 to 11, 1988 by Lambert Drilling of Bridgeville, PA using a truck-mounted drill. Driller was John Crockett.

The main part of the drilling was carried out with a hollow stem auger drill equipped with a split spoon sampler. The split spoon and bit had a diameter of 3 in. and a length of 24 in. It was driven with a 140 pound hammer, dropped 30 in. Blow counts are recorded in Appendix A.

Before each drill hole of the FC-series , the split spoon and bit was thoroughly scrubbed in soapy water and then rinsed in clean water to avoid contamination.

Sample Handling in Field

On removal from the hole the split spoon was scanned for radioactivity by GPU personnel. The split spoon was then opened and the half containing the sample was laid on a sheet of Kraft paper. A color photo was taken (see Appendix B) with a label specifying the hole and footage. The recovery of sample was measured to the nearest half inch. The core was then examined by Rose and divided into different types of material, which were measured and described on a geologic log (Appendix A), using a handlens and other field tools as necessary. The hole was divided into 3 or 4 depth ranges, based on type of material, with emphasis on fly ash. Each sample was then wrapped in Saran wrap and transferred to a core box.

Mapping

During the period of drilling, a plane table and telescopic alidade were used to construct a planimetric map showing the drilled location of all holes, plus buildings and fence lines in the Nuclear Site. The area within the Nuclear Site was mapped at 1 in. = 20 ft. (Figure 2), and the drillholes outside were mapped at 1 in. = 50 ft. (Figure 3).

Sample Preparation, FC-Series

The sample preparation procedure is listed in Table 1. In general, the procedure follows ASTM Standard Method D421-85 (Dry Preparation of Soil Samples for Particle Size Analysis and Determination of Soil Constants), and

Table 1.

PROCEDURE FOR PREPARING FC-SERIES 24" CORE SAMPLES, SAXTON PROJECT, FOR RADIOMETRIC AND SIEVE ANALYSIS

1. Weigh sample (in package, then weigh packing after next step).

2. Place on paper sheet, gently disaggregate large clods.

3. Dry in air for 2 days; stir up after 1 day. Shield to prevent dirt from falling into samples.

4. Weigh (air-dry weight).

5. Disaggregate by use of rubber stopper in mortar. Mortar should be cleaned by grinding quartz sand, washing with detergent, and drying before use.

6. Sieve sample on 4-mesh and 10-mesh screens; record weights of sample retained on 4-mesh screen, 10-mesh screen and passing 10-mesh screen.

7. If entire sample passes 10-mesh screen:
   a. split out sufficient material to fill 100 ml. tared beaker (100-200 g); record amount of sample used.
   b. label and retain remainder of sample for sieve analysis.

8. If entire sample passes 4-mesh screen:
   a. Split out sample retained on the 10-mesh screen and passing 10-mesh in amounts proportionate to weights of such fractions in the original sample such that a representative sample of 100-200 g is obtained.
   b. Thoroughly mix the two splits obtained above, add to tared 100 ml. beaker; record amount.
   c. Store remainder of sample as separate size fractions in labelled bags.

9. If sample contains material coarser than 4-mesh:
   a. Crush material retained on the 4-mesh screen to pass 4-mesh screen.
   b. To a tared 100 ml. beaker add split-out: crushed material; material originally retained on 10-mesh screen; and material passing 10-mesh screen in proportion to total sample (as in 8a.) so that a 100-200 g representative sample is obtained.

c. Mix, weigh, record and store as in 8b. and 8c.

Note: a. There were two samples where the hardness of material, retained on the 4-mesh screen, made crushing of that entire size fraction overly burdensome. As the coarse material was, in both cases, homogeneous (crushed limestone) only some of the material was crushed to pass the 4-mesh screen. The sample was then treated as in 9b.

b. There were a few samples in which the material retained on the 10-mesh screen either originally or after crushing of the 4-mesh fraction may not have met with ASTM requirements of sufficient weight to obtain meaningful splits. For particles having a nominal diameter of 3/8" (about 9 mm) the ASTM requirement is 500 g; for particles passing the 10-mesh screen (less than 2 mm in dia.) it is 115 g. Material split out from 10-mesh screens (diameter 2.0-4.5 mm) in generally had weights of 200-500 g. As ASTM does not list weight criterion for this size fraction (it must be between115 g and 500 g) and the weight of the sample in this size fraction was always greater than 200 g, probably no size biasing of samples was encountered during splitting.

D422-63 (Particle Size Analysis of Soils). In addition, we wished to obtain a -10 mesh (2 mm) portion representative of the entire sample for use in later counting and chemical studies. Care was exercised throughout to ensure that samples were not contaminated by external sources or by other samples from Saxton.

In two respects the ASTM Procedures were not followed:

1. For samples containing particles coarser than 3/8", the sample size was commonly not large enough to meet ASTM requirements for accurate sieve analyses of coarse particles. For example, if particles larger than 1" are present, a sample of 2000 g is required. Therefore, particle size data were obtained mainly for the fraction finer than 3/8".

2. The red clay commonly was not disaggregated easily after drying, but it would disaggregate with effort. The ASTM procedure calls for disaggregation only on the 10 mesh screen. We also disaggregated particles on all finer screens using a rubber stopper, in order to obtain a more accurate measure of the clay and silt sized particles.

Gamma Spectroscopic Analysis

The radioactivity in the soil samples was identified and quantified using high-resolution high-purity germanium detectors. Three such detectors having efficiencies of between 25 and 30% for ^{60}Co were used in this project. A three-input Nucleus Personal Computer Analyzer was used in this work, with each detector having its own ADC and 8192 channnels of memory. The gamma energy range of each detector is from about 50 Kev to 2 Mev.

An extensive quality control plan is in place at the LLRML to insure both precision and accuracy in its analytical results. This plan includes the daily counting of point sources and plotting the measured values for three nuclides (^{60}Co, ^{153}Eu, and ^{137}Cs) on control charts. This is used to insure that each of the three detector systems is "in control". A 15 minute background count is also collected daily and control charted. This measurement is taken to insure that the counting chambers have not become contaminated. A twelve hour background count is taken weekly or when the 15 minute background count indicates that there may be a change in background.

As part of its state certification program, the LLRML participates in EPA's Interlaboratory Comparison Program in which blind cross check samples, provided by EPA's ESML-Las Vegas Laboratory, are received on a regular basis and must be successfully analyzed.

Finally, every tenth sample is analyzed in duplicate and the results of the two measurements are evaluated, along with all the other analytical results of the lab, by the LLRML technical supervisor (Jester).

For this project, the detector efficiency for soil samples in the 100 ml beakers was determined by using two Canadian reference standards (DH-1a and Bl-4) which both have well established values for their uranium and thorium contents. Once the ^{214}Pb and ^{214}Bi in the samples reach equilibrium with the radon-222 these gamma-emitting radionuclides and several other gamma emitters in the uranium and thorium series are used to determine the detector efficiency for this geometry. The resulting efficiency varies as a function of photon energy from a maximum efficiency of about 1.8×10^{-2} counts per disintegration at 300 kev down to about 4×10^{-3} counts per disintegration near 2 mev. It is this detector efficiency "E" which is used in the calculation procedures given in Appendix "C".

Also given in this appendix is the equation used to determine the statistical counting error, which results from the procedures used to determine the net peak area used in the radioisotopic analysis. The standard deviation results from the statistical uncertainty of the net area of the gamma peaks in both the sample and the background and the uncertainty resulting from the establishment of the baseline for the peak in both the sample and the background. The minimum detectable concentration equation given in Appendix "C" is based on recommended procedures developed to avoid both the reporting of false positives and not reporting true positives.

The 34 FC- series samples were dried, sieved, and then weighed into tared 100 ml standard counting containers. Each sample was counted for 12 hours with one of the three detector systems. A number of gamma lines were seen, most of which were associated with the uranium and thorium decay chains. The ^{212}Pb of the thorium series was chosen as the representative of this series and its concentration is called ^{232}Th in this report. Since in the Saxton samples the ^{214}Pb and ^{214}Bi are not in equilibrium with radon-222, the next best radionuclide in the uranium decay chain, namely ^{226}Ra, was chosen to represent this series in the reported results. The major naturally occurring radionuclide found in these soil samples was ^{40}K and is reported. Two man made radionuclides were detected in these samples, namely the long lived fission product ^{137}Cs and the neutron activation product ^{60}Co. Possible trace amounts of ^{7}Be were detected in 2 samples. The results of the gamma spectroscopy are presented in Table 2.

Table 2

Gamma Spectrometric Analyses of Split Samples from FC-Series Drillholes

Sieve Fractions

PSU Number	Location	Depth (in.) and Description	Nuclide	Concentration	1-Sigma Error	MDC (1)
				-----------	pCi/gram	-----------
5176	FC-1	0 to 2	K-40	10.1	0.9	2.5
		Split 1	Co-60	0.02	0.03	0.12
		+20	Cs-137	4.1	0.1	0.2
			Ra-226	2.0	0.7	2.7
			Th-232	1.21	0.07	0.23
5176	FC-1	0 to 2	K-40	7.1	0.7	2.0
		Split 2	Co-60	0.44	0.04	0.11
		-20	Cs-137	11.9	0.1	0.1
			Ra-226	5.	1.	4.
			Th-232	2.65	0.09	0.26
5176	FC-1	0 to 2	K-40	12.	4.	14.
		Split 3	Co-60	-0.2	0.2	0.8
		-140	Cs-137	13.4	0.4	1.0
			Ra-226	12.	5.	18.
			Th-232	1.0	0.4	1.5
5186	FC-6	0 to 4	K-40	6.7	0.7	2.1
		Split 1	Co-60		Not Detected	
		+10 -4	Cs-137	3.52	0.08	0.16
			Ra-226	2.0	0.8	3.0
			Th-232	0.67	0.07	0.25
5186	FC-6	0 to 4	K-40	6.6	0.6	1.7
		Split 2	Co-60	0.03	0.03	0.09
		+40 -10	Cs-137	5.10	0.09	0.15
			Ra-226	2.0	0.6	2.2
			Th-232	0.94	0.06	0.19
5186	FC-6	0 to 4	K-40	10.2	0.6	1.6
		Split 3	Co-60	0.01	0.03	0.11
		+60 -20	Cs-137	9.2	0.1	0.1
			Ra-226	6.0	1.1	4.2
			Th-232	2.31	0.09	0.28
5186	FC-6	0 to 4	K-40	10.	1.	4.
		Split 4	Co-60		Not Detected	
		+200	Cs-137	8.7	0.2	0.3
			Ra-226	0.7	1.2	4.5
			Th-232	1.0	0.1	0.4

Table 2

Gamma Spectrometric Analyses of Split Samples from FC-Series Drillholes (continued)

Sieve Fractions

PSU Number	Location	Depth (in.) and Description	Nuclide	Concentration	1-Sigma Error	MDC (1)
				pCi/gram		
5186	FC-6	0 to 4	K-40	10.5	0.9	2.7
		Split 5	Co-60	0.08	0.05	0.16
		-200	Cs-137	11.7	0.1	0.2
			Ra-226	4.	1.	4.
			Th-232	1.26	0.09	0.30
5201	FC-10	0 to 4	K-40	21.9	0.7	1.4
		Split 1	Co-60	-0.02	0.02	0.09
		+4	Cs-137	0.16	0.03	0.11
			Ra-226	10.7	0.9	3.0
			Th-232	4.94	0.09	0.18
5201 Recount	FC-10	0 to 4	K-40	23.8	0.8	1.8
		Split 1	Co-60		Not Detected	
		+4	Cs-137	0.21	0.04	0.12
			Ra-226	8.0	0.6	2.0
			Th-232	4.06	0.08	0.17
5201	FC-10	0 to 4	K-40	10.7	0.8	2.2
		Split 2	Co-60		Not Detected	
		+10	Cs-137	0.10	0.05	0.16
			Ra-226	5.6	0.8	3.0
			Th-232	2.51	0.08	0.25
5201	FC-10	0 to 4	K-40	8.1	0.7	2.2
		Split 3	Co-60	-0.04	0.04	0.14
		+40 -10	Cs-137	0.36	0.05	0.17
			Ra-226	10.	1.	6.
			Th-232	3.1	0.1	0.4
5201	FC-10	0 to 4	K-40	11.	1.	3.
		Split 4	Co-60		Not Detected	
		+140 -40	Cs-137	1.17	0.07	0.18
			Ra-226	5.7	0.8	2.9
			Th-232	2.67	0.09	0.24
5201	FC-10	0 to 4	K-40	15.	1.	4.
		Split 5	Co-60	0.05	0.05	0.16
		-200 +200	Cs-137	2.1	0.1	0.3
			Ra-226	11.	2.	7.
			Th-232	4.1	0.2	0.4

(1) Minimum Detectable Concentration

Table 2

Gamma Spectrometric Analyses of Samples from FC-Series Drillholes

Bulk Samples

PSU Number	Location	Depth (in.)	Nuclide	Concentration	1-Sigma Error	MDC (1)
				pCi/gram		
5176	FC-1	0 to 2	K-40	4.5	0.4	1.2
			Co-60	0.34	0.03	0.07
			Cs-137	7.62	0.08	0.09
			Ra-226	2.5	0.8	3.1
			Th-232	1.54	0.06	0.19
5177	FC-1	2 to 15	K-40	9.5	0.2	0.5
			Co-60	0.034	0.009	0.030
			Cs-137	2.45	0.03	0.04
			Ra-226	2.0	0.3	1.3
			Th-232	1.39	0.03	0.08
5178	FC-1	15 to 24	K-40	7.0	0.2	0.5
			Co-60	0.034	0.008	0.029
			Cs-137	1.40	0.02	0.04
			Ra-226	2.9	0.4	1.3
			Th-232	1.26	0.03	0.08
5180	FC-4	0 to 3	K-40	4.7	0.2	0.5
			Co-60	0.003	0.008	0.027
			Cs-137	1.80	0.03	0.03
			Ra-226	1.7	0.3	0.9
			Th-232	0.25	0.02	0.06
5179	FC-4	3 to 8.5	K-40	6.6	0.2	0.5
			Co-60	0.005	0.008	0.030
			Cs-137	0.16	0.01	0.04
			Ra-226	3.8	0.3	1.2
			Th-232	1.23	0.03	0.08
5181	FC-4	8.5 to 14.5	K-40	11.0	0.4	0.8
			Co-60		Not Detected	
			Cs-137	0.001	0.014	0.051
			Ra-226	2.0	0.2	0.8
			Th-232	0.86	0.03	0.07
5182	FC-4	14.5 to 21.5	K-40	5.5	0.2	0.4
			Co-60	0.002	0.007	0.026
			Cs-137	0.014	0.009	0.032
			Ra-226	1.7	0.3	1.1
			Th-232	0.74	0.02	0.07

Table 2

Gamma Spectrometric Analyses of Samples from FC-Series Drillholes (continued)

Bulk Samples

PSU Number	Location	Depth (in.)	Nuclide	Concentration	1-Sigma Error	MDC (1)
				pCi/gram		
5183	FC-5	0 to 1.5	K-40	8.7	0.4	0.8
			Co-60	0.47	0.02	0.05
			Cs-137	25.85	0.12	0.08
			Ra-226	3.7	0.6	2.1
			Th-232	1.37	0.05	0.14
5184	FC-5	1.5 to 6	K-40	8.9	0.2	0.5
			Co-60	0.15	0.01	0.04
			Cs-137	12.86	0.07	0.05
			Ra-226	2.8	0.4	1.5
			Th-232	1.14	0.04	0.10
5185	FC-5	6 to 21	K-40	15.2	0.3	0.5
			Co-60	0.008	0.009	0.033
			Cs-137	2.73	0.03	0.04
			Ra-226	2.4	0.3	1.1
			Th-232	1.35	0.03	0.07
5186	FC-6	0 to 4	K-40	7.0	0.2	0.5
			Co-60	0.04	0.01	0.03
			Cs-137	4.60	0.04	0.03
			Ra-226	2.6	0.3	1.1
			Th-232	0.78	0.03	0.08
5186 Recount Remixed	FC-6	0 to 4	K-40	6.8	0.3	0.6
			Co-60	0.03	0.[illegible]1	0.03
			Cs-137	4.01	0.04	0.05
			Ra-226	1.2	0.2	0.7
			Th-232	0.61	0.02	0.06
5187	FC-6	4 to 8	K-40	6.7	0.2	0.5
			Co-60	0.006	0.008	0.029
			Cs-137	0.74	0.02	0.04
			Ra-226	2.1	0.3	1.2
			Th-232	0.93	0.03	0.08
5188	FC-6	8 to 16	K-40	6.0	0.2	0.4
			Co-60		Not Detected	
			Cs-137	-0.002	0.009	0.032
			Ra-226	2.2	0.3	1.1
			Th-232	0.81	0.02	0.07

Table 2

Gamma Spectrometric Analyses of Samples from FC-Series Drillholes (continued)

Bulk Samples

PSU Number	Location	Depth (in.)	Nuclide	Concentration	1-Sigma Error	MDC (1)
				-----------	pCi/gram	-----------
5188 Recount	FC-6	8 to 16	K-40	6.4	0.2	0.4
			Co-60	0.011	0.007	0.027
			Cs-137	0.002	0.009	0.033
			Ra-226	2.3	0.3	1.0
			Th-232	0.73	0.02	0.07
5189	FC-7	0 to 4	K-40	6.9	0.3	0.6
			Co-60	-0.01	0.01	0.04
			Cs-137	0.70	0.02	0.05
			Ra-226	2.2	0.3	1.2
			Th-232	0.83	0.03	0.08
5190	FC-7	4 to 13	K-40	11.4	0.3	0.6
			Co-60		Not Detected	
			Cs-137	0.00	0.01	0.04
			Ra-226	3.3	0.3	1.0
			Th-232	1.22	0.03	0.08
5191	FC-7	13 to 22	K-40	8.6	0.3	0.6
			Co-60	0.020	0.009	0.027
			Cs-137	-0.009	0.010	0.039
			Ra-226	1.4	0.2	0.7
			Th-232	0.95	0.02	0.05
5192	FC-3	0 to 5	K-40	20.1	0.4	0.6
			Co-60		Not Detected	
			Cs-137	1.38	0.03	0.05
			Ra-226	2.8	0.4	1.3
			Th-232	1.75	0.04	0.09
5193	FC-3	5 to 13	K-40	11.6	0.3	0.5
			Co-60		Not Detected	
			Cs-137	0.06	0.01	0.03
			Ra-226	2.7	0.3	1.1
			Th-232	1.31	0.03	0.08
5193 Recount	FC-3	5 to 13	K-40	11.9	0.3	0.5
			Co-60	0.004	0.008	0.030
			Cs-137	0.06	0.01	0.04
			Ra-226	1.8	0.3	1.1
			Th-232	1.28	0.03	0.07

Table 2

Gamma Spectrometric Analyses of Samples from FC-Series Drillholes (continued)

Bulk Samples

PSU Number	Location	Depth (in.)	Nuclide	Concentration	1-Sigma Error	MDC (1)
				pCi/gram		
5194	FC-3	13 to 24	K-40	14.2	0.3	0.4
			Co-60		Not Detected	
			Cs-137	0.008	0.009	0.032
			Ra-226	2.7	0.3	0.9
			Th-232	1.28	0.03	0.06
5195	FC-9	0 to 9	Be-7	0.4	0.1	0.5
			K-40	6.2	0.3	0.6
			Co-60	0.005	0.010	0.037
			Cs-137	0.04	0.01	0.05
			Ra-226	5.2	0.5	1.7
			Th-232	3.18	0.05	0.11
5196	FC-9	9 to 12	K-40	6.2	0.3	0.8
			Co-60		Not Detected	
			Cs-137	0.09	0.02	0.05
			Ra-226	3.5	0.5	1.5
			Th-232	1.56	0.04	0.10
5197	FC-9	12 to 23.5	K-40	6.4	0.2	0.4
			Co-60	-0.004	0.007	0.027
			Cs-137	-0.008	0.009	0.034
			Ra-226	2.3	0.3	1.1
			Th-232	0.77	0.02	0.07
5198	FC-8	0 to 6	K-40	14.7	0.4	0.8
			Co-60	0.01	0.02	0.05
			Cs-137	0.85	0.03	0.06
			Ra-226	7.5	0.5	1.7
			Th-232	3.18	0.05	0.11
5199	FC-8	6 to 12	K-40	12.3	0.4	0.7
			Co-60		Not Detected	
			Cs-137	0.007	0.014	0.047
			Ra-226	5.5	0.4	1.4
			Th-232	2.51	0.04	0.10
5200	FC-8	12 to 16.5	Be-7	0.08	0.10	0.31
			K-40	9.2	0.3	0.7
			Co-60		Not Detected	
			Cs-137	0.03	0.01	0.04
			Ra-226	1.4	0.2	0.7
			Th-232	0.90	0.02	0.06

Table 2

Gamma Spectrometric Analyses of Samples from FC-Series Drillholes (continued)

Bulk Samples

PSU Number	Location	Depth (in.)	Nuclide	Concentration	1-Sigma Error	MDC (1)
				pCi/gram		
5201	FC-10	0 to 4	K-40	6.4	0.3	0.6
			Co-60	-0.007	0.010	0.037
			Cs-137	0.31	0.02	0.05
			Ra-226	4.3	0.4	1.5
			Th-232	1.77	0.04	0.11
5201	FC-10	0 to 4	K-40	9.9	0.3	0.7
Recount			Co-60		Not Detected	
			Cs-137	0.42	0.02	0.06
			Ra-226	5.0	0.4	1.5
			Th-232	2.15	0.04	0.10
5202	FC-10	4 to 17	K-40	5.5	0.3	0.7
			Co-60	0.008	0.010	0.037
			Cs-137	0.02	0.01	0.05
			Ra-226	4.2	0.5	1.6
			Th-232	2.01	0.04	0.11
5203	FC-10	17 to [illegible]	K-40	8.9	0.4	0.9
			Co-60		Not Detected	
			Cs-137	0.00	0.02	0.06
			Ra-226	4.3	0.5	1.8
			Th-232	2.35	0.05	0.12
5204	FC-11	0 to 4	K-40	7.0	0.3	0.6
			Co-60	-0.003	0.009	0.035
			Cs-137	0.43	0.02	0.04
			Ra-226	1.9	0.4	1.5
			Th-232	0.71	0.03	0.10
5205	FC-11	4 to 17.5	K-40	23.9	0.4	0.7
			Co-60	0.001	0.009	0.032
			Cs-137	0.00	0.01	0.04
			Ra-226	1.8	0.2	0.6
			Th-232	1.27	0.02	0.05
5205	FC-11	4 to 17.5	K-40	25.4	0.4	0.6
Recount			Co-60		Not Detected	
			Cs-137	0.01	0.01	0.04
			Ra-226	1.3	0.2	0.6
			Th-232	1.15	0.02	0.05

Table 2

Gamma Spectrometric Analyses of Samples from FC-Series Drillholes (continued)

Bulk Samples

PSU Number	Location	Depth (in.)	Nuclide	Concentration	1-Sigma Error	MDC (1)
				pCi/gram		
5206	FC-11	17.5 to 22	K-40	15.0	0.4	0.6
			Co-60		Not Detected	
			Cs-137	0.05	0.01	0.05
			Ra-226	4.9	0.4	1.4
			Th-232	2.28	0.04	0.09
5207	FC-12	0 to 3	K-40	3.9	0.3	0.9
			Co-60		Not Detected	
			Cs-137	0.96	0.03	0.05
			Ra-226	2.9	0.5	1.7
			Th-232	0.96	0.04	0.11
5208	FC-12	3 to 9.5	K-40	4.2	0.3	0.9
			Co-60		Not Detected	
			Cs-137	0.42	0.02	0.07
			Ra-226	3.0	0.5	1.8
			Th-232	1.08	0.04	0.12
5209	FC-12	9.5 to 17	K-40	13.0	0.4	0.7
			Co-60		Not Detected	
			Cs-137	0.03	0.02	0.05
			Ra-226	6.5	0.4	1.4
			Th-232	3.01	0.04	0.09

(1) Minimum Detectable Concentration

Table 2

Gamma Spectrometric Analyses of Extraction Samples from FC-Series Drillholes

Selective Extractions

PSU Number	Location	Depth (in.) and Description	Nuclide	Concentration	1-Sigma Error	MDC (1)
				-----------	pCi/milliliter	----------
5176	FC-1	0 to 2	K-40	0.03	0.22	0.74
		Extraction	Co-60		Not Detected	
			Cs-137	0.22	0.02	0.06
			Ra-226	-0.3	0.3	1.1
			Th-232	-0.004	0.024	0.092
5176	FC-1	0 to 2	K-40	-0.4	0.3	1.0
Recount		Extraction	Co-60	-0.02	0.02	0.06
			Cs-137	0.23	0.02	0.07
			Ra-226	0.1	0.4	1.4
			Th-232	0.03	0.03	0.12
5176	FC-1	0 to 2	K-40	0.2	0.2	0.7
		Organic	Co-60		Not Detected	
		Extraction	Cs-137	0.33	0.02	0.06
			Ra-226	0.02	0.25	1.00
			Th-232	0.003	0.023	0.086
5176	FC-1	0 to 2	K-40	-0.2	0.2	0.7
		FeOx	Co-60	-0.02	0.01	0.05
		Extraction	Cs-137	0.06	0.02	0.06
			Ra-226	0.5	0.3	1.1
			Th-232	0.04	0.03	0.09
5176	FC-1	0 to 2	K-40	0.4	0.2	0.8
		Acid	Co-60	0.12	0.02	0.04
		Extraction	Cs-137	1.94	0.04	0.08
			Ra-226	-0.006	0.275	1.047
			Th-232	0.08	0.02	0.08
5186	FC-6	0 to 4	K-40	0	0.3	1.0
		Extraction	Co-60	-0.01	0.01	0.06
			Cs-137	0.41	0.03	0.07
			Ra-226	0.2	0.4	1.5
			Th-232	0.08	0.03	0.12
5186	FC-6	0 to 4	K-40	0.2	0.2	0.7
		Organic	Co-60	0.007	0.011	0.043
		Extraction	Cs-137	0.46	0.02	0.06
			Ra-226	-0.3	0.3	1.0
			Th-232	0.03	0.02	0.08

Table 2

Gamma Spectrometric Analyses of Extraction Samples from FC-Series Drillholes (continued)

Selective Extractions

PSU Number	Location	Depth (in.) and Description	Nuclide	Concentration	1-Sigma Error	MDC (1)
				pCi/milliliter		
5186	FC-6	0 to 4	K-40	-0.08	0.20	0.70
		FeOx	Co-60	0.003	0.010	0.037
		Extraction	Cs-137	0.39	0.02	0.06
			Ra-226	0.2	0.2	1.0
			Th-232	0.04	0.02	0.08
5186	FC-6	0 to 4	K-40	-0.2	0.3	1.0
		Acid	Co-60	-0.02	0.02	0.06
		Extraction	Cs-137	0.96	0.03	0.08
			Ra-226	0.8	0.4	1.5
			Th-232	0.18	0.03	0.12
5186	FC-6	0 to 4	K-40	-0.2	0.2	0.8
		Acid	Co-60	-0.01	0.01	0.05
		Extraction	Cs-137	0.18	0.02	0.07
		Excess	Ra-226	-0.1	0.3	1.1
			Th-232	0.04	0.03	0.09

PSU Number	Location	Depth (in.) and Description	Nuclide	Concentration	1-Sigma Error	MDC (1)
				pCi/gram		
5176	FC-1	0 to 2	K-40	6.4	0.6	1.7
		Sand	Co-60	0.03	0.03	0.11
		+325	Cs-137	4.33	0.08	0.14
			Ra-226	6.	1.	4.
			Th-232	2.10	0.09	0.28
5176	FC-1	0 to 2	K-40	16.	3.	9.
		Clay	Co-60	0.2	0.1	0.5
		-325	Cs-137	31.2	0.5	0.7
			Ra-226	2.	3.	10.
			Th-232	1.1	0.2	0.9
5186	FC-6	0 to 4	K-40	10.8	0.6	1.6
		Sand	Co-60	0.11	0.03	0.08
		+325	Cs-137	4.58	0.08	0.12
			Ra-226	1.7	0.5	1.8
			Th-232	1.56	0.05	0.14
5186	FC-6	0 to 4	K-40	15.2	0.8	2.0
		Clay	Co-60	-0.04	0.04	0.14
		-325	Cs-137	14.0	0.1	0.2
			Ra-226	5.	1.	5.
			Th-232	1.7	0.1	0.3

Sieving

The ASTM procedure D422-63 was followed for sieving, in combination with the procedure of Table 1. The fraction passing 10 mesh was passed through a set of sieves (mesh sizes 20, 40, 60, 140, and 200) on a Ro-Tap sieve shaker. The fraction coarser than 10 mesh was sieved thru a 4-mesh sieve. In general, the mass of coarse fraction was not sufficient to measure coarser particles accurately according to the criteria of the procedure. The fines passing 200-mesh were suspended in water with the stirring apparatus and then brought to 1 liter in a sedimentation cylinder. The density was measured with a hydrometer after periods up to 24 hrs. to obtain the proportion of grains finer than 5 µm. and about 1 µm.

Each fraction was examined under a binocular microscope and the types of particles recorded (Appendix D).

Chemical and Mineralogical Analyses

A representative split of six samples was submitted to the Mineral Constitution Laboratory, Penn State Univ., for chemical and mineralogical analysis. Samples were ground to pass 100 mesh, and then analyzed for total carbon, hydrogen and nitrogen by analysis of volatilized gases by a LECO C-H-N gas analyzer. Results are in Appendix E.

A portion of the sample was ashed and then fused with $LiBO_2$ and dissolved in HNO_3. The resulting solution was analyzed for Si, Al, Fe, Mg, Ti, Ca, Na, K, Mn and P by plasma emission spectrometry and atomic absorption (Suhr and Gong, 1983), (Appendix E).

Another representative portion of the sample was ground to a powder, mounted on a glass slide, and an X-ray diffraction pattern made. The minerals were identified by comparison to standard mineral patterns (Appendix E).

Selective Extraction

Two samples were chosen for selective extraction: FC-1, 0-4" (PSU#5176) and FC-6, 0-4" (PSU#5186). Sample FC-1 is located about 50 ft. north of the containment vessel and FC-6 is located about 12 ft. east of the north end of the radwaste building. Sample FC-1 is mostly fly ash with minor natural silt and clay; the bulk ^{137}Cs content is 7.6 pCi/g. Sample FC-6 is about one-half fly ash and one-half crushed gray limestone with minor silt and clay; the bulk ^{137}Cs content is 4.0 pCi/g, but for the sample with limestone removed it is 8.2 pCi/g. The latter sub-sample was used for selective extraction.

These two samples were chosen for several reasons: Both samples contain abundant fly ash which is suspected of being contaminated by reactor-generated ^{137}Cs; the samples have higher radioactivity than most others. Only one sample has a higher ^{137}Cs value (FC-5, 0-1.5" - 25 pCi/g ^{137}Cs). Also, the samples are in two distinctly different locations and may have been subjected to different contamination pathways and mechanisms. Sample FC-1 is near the spent resin tanks immediately to the north of the containment vessel and may have been contaminated by possible leakage from the tanks; later it could have been contaminated by the process of removing the resin tanks in 1972. Contamination could also have occurred in this sample after the site was restored to original grade after the removal of the tanks. FC-6 is just outside the radwaste building where it may have become contaminated by leakage of stored liquid waste. It is also possible that FC-6 could have become contaminated during the decontamination of the radwaste building in the past year.

For both of these samples a selective extraction procedure was performed in hopes of ascertaining the host phase, cause and chronology of the suspected ^{137}Cs contamination.

A selective extraction procedure, modified after Jackson (1956) and Schmiermund (1977), was performed to obtain elements of interest from each of the soil phases. The procedure is designed to extract the easily-removed surficial coatings first and leave the more resistant substrates to late stages. Cross-contamination of analyte between extractions of different phases is minimized by washing between treatments. The extractants for the Saxton samples are as follows (in order): ammonium acetate (extracts ^{137}Cs held in exchangeable cation sites on solids), hydrogen peroxide (decomposes organic phases such as humic materials), sodium dithionite (decomposes limonite and other Fe-oxides), warm 1:1 nitric acid/water (extracts more strongly bound ^{137}Cs in solids); the residue is sieved through on a #325 mesh (separates the sand-size fraction from the silt-and clay-sized fractions). The extracts from this procedure were stabilized with nitric acid, placed in a standard geometry and measured on a gamma spectrometer for the presence of ^{137}Cs and other radionuclides.

The detailed procedure was follows: 60.54 g of FC-1, 0-4" (PSU#5176) and 122.07 g (the fly ash portion of this sample only; the crushed limestone was removed as it contains no ^{137}Cs) of FC-6, 0-4" (PSU#5186) were distributed among twelve 50 ml polyethylene tubes.

(1) 20 ml of 1 M ammonium acetate, adjusted to pH 5 with nitric acid, was added to each of the twelve tubes. The tubes were placed in an ultrasonic bath for 15 min. The tubes were then centrifuged at 2500 rpm for 15 min. and the supernatant liquid was carefully decanted off to a beaker and labelled "exchangeable fraction". This step was repeated and then the tubes were washed with distilled water to remove the reagent; the water was added to the beaker labelled "exchangeable fraction", a few drops of concentrated nitric acid was added and the total volume was reduced to 100 ml. by evaporation.

(2) Next, 5 ml of 30% hydrogen peroxide, adjusted to pH 5 with nitric acid, was added to each of the twelve tubes; as the substrate foamed violently, no ultrasound agitation was deemed necessary. After 15 min., 10 ml of water was added and the tubes were centrifuged as in the previous step. The supernatant liquid was decanted to a beaker labelled "organic fraction". This step was repeated and the tubes were again washed with distilled water; the water was added to the beaker, stabilized with nitric acid and the total volume was reduced to 100 ml. (3) To extract the Fe-oxides, 20 ml of a sodium citrate-sodium carbonate buffer (pH=8.3) were added to each of the tubes. The tubes were placed in a constant temperature bath at 78°C and sodium dithionite was added in 0.5 g portions while stirring. Three portions were added; the tubes were allowed to sit in the bath for 15 min. and then were centrifuged, washed, acidified and reduced in volume to 100 ml as in the previous steps. (4) Next, 20 ml of 1:1 nitric acid/water at 60°C was added to each of the twelve tubes; stirring was unnecessary as the substrate reacted violently. The tubes sat at 60°C for 20 min. and then were centrifuged, washed and the volume of extract reduced to 100 ml. (5) The residue remaining was washed over a 325 mesh screen (50 micrometers) to separate the sand fraction from the silt and clay fractions. The separated fractions were oven dried at 110°C overnight, weighed and sent to the Low-Level Lab, as were the previous extractions. The samples were counted in a standard geometry on the germanium detectors for 12 hours; the spectra obtained were then quantified.

RESULTS

Surficial Materials in Drillholes

A limited number of types of materials were encountered in the FC-series drillholes (Figures 6-16). Most of these same materials were encountered in the T- and B-series drillholes (Rose and Jester, 1988).

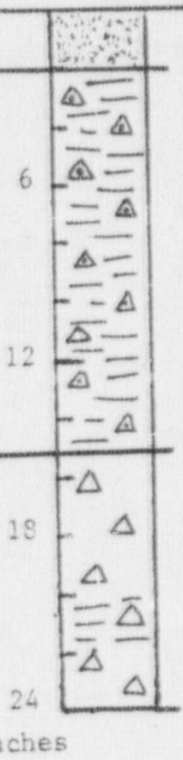
Figure 6.

SAXTON PROJECT

DRILLHOLE NO. FC-1

Recovery: 24 in. (100%)

Radionuclides (pCi/g)					Geologic Log
^{232}Th	^{226}Ra	^{40}K	^{60}Co	^{137}Cs	
1.5	(2.5)	4.5	0.3	7.6	Fly ash
1.4	2.0	9.5	(0.03)	2.4	Reddish sandy silt and siltstone fragments with minor bottom ash
1.3	2.9	7.0	0.03	1.4	Mostly bottom ash; red clay at 20-22"



Note: If recovery differs from 100%, units are expanded proportionately.

( ) Indicates concentration less than Minimum Detectable Concentration

- Not detected (zero or negative concentration, or no peak detected)

LEGEND

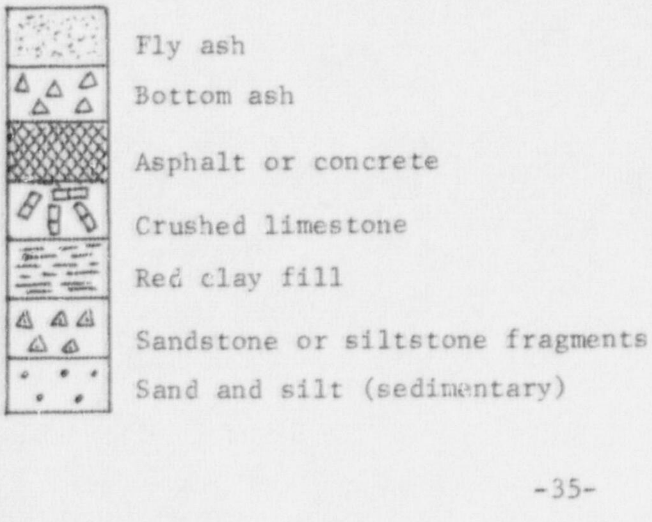


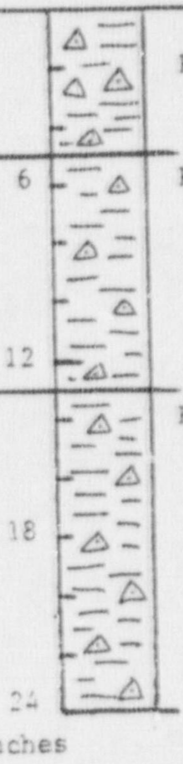
Figure 7.

SAXTON PROJECT

DRILLHOLE NO. FC-3

Recovery: 24 in. (100%)

Radionuclides (pCi/g)					Geologic Log
^{232}Th	^{226}Ra	^{40}K	^{60}Co	^{137}Cs	
1.7	2.8	20.1	-	1.4	Red clay with siltstone fragments and minor bottom ash
					Red clay with sparse rock fragments
1.3	2.7	11.6	-	0.06	
1.3	1.8	11.9	(0.004)	0.07	
					Red clay with sandstone fragments
1.3	2.7	14.2	-	(0.008)	



Note: If recovery differs from 100%, units are expanded proportionately.

( ) Indicates concentration less than Minimum Detectable Concentration

- Not detected (zero or negative concentration, or no peak detected)

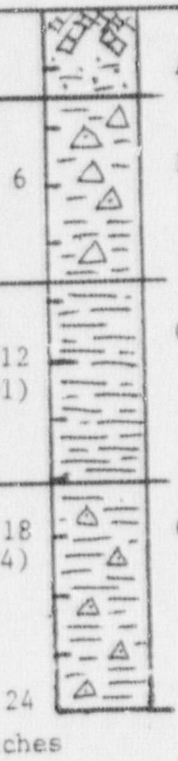
Figure 8.

SAXTON PROJECT

DRILLHOLE NO. FC-4

Recovery: 21.5 in. (90 %)

Radionuclides (pCi/g)					Geologic Log
^{232}Th	^{226}Ra	^{40}K	^{60}Co	^{137}Cs	
0.2	1.7	4.7	(0.003)	1.8	Asphalt, crushed limestone and brown silt/clay
1.2	3.8	6.6	(0.005)	0.2	Bottom ash with red clay
0.9	2.04	11.0	-	(0.001)	Orange brown clay
0.7	1.7	5.5	(0.002)	(0.014)	Orange brown clay with red sandstone fragments



Note: If recovery differs from 100%, units are expanded proportionately.

( ) Indicates concentration less than Minimum Detectable Concentration

- Not detected (zero or negative concentration, or no peak detected)

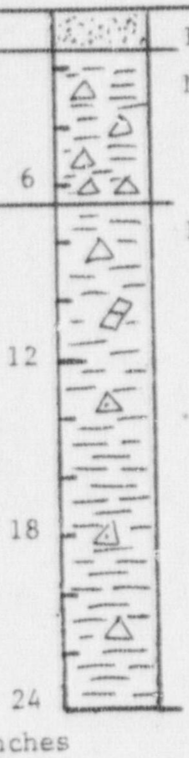
Figure 9.

SAXTON PROJECT

DRILLHOLE NO. FC-5

Recovery: 21 in. (87.5%)

Radionuclides (pCi/g)					
^{232}Th	^{226}Ra	^{40}K	^{60}Co	^{137}Cs	Geologic Log
1.4	3.7	8.7	0.5	25.8	Fly ash
1.1	2.8	8.9	0.1	12.9	Mostly red clay with 20% fly ash
1.4	2.4	15.2	(0.008)	2.73	Red clay with sparse bottom ash, crushed limestone, sandstone and siltstone



Note: If recovery differs from 100%, units are expanded proportionately.

( ) Indicates concentration less than Minimum Detectable Concentration

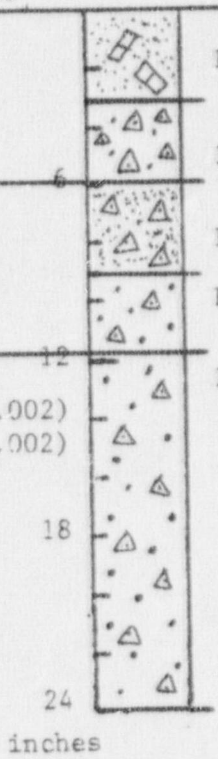
\- Not detected (zero or negative concentration, or no peak detected)

Figure 10.

SAXTON PROJECT

DRILLHOLE NO. FC-6

Recovery: 16 1/2 in. (69 %)



Radionuclides (pCi/g)					
^{232}Th	^{226}Ra	^{40}K	^{60}Co	^{137}Cs	Geologic Log
					Fly ash and crushed limestone
0.8	2.6	7.0	0.03	4.6	Buff sandy silt with red sandstone-siltstone fragments
0.6	1.2	6.8	(0.02)	4.0	
0.9	2.1	6.7	(0.006)	0.7	Fly ash with rock fragments
					Reddish silt with rock fragments
0.8	2.2	6.0	-	(-0.002)	Buff silt with sandstone fragments
0.7	2.3	6.4	(0.01)	(0.002)	

Note: If recovery differs from 100%, units are expanded proportionately.

( ) Indicates concentration less than Minimum Detectable Concentration

- Not detected (zero or negative concentration, or no peak detected)

Figure 11.

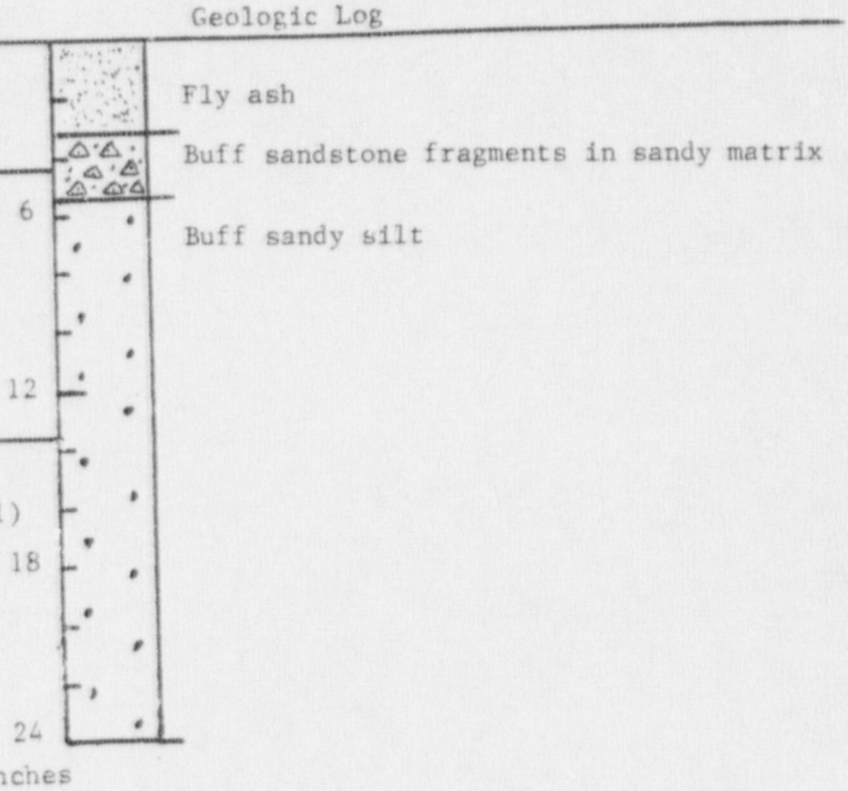
SAXTON PROJECT

DRILLHOLE NO. FC-7 Recovery: 22 1/2 in. (94 %)

Radionuclides (pCi/g)

^{232}Th	^{226}Ra	^{40}K	^{60}Co	^{137}Cs
0.8	2.2	6.9	(-0.01)	0.7
1.2	3.3	11.4	-	(0.0)
1.0	1.4	8.6	(0.02)	(-0.01)

Geologic Log



Note: If recovery differs from 100%, units are expanded proportionately.

( ) Indicates concentration less than Minimum Detectable Concentration

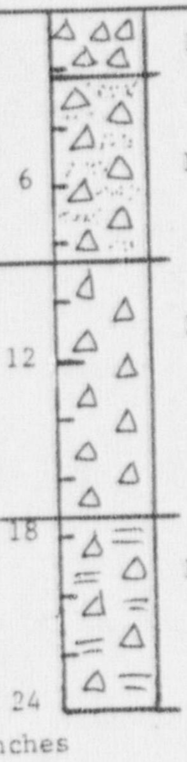
- Not detected (zero or negative concentration, or no peak detected)

Figure 12.

SAXTON PROJECT

DRILLHOLE NO. FC-8

Recovery: 16.5 in. (69 %)



Radionuclides (pCi/g)						
^{7}Be	^{232}Th	^{226}Ra	^{40}K	^{60}Co	^{137}Cs	Geologic Log
						Bottom ash
-	3.2	7.5	14.7	(0.01)	0.9	Fly ash and bottom ash
-	2.5	5.5	12.3	-	(0.01)	Bottom ash
(0.08)	0.9	1.4	9.2	-	(0.03)	Bottom ash with 20% red clay

Note: If recovery differs from 100%, units are expanded proportionately.

( ) Indicates concentration less than Minimum Detectable Concentration

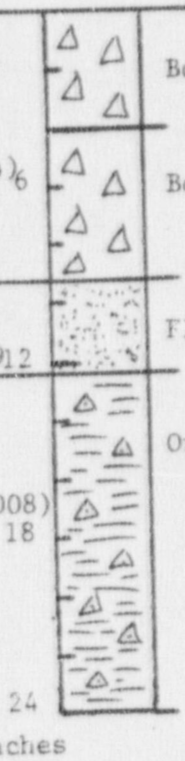
- Not detected (zero or negative concentration, or no peak detected)

Figure 13.

SAXTON PROJECT

DRILLHOLE NO. FC-9

Recovery: 23.5 in. (98%)



Radionuclides (pCi/g)						
$^{7}\mathrm{Be}$	$^{232}\mathrm{Th}$	$^{226}\mathrm{Ra}$	$^{40}\mathrm{K}$	$^{60}\mathrm{Co}$	$^{137}\mathrm{Cs}$	Geologic Log
						Bottom ash
0.4	3.2	5.2	6.2	(0.005)	(0.04)	Bottom ash, slightly coherent
-	1.6	3.5	6.2	-	0.09	Fly ash
-	0.8	2.3	6.4	(-0.004)	(-0.008)	Orange-brown clay with siltstone and sandstone fragments

Note: If recovery differs from 100%, units are expanded proportionately.

( ) Indicates concentration less than Minimum Detectable Concentration

- Not detected (zero or negative concentration, or no peak detected)

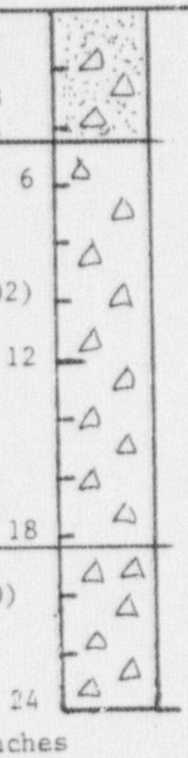
Figure 14.

SAXTON PROJECT

DRILLHOLE NO. FC-10

Recovery: 22 in. (92 %)

Radionuclides (pCi/g)					Geologic Log
^{232}Th	^{226}Ra	^{40}K	^{60}Co	^{137}Cs	
1.8	4.3	6.4	(-0.007)	0.3	Fly ash with sparse bottom ash
2.2	5.0	9.0	-	0.4	
2.0	4.2	5.5	(0.008)	(0.02)	Bottom ash
2.3	4.3	8.9	-	(0.0)	Bottom ash with efflorescence



Note: If recovery differs from 100%, units are expanded proportionately.

( ) Indicates concentration less than Minimum Detectable Concentration

\- Not detected (zero or negative concentration, or no peak detected)

Figure 15.

SAXTON PROJECT

DRILLHOLE NO. FC-11 Recovery: 22 in. (92 %)

Radionuclides (pCi/g)					Geologic Log
^{232}Th	^{226}Ra	^{40}K	^{60}Co	^{137}Cs	
0.7	1.9	7.0	(-0.003)	0.4	Soil and fly ash grading down to crushed limestone
1.3	1.8	23.9	(0.001)	(0.00)	Crushed limestone in a fine gray matrix
1.2	1.3	25.4	-	(0.01)	
2.3	4.9	15.0	-	0.05	Black and orange bottom ash with some red siltstone

Note: If recovery differs from 100%, units are expanded proportionately.

( ) Indicates concentration less than Minimum Detectable Concentration

- Not detected (zero or negative concentration, or no peak detected)

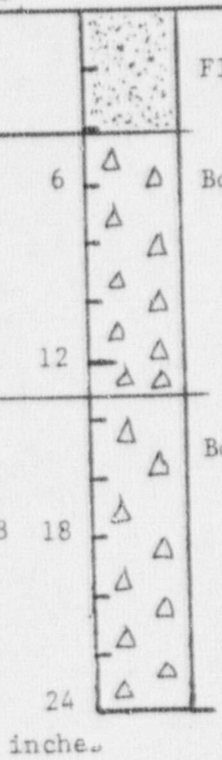
Figure 16.

SAXTON PROJECT

DRILLHOLE NO. FC-12

Recovery: 17 1/2 in. (73 %)

Radionuclides (pCi/g)					
^{232}Th	^{226}Ra	^{40}K	^{60}Co	^{137}Cs	Geologic Log
0.9	2.9	3.9	-	1.0	Fly ash
1.0	3.0	4.2	-	0.4	Bottom ash and coal
3.0	6.5	13.0	-	0.03	Bottom ash



Note: If recovery differs from 100%, units are expanded proportionately.

( ) Indicates concentration less than Minimum Detectable Concentration

- Not detected (zero or negative concentration, or no peak detected)

In FC-6, -7 and possibly -9 and -4, the deeper layers are composed of bedded sand and silt with a small proportion of fine rock fragments. This material is believed to represent the natural near-surface flood plain deposits of the former Raystown Branch, although the possibility that they are disturbed materials cannot be entirely rejected. The key feature suggesting an undisturbed nature is their thinly bedded (layered) and somewhat sorted character, as would be expected for sediments deposited on a flood plain but not material disturbed by human activities.

Several types of fill and artificially redistributed surficial material were encountered. Bottom ash makes up much of FC-8, -10, and -12 and parts of FC-1, -4, -9, and -11, and occurs as a subordinate component mixed with other materials in several holes. The bottom ash has either been deliberately used as a fill, as for example in the sites of the former spent resin and waste liquid storage tanks, or was disposed of on the surface and was later spread into a surface layer during site cleanup in the early 1970's.

Red silty clay with varying amounts of red siltstone and sandstone fragments makes up a large portion of FC-1, -3, -5, and several T-series holes, and is present as small admixtures in other holes. Most of this material appears to be ground mudstone-siltstone, probably quarried at the east edge of the site and used deliberately for fill and for construction of the bunkers (FC-3). The red clay fill may have also been spread around the site during cleanup operations. Some may also be the natural silty surficial deposits that have been redistributed during construction.

Crushed limestone is a major component of FC-11 and of the surface zone of FC-4 and -6. In FC-4 it is a component of the asphalt floor of the bunker as well as a subgrade for the asphalt. In the other areas it appears to have been spread on the surface for roadways, fill or parking. This material was not quarried on site because this type of limestone is not present at the site; it may have come from limestone quarries near Everett or elsewhere in the region.

Fly ash forms a surface layer 1 to 4 in. thick in FC-1, -5, -6, -7, -10, -11, and -12, and is present beneath fill in FC-6, -8, and -9. In most of these locations it is mixed with varying amounts of rock fragments, bottom ash and crushed limestone. Most of the fly ash probably accumulated prior to 1970, when the coal-fired plant ceased regular operation, but appreciable redistribution may have occurred by wind action since that time, because the surface above the former spent resin tank is covered by several inches of fly ash.

Sieve Analyses

Some representative cumulative distributions of sieve analyses are plotted in Figures 17 to 18.

The fly ash is characterized by a high proportion of material in the sand size range (74μm to 500μm), as illustrated in Figure 17 for FC-1, which is a relatively pure fly ash. Other "fly ash" samples have a considerable admixture of coarser rock fragments (including crushed limestone) and bottom ash. The quantity of material finer than 74 μm is small, less than 15%.

Fill material of "red clay and siltstone" is also characterized by a high proportion of fine sand (74 to 500μm. but by higher proportions (10-20%) of silt and clay (< 74μm) and a significant amount of gravel-sized rock fragments (Figure 18).

A natural "silty sand" is shown on Figure 18. The size distribution is similar to that of the red clay and siltstone, except that coarse particles are slightly less abundant.

A material dominated by bottom ash is also plotted on Figure 18. The proportion of clay, silt and fine sand is much lower that the other types of samples (< 20%), and the dominant size is between 2 and 5 mm.

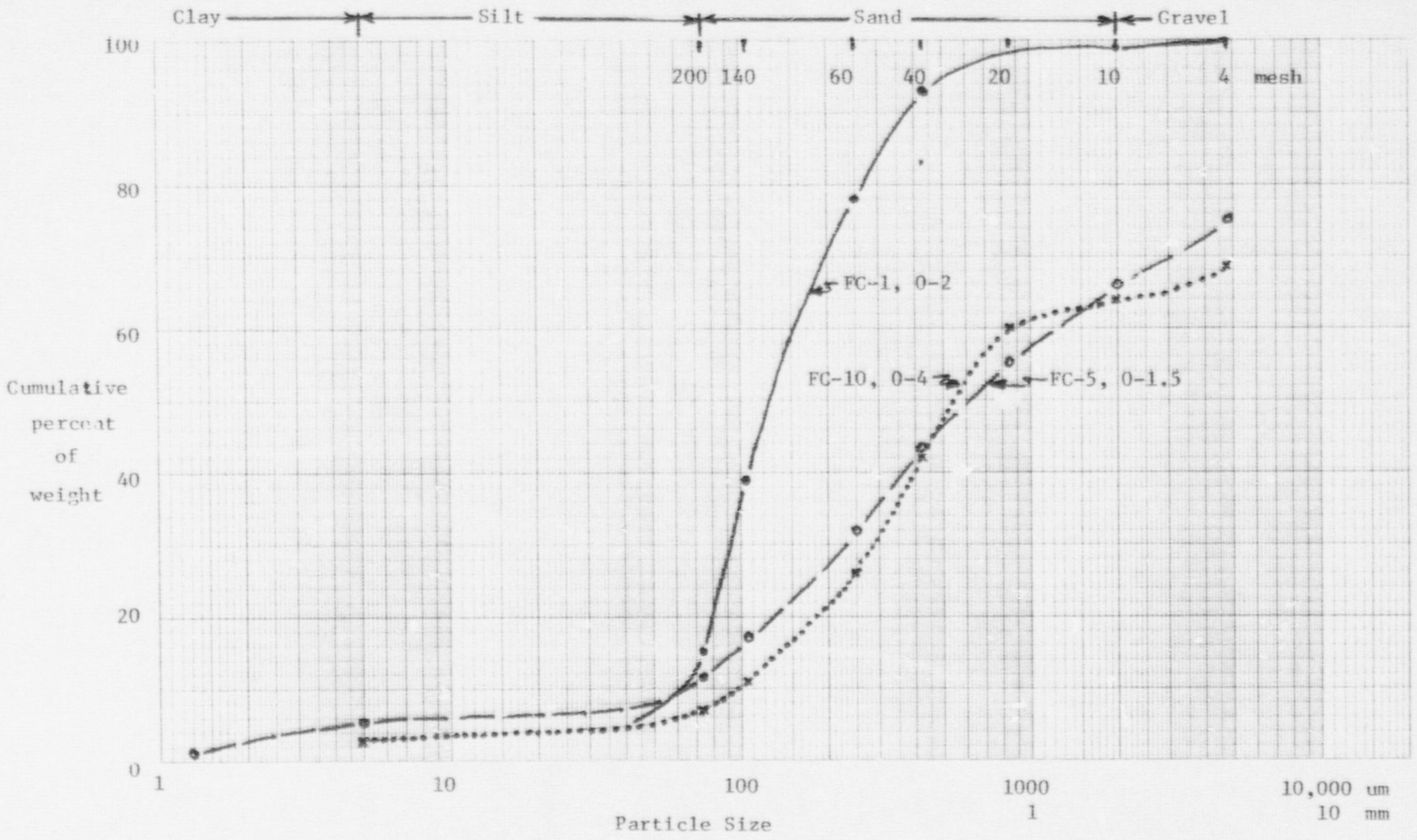


Figure 17. Particle size distribution for some samples rich in fly ash. Each point indicates the percentage of total sample weight that consists of particles smaller than the indicated diameter.

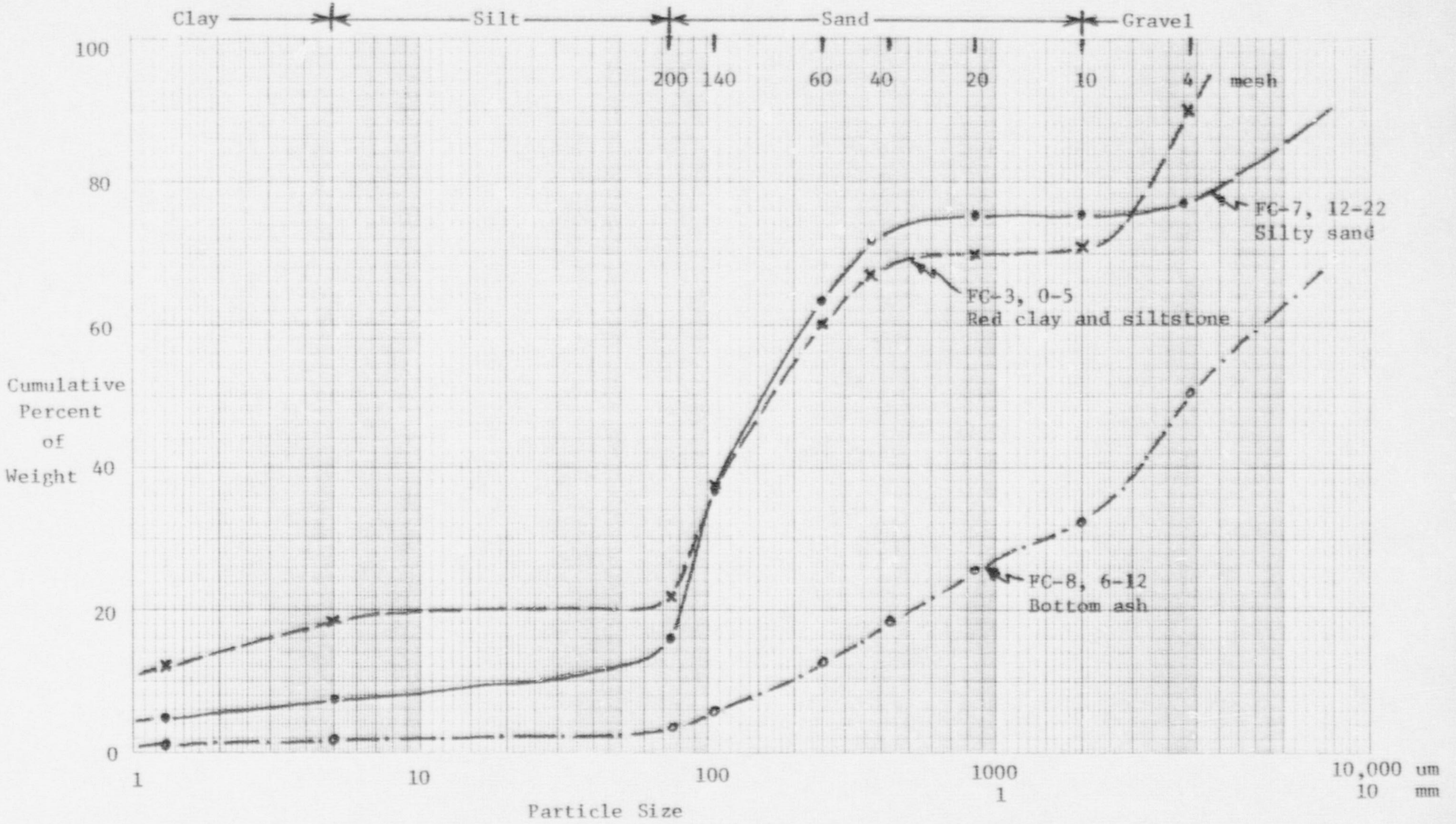


Figure 18. Particle size distribution for some representative samples. Each point indicates the percentage of total sample weight that consists of particles with diameter smaller than the indicated value.

Chemical Composition of Samples

The chemical composition of the samples is listed in Appendix E.

The analyses show that all "fly ash" and "bottom ash" contains a significant amount of carbon, in the range of 15 to 43%. This carbon apparently represents unburned or incompletely burned coal. In several of these samples, coal dust or fine coal particles were recognized visually or microscopically, but the amounts recognized were small, generally less than 10%. The much larger ammount of C found chemically suggests that fly ash and bottom ash contain a major component of unburned carbon. This feature is consistent with the opaque nature of the particles.

Two samples (FC-6, 0-4 and FC-6, 4-8) contain considerable Ca as well as moderate C. In these samples, the chemical form of carbon is probably largely $CaCO_3$, which is observed in the form of crushed limestone.

Sample 5188 (FC-6, 8-16") is a natural silt with rock fragments. The content of C is very low (0.41%), reflecting its lack of coal, calcite and plant materials. The inorganic constituents show high SiO_2 and appreciable Al_2O_3, Fe_2O_3, and K_2O, appropriate for the observed composition of quartz silt and subordinate illitic clay.

The inorganic fraction of the fly ash has a relatively Al-rich composition that might be expected for the clay-bearing inorganic fraction of a coal. Silica ranges from 49 to 66%, and Al_2O_3 from 9 to 33%, with lesser amounts of Fe and K. Small amounts of S, probably originally from pyrite in the coal, are present in all samples. The fly ash is well within the composition reported for fly ash elsewhere.

Radionuclides Detected in Samples

Detectable quantities of 6 radionuclides were identified: ^{137}Cs, ^{60}Co, ^{7}Be, ^{40}K, ^{226}Ra, and ^{232}Th (Table 2). Peaks for a number of other U and Th decay products in addition to ^{226}-Ra were detected but have not been quantified. In addition to these nuclides, some small peaks remain unidentified on the gamma spectra, but no definite identification has been possible.

The ^{40}-K, ^{232}Th and ^{226}Ra are natural radioactivity in the soil and rock. The levels of ^{226}Ra in most cores are 2 to 3 pCi/g, which is the activity that would be in equilibrium with 6 to 9 ppm of uranium. Levels of 3 to 5 ppm U are common in shales of the Catskill Formation farther east, and levels of 5 to 10 ppm are found in some samples (Pirc, 1979, Bell, 1980).

Most samples have ^{232}Th activities of 0.5 to 1.5 pCi/g, equivalent to Th contents of 5 to 15 ppm. These values are in the range of 5 to 20 ppm Th in Catskill shales farther east (Pirc, 1979; Bell, 1980).

Levels of ^{40}K range from about 4 to 25 pCi/g, but most are in the range of 5 to 10 pCi/g. These values correspond to values of K between 0.5 and 3.0%.

The ^{137}Cs and ^{60}Co clearly originated from either reactor operation or atmospheric fallout from weapons tests or the Chernobyl accident. The ^{7}Be is formed in the upper atmosphere.

^{137}Cs is clearly the most abundant of these nuclides, with levels up to 25.8 pCi/g (sample FC-5). The ^{60}Co is present above The Minimum Detectable Concentration (MDC) in only 6 samples, the highest values being 0.47 pCi/g.

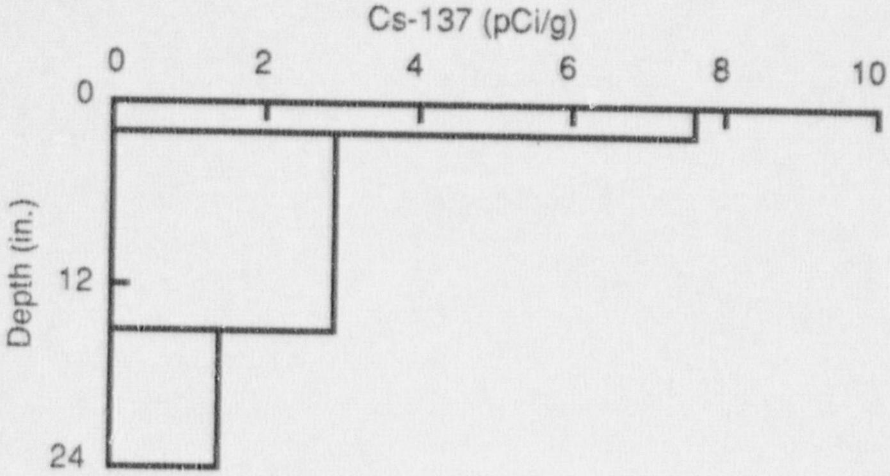
In a gross way, the ^{60}Co is abundant in samples with high values of ^{137}Cs, but the correlation is only fair in detail (i.e., samples with 25.85, 12.85 and 7.62 pCi/g ^{137}Cs contain 0.47, 0.15 and 0.34 pCi/g Co-60, respectively). ^{7}Be is detected in only 2 samples, but neither exceeds the MDC. In view of this pattern, the emphasis in the following discussion will be on ^{137}Cs.

Distribution of ^{137}Cs with Depth

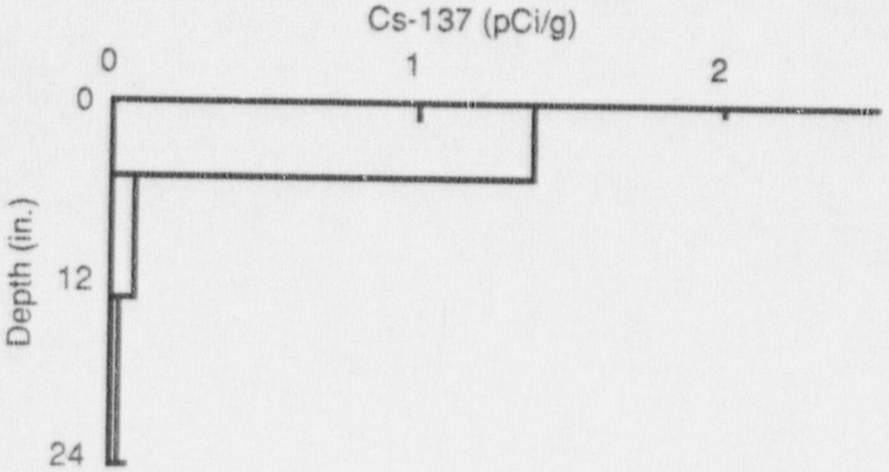
In all 10 drillholes with detectable ^{137}Cs, the surface layer has markedly higher concentrations than deeper layers, and the differences in many holes exceed a factor of 10 (Figures 19-23). The exception is FC-9, in which the surface layer contains 0.04 pCi/g, slightly less than the MDC, but the underlying sample contains 0.09 pCi/g, slightly more than the MDC. In all holes except FC-11, the deepest horizon contains the least ^{137}Cs. In FC-11, the concentration in the second horizon is 0.007 pCi/g (less than the MDC) and in the deepest horizon it is 0.048 pCi/g, barely exceeding the MDC of 0.046. This behavior clearly indicates a surface source for the ^{137}Cs, either atmospheric fallout or surface dispersion of contamination from the nuclear plant. The exceptions to the pattern of decreasing ^{137}Cs with depth may arise from burial of material once at the surface (i.e., FC-9 is adjacent to the coal-fired plant site, and has been regraded, and FC-11 clearly had crushed stone spread over the surface at some time).

In most samples, the high ^{137}Cs material at the surface is dominantly fly ash (FC-1, 5, 6, 7, 8, 10, 11, 12). Exceptions are FC-3 and -4, which are in the bunker area and have clay and asphalt as the enriched surface layer. In all samples outside the nuclear facility that have readily detectable amounts of ^{137}Cs in layers below the surface (FC-6, 11, 12), the subsurface material with high values is bottom ash or fly ash. This relation suggests that these surficial materials accumulated ^{137}Cs and were later buried. The present surficial materials at these sites either accumulated additional ^{137}Cs at a later time possibly from atmospheric fallout, or were redistributed by re-grading or wind action.

In FC-1 and FC-5, the subsurface layers may have accumulated ^{137}Cs from appreciable downward migration from the appreciable contamination in surface

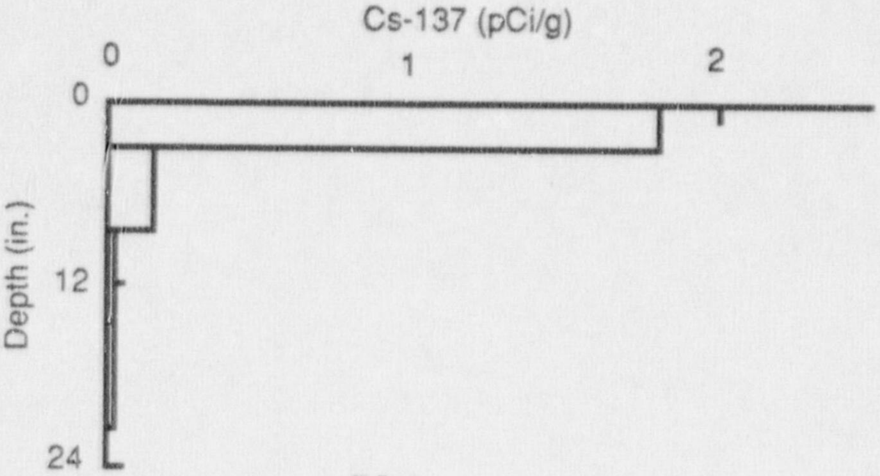


FC-1

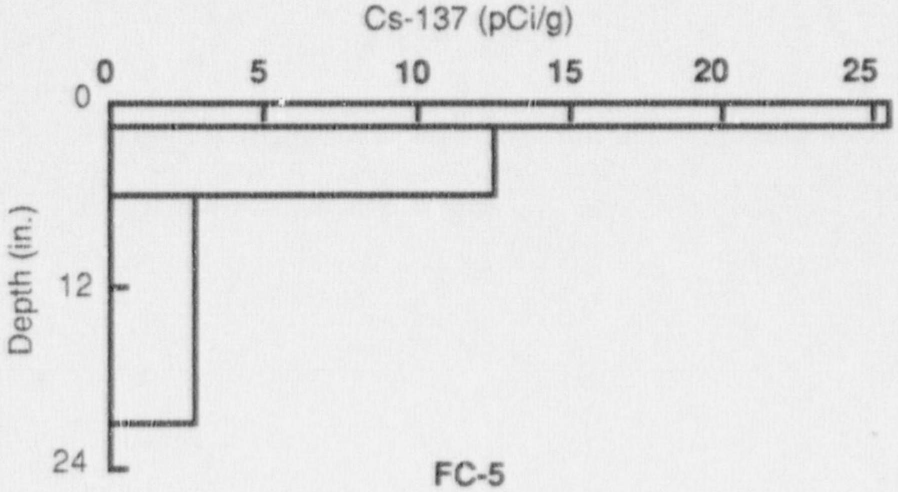


FC-3

Figure 19. Activity of ^{137}Cs vs. depth



FC-4



FC-5

Figure 20. Activity of ^{137}Cs vs. depth

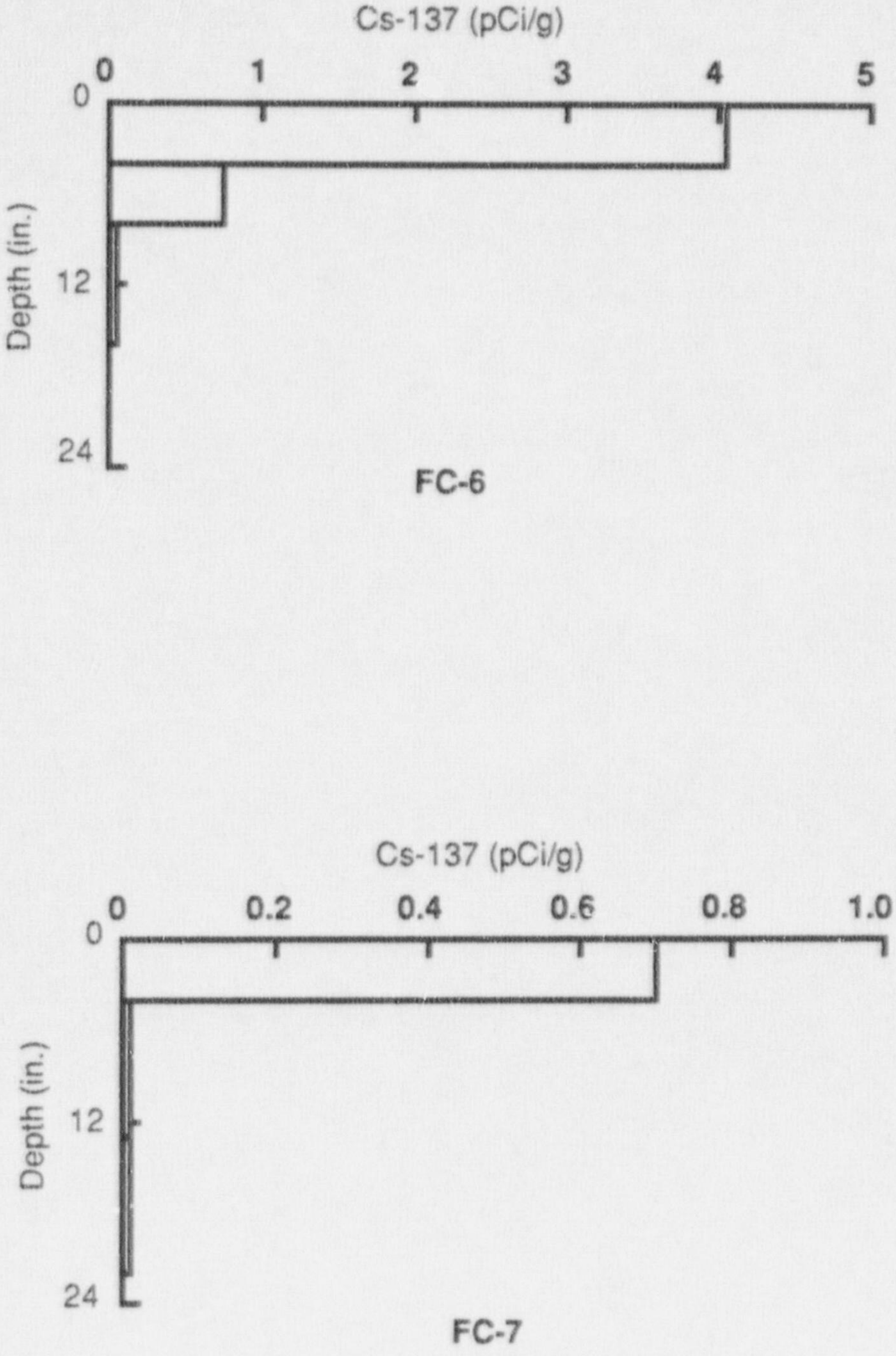
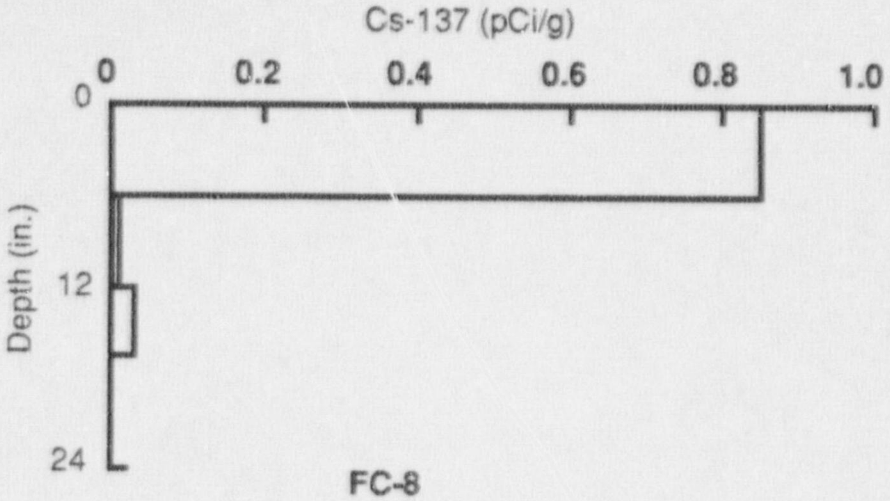


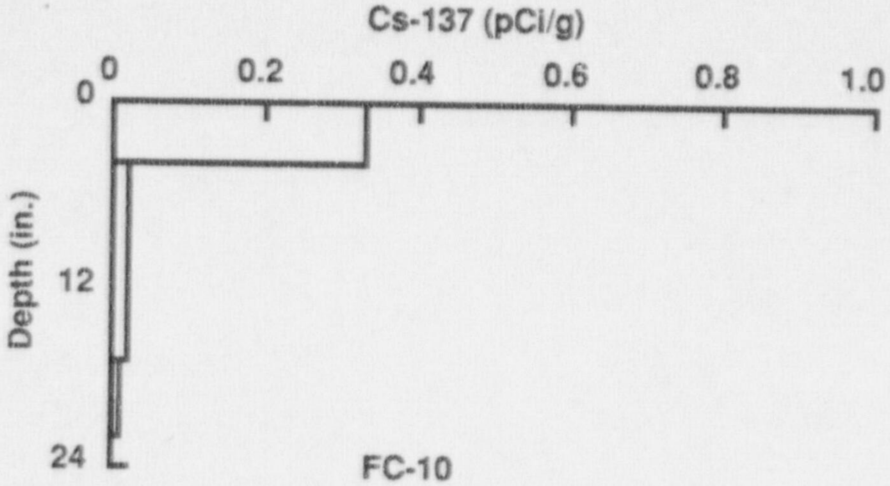
Figure 21. Activity of ^{137}Cs vs. depth.



FC-8

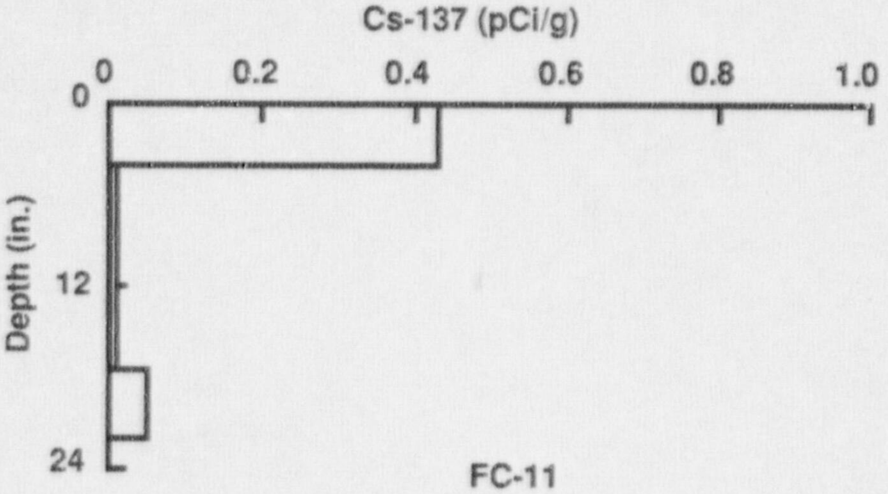
FC-9

Not plotted. Intervals 0-9 and 12-23.5 are less than 0.01 pCi/g and less than MDC; interval 9-12 is 0.09 pCi/g.

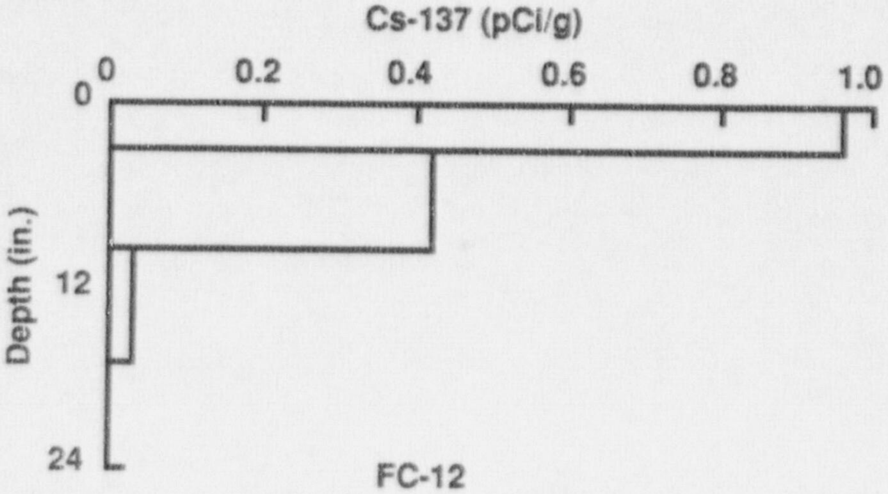


FC-10

Figure 22. Activity of ^{137}Cs vs. depth



FC-11



FC-12

Figure 23. Activity of ^{137}Cs vs. depth.

layers. The subsurface contamination in these holes is in materials that are dominantly red clay and silt, but do contain a component of ash.

Areal Distribution of ^{137}Cs

The areal distribution of ^{137}Cs in surface horizons is shown on Figure 24. All values exceeding 1 pCi/g are within the fence of the Nuclear Facility. Values outside the Nuclear Facility range from 0.04 to 0.96 pCi/g, with a median of about 0.55 pCi/g.

The levels of ^{137}Cs outside the fence are similar to the amount of ^{137}Cs in atmospheric fallout from nuclear weapons tests. A graph of ^{137}Cs fallout for New Yor. City indicates about 25 dpm/cm^2 or 11.26 pCi/cm^2 of fallout in the period 1952 to 1978, mainly during 1958-60 and 1963-65 (Smith et al., 1987). Assuming that half of this ^{137}Cs has decayed ($T_{1/2}$ of ^{137}Cs is 30.2 yrs), and that a surface layer thickness of 12 cm and density $1.5 g/cm^3$ contains the fallout, then the calculated concentration is 0.3 pCi/g. ^{137}Cs levels of 0.08 to 1.3 pCi/g are observed in soils apparently unaffected by nuclear power plants (Bunzl et al, 1984). A better comparison using soils several miles from the Saxton Facility is desirable, but it seems likely that most of the ^{137}Cs from sites outside the fence of the Nuclear Facility is from weapons testing fallout, with at most only a subordinate contribution from the SNEC operations.

Hole FC-5 shows the highest concentrations of ^{137}Cs (25.8 pCi/g). This hole is a few feet from the vicinity of a drain where slight contamination had been recognized by GPU personnel. The contamination has penetrated to at least the bottom of hole FC-5 at 24 in., in fill material predominantly consisting of red clay with an admixture of bottom ash, crushed limestone, sandstone and siltstone.

In FC-1, a similar pattern of ^{137}Cs is found, with highest values in surface fly ash, but detectable values of 1.4 pCi/g occur in bottom ash at 15-

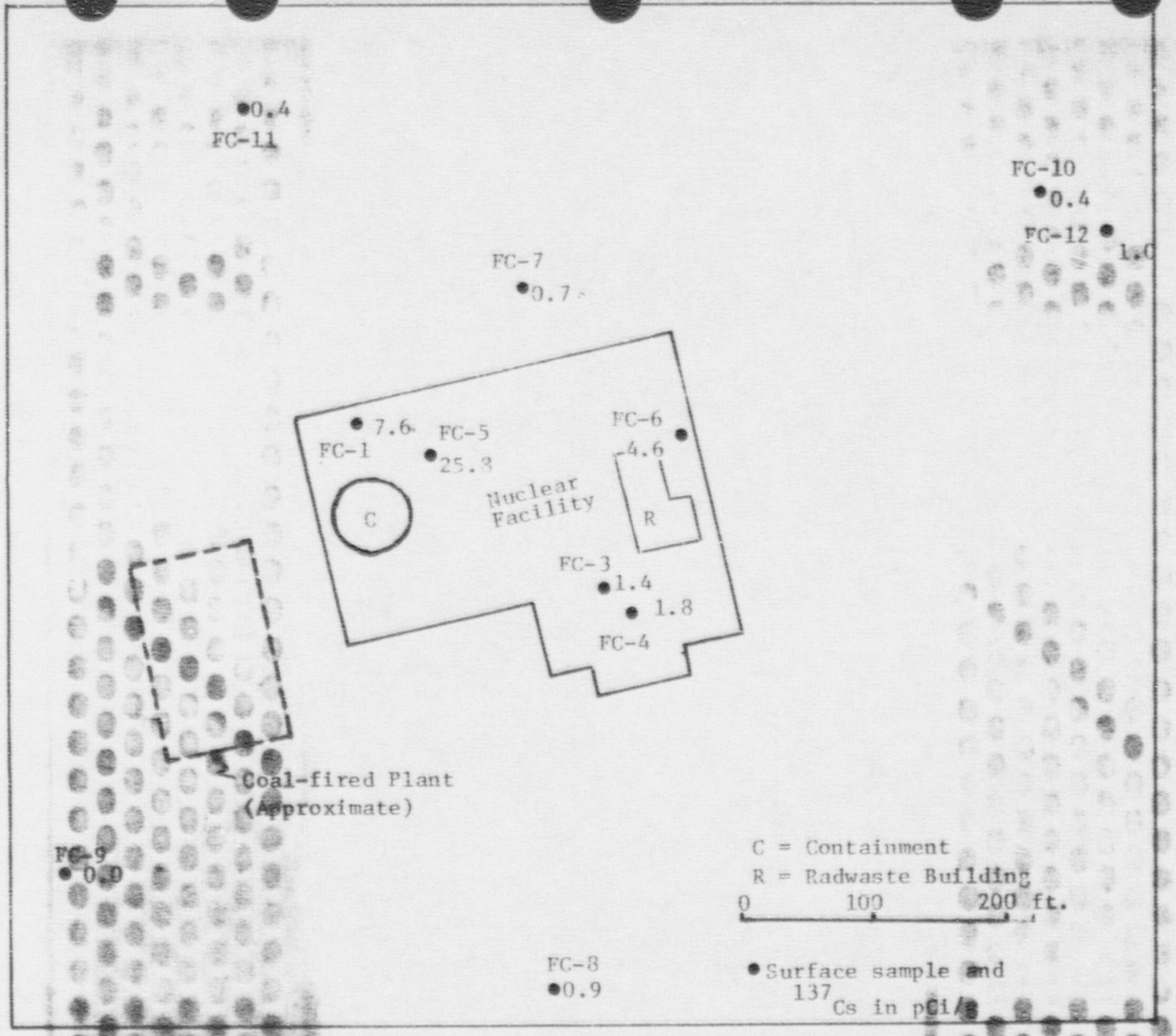


Figure 24. Distribution of ^{137}Cs (pCi/g) in surficial samples from drillholes.

24 in. The presence of bottom ash at 24 in. indicates that the entire thickness cut by the hole is fill. This behavior contrasts with hole FC-6, where the top two layers contain appreciable ^{137}Cs, but the bottom layer of silt with sandstone fragments lacks detectable ^{137}Cs and appears to be natural material, undisturbed by Nuclear Facility construction.

The detectable values of ^{137}Cs in FC-3 and FC-4 in the bunker are restricted to the top layers, and deeper layers contain less than the MDC.

In summary, elevated ^{137}Cs levels are found in samples within the facility fence, and in two holes the contamination extends into the deepest samples. Outside the fence, levels in samples collected for this study are approximately that expected for worldwide atmospheric fallout from weapons testing, and decrease to essentially zero in undisturbed natural materials at depth.

Distribution of ^{137}Cs by Particle Size

For three samples, (FC-1, 0-1.5, PSU 5176; FC-6, 0-4, PSU 5186; FC-10, 0-4, PSU 5201), the radioactivity of a series of sieve fractions was studied. Samples 5176 and 5186 are from within the facility fence and are dominated by fly-ash with anomalous ^{137}Cs, whereas 5201 is a fly ash with "fallout-level" ^{137}Cs. Table 3 summarizes the data.

In all three samples, the ^{137}Cs content increases markedly with decreasing particle size. The increase is by a factor of at least 3 from the coarsest to the finest fraction in each sample. This data suggests that the host for ^{137}Cs tends to be enriched in the smaller particle sizes or that ^{137}Cs is enriched on surfaces.

For two of the three samples, a fraction coarser than 140 mesh (105µm, boundary of silt and sand) contains the largest proportion of ^{137}Cs in the sample. Thus, although the silt and clay fractions contain the highest concentrations of ^{137}Cs, the abundance of fines in the sample is low enough that most of the ^{137}Cs is in the sand size fraction.

Table 3. Distribution of ^{137}Cs by Particle Size

Sample	Sieve fract.[1]	Size (mm)	^{137}Cs[2]	% of mass[3]	% of ^{137}Cs[4]
5176	+20 mesh	>0.85 (Sand)	4.08 pCi/g	2.0	0.7
FC-1, 0-1.5	-20 +140	0.10-0.85(Sand)	11.91	59.3	57.4
	-140	<0.10 (Silt/Clay)	13.35	38.7	42.0
5186	+4	>4.75 (Gravel)	0.*	29.8	0
FC-6, 0-4	-4 +10	2-4.75 (Sand)	3.52	14.6	9.8
	+10 -40	0.425-2 (Sand)	5.09	13.5	13.1
	-40 +140	0.10-0.425 (Sand)	9.22	27.0	47.3
	-140 +200	0.074-0.10 (Silt)	8.71	4.6	7.6
	-200	<0.074 (Silt/Clay)	11.68	10.0	22.2
5201	+4	>4.75 (Gravel)	0.164	23.6	4.8
FC-10, 0-4	-4 +10	2-4.75 (Sand)	0.099	9.3	1.1
	-10 +40	0.425-2 (Sand)	0.357	22.8	10.2
	-40 +140	0.10-0.425 (Sand)	1.172	26.5	38.9
	-140	<0.10 Silt/Clay)	2.104	17.0	44.8

*Block of limestone (2 in. diam.) assumed to contain no ^{137}Cs.

[1] The sieve fraction indicates the U.S. Standard Mesh screen on which the indicated mass was retained. Size indicates the nominal opening of the sieve.

[2] The Activity of ^{137}Cs per gram of this fraction.

[3] The percentage of the total sample mass retained on this sieve.

[4] The percentage of the total ^{137}Cs activity residing in this sieve fraction.

Distribution of ^{137}Cs in Selective Chemical Extracts

The results of the sequential chemical extractions on two fly ash samples are listed in Table 4 and summarized in Figure 25. Six fractions have been separated, designed to selectively extract exchangeable cations, cations bound in organic matter, cations incorporated in ferric iron oxides, cations extractable by strong acid (1:1 HNO_3), and those in the undissolved residue of "sand" size (coarser than 325 mesh or 50µm), and those of "silt-clay" size (finer than 325 mesh). The various extractions are not completely selective for the named fractions, but should represent dominantly the intended material.

Comparison of the fractions with the original sample indicates that the sum of ^{137}Cs activities for the fractions slightly exceeds the measured activity for the original sample (123% and 110% recovery for 5176 and 5186, respectively). The excess recovery exceeds the counting error and appears to result from calibration problems with the different types of samples. However, the error is relatively small in comparison with the fractions of higher activity, so the major conclusions below seem justified. However, the activities of fractions are likely to be overestimated rather than underestimated.

In both samples, the proportion of activity in the exchangeable, organic and Fe-oxide fractions is small, indicating very little ^{137}Cs is weakly bound and capable of mobility in soil formation and ground water. In both samples, the proportion of activity in these forms is less than 15% of the total.

In sample 5186, the acid extractable ^{137}Cs is only 11% of the total, and in sample 5176, it is 34%. The remaining 53% in 5176 and 75% in 5186 was not removed by any of the chemical extractions, and remains in the solid particles. The bulk of the ^{137}Cs is therefore very strongly bound to the solids. The 1:1 HNO_3 leach is expected to strip off most ions that became

Table 4 Distribution of ^{137}Cs and ^{40}K in Products of Selective Chemical Extraction

Sample FC-1, 0 - 1.5 in. (PSU 5176)

	^{137}Cs						^{40}K	
Fraction	Activity	Error (16)	% Error	% of ^{137}Cs	Mass	Activity	Activity	% of ^{40}K
Exchangeable	25 pCi	2.2	9	4.4	-	-	n.d.	0
Organic	39	2.4	6	6.9	-	-	(28)	(6.8)
Fe-Oxide	6	2.0	33	1.1	-	-	n.d.	0
Acid	194	4.4	2	34.1	-	-	(39)	(9.5)
Sand (+325 mesh)	192	3.5	2	33.7	44.3g	4.326pCi/g	285	59.5
Silt/Clay (-325 mesh)	113	1.8	2	19.9	3.63	31.171	58	14.1
Total of Fractions	569	7	1.2	100.1	47.93	-	410	99.1
Initial Sample	461	4.7	1.0	-	60.54g	7.62pCi/g	271	

Sample FC-6, 0-4 (PSU 5186) (Coarse limestone fragments removed to leave fly ash only)

	^{137}Cs						^{40}K	
Fraction	Activity	Error (26)	% Error	% of ^{137}Cs	Mass	Activity	Activity	% of ^{40}K
Exchangeable	45 pCi	2.7	6.1	4.1	-		(25)pCi	(1.9)
Organic	55	2.5	4.6	5.0	-		(20)	(1.5)
Fe-Oxide	47	2.5	5.4	4.3	-		n.d.	0
Acid	120	5.7	4.8	11.0	-		n.d.	0
Sand (+325 mesh)	306	5.3	1.7	27.9	66.8g	4.58pCi/g	719	54.1
Silt/Clay (-325 mesh)	522	5.3	1.0	47.7	37.2	14.04	564	42.5
Total of Fractions	1095	10	0.9	100.0	104.0g	-	1328	100
Initial Sample	996	50	5.0	-	122.1	8.17pCi/g	835	

( ) Indicates amount less than MDC
n.d. Not detected (apparent negative value)

See explanation on following page.

Explanation of Table 4

Column 1. The fraction or step in the selective extraction, or a calculated value for the sum of the fractions, and the measured value for the initial sample.

Column 2. The activity of ^{137}Cs in the indicated fraction or material. For the exchangeable, organic, Fe-oxide and acid fractions, the determinations of Table 2 are pCi/ml, and the values in Column 2 were calculated from pCi/ml times the milliliters of this fraction (usually 100 to 120 ml). For the sand and silt/clay, the values in Table 2 in pCi/g were multiplied by grams of this fraction (Col. 6) to obtain the total activity in the fraction. Examples: The initial samples weighed 60.54 and 122.1 g for samples 5176 and 5186, respectively, containing 7.62 and 8.17 pCi/g, respectively. The total activity in sample 5176 is therefore 60.54 g x 7.62 pCi/g = 461 pCi. The organic fraction of sample 5176 contained 0.325 pCi/ml, and had a volume of 120 ml, to give 39. pCi of ^{137}Cs. The sum of the activities of the fractions in sample 5176 is 569 pCi, compared to 461 pCi measured in the initial sample. The excess appears to result from differences in absorption and counting geometry for the fractions vs. the total sample.

Column 3. Counting error (pCi) at the 1 standard deviation level, calculated from values in Table 2. Counting error for the sum (S_T) is computed as the weighted sum of individual fractionss ($S_T^2 = a_1 5_1^2 + a5_2^2 + ...$) where S_i is the 1σ counting error for an individual fraction, and a_i is the weight of this fraction in the total (pCi in fraction/pCi in sum).

Column 4. Counting error as a percentage of the activity in the fraction, calculated from columns 2 and 3.

Column 5. The percentage of ^{137}Cs in each fraction relative to the sum of the fractions, as listed in Column 2.

Column 6. The mass of sand or silt/clay recovered at the end of the selective extraction procedure, the sum of the sand + silt/clay masses, and the initial sample mass subjected to the selective extractions. The differences between initial and fraction totals represent mass dissolved in the first 4 steps.

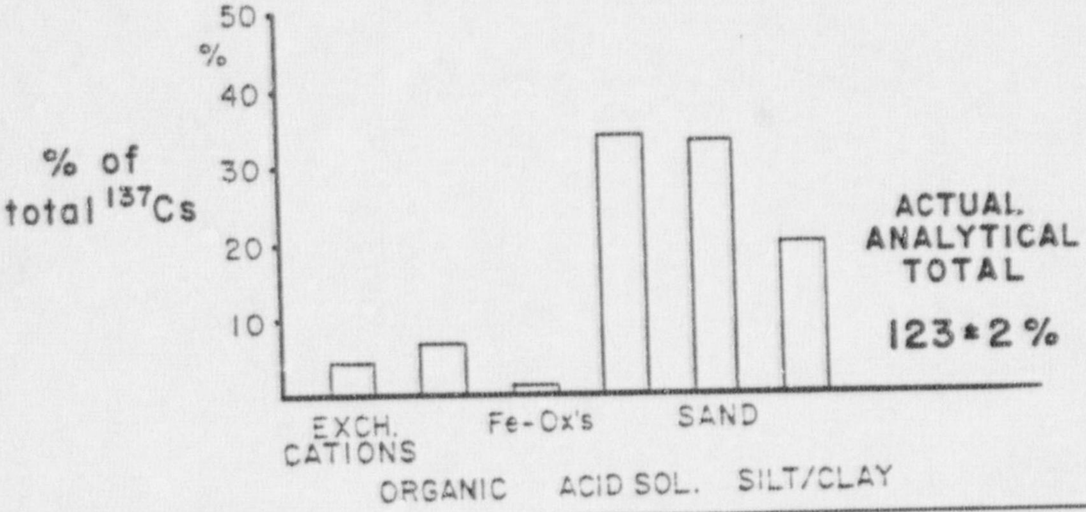
Column 7. The activity of ^{137}Cs per gram of the sand and silt/clay fractions (Col. 2/Col. 6), or the activity /g of ^{137}Cs in the total sample.

Column 8. Data for ^{40}K like that in Column 2 for ^{137}Cs.

Column 9. Data for ^{40}K like that in Column 5 for ^{137}Cs.

SELECTIVE EXTRACTION OF TWO SAXTON, PA SAMPLES: FC-1 and FC-6

FC-1, 0-4" (PSU: 5176)
TOTAL ^{137}Cs - 7.62 pCi/g



FC-6, 0-4" (PSU: 5186)
TOTAL ^{137}Cs - 8.17 pCi/g

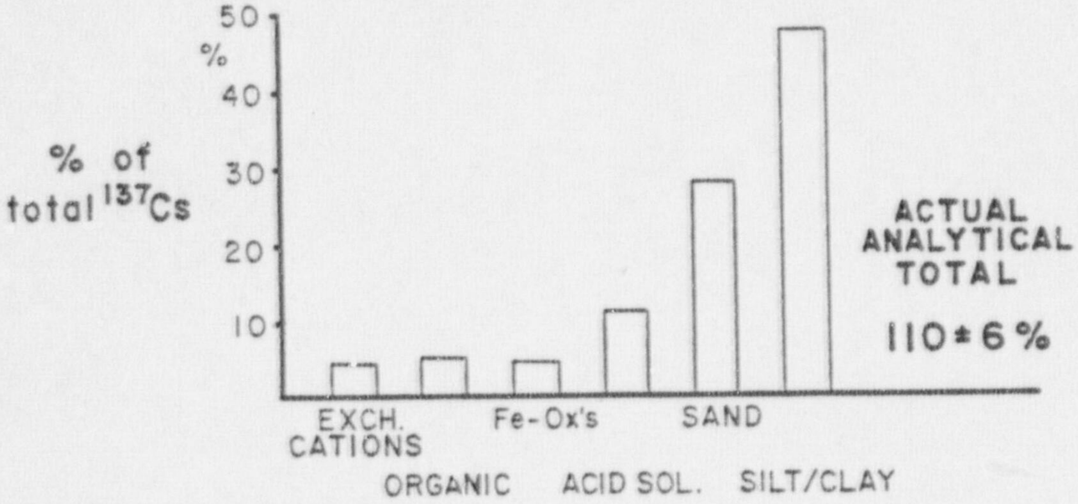


Figure 25. Distribution of ^{137}Cs among fractions of selective extractions.

incorporated in the sample by adsorption or precipitation from solution; indeed, the exchangeable, organic and Fe-oxide extractions would be expected to extract much of an adsorbed fraction. Thus, the ^{137}Cs is incorporated very firmly in the sample.

Additional insight on the form of ^{137}Cs can be gained by comparison with ^{40}K. Unfortunately, the counting error for ^{40}K is relatively large, so that activities in the exchangeable, organic and Fe-oxide fractions are consistently below the MDC, but the MDC is relatively high. However, the consistent pattern of low ^{137}Cs in all six of the mobile fractions and the reasonable sums of the ^{40}K fractions lend strength to the argument that ^{40}K is very low in these fractions. Both Cs and K are alkali metals, with similar ionic size, charge and bonding properties.

If the ^{137}Cs was actually incorporated into well-fused ash during the process of forming the ash in the coal-fired plant, then one might expect the ^{137}Cs and ^{40}K to behave similarly during selective extraction. However ^{40}K appears distinctly more firmly bound than ^{137}Cs. An estimated total of 84 and 97% of the ^{40}K remains in the sand and silt/clay fractions compared to 53 and 75% of the ^{137}Cs. Based on this data, ^{137}Cs is not bound as strongly as ^{40}K, the latter probably being distributed within the silicate network of the glass particles, or in unfused illite or other K-bearing aluminosilicates. In contrast, at least some ^{137}Cs apparently occurs on or near the surface of the particles.

Autoradiography

In order to discern the distribution of ^{137}Cs in surficial materials at Saxton, PA, with greater resolution, autoradiography was performed on five samples initially (another autoradiograph is in progress using six samples). Autoradiography is the process where a sample is placed on a film sensitive to the radiation of interest, for a period of time. Radioactivity in the sample, either natural or anthropogenic, exposes the film immediately adjacent to the radioactive source in the sample. After the film is developed, a comparison is made between the exposed areas on the film and the grains in the sample; where grains in the sample are strongly radioactive, areas of high exposure are resultant. The grains in question may be removed from their mounting medium to be analyzed further. In addition, this method will identify those types of grains that are typically more radioactive than other grain types. A cut and polished grain mount may also be used in an autoradiograph in order to characterize the spatial distribution of radionuclides within a single grain.

The first autoradiograph made for this study used Dupont chronex safety double-emulsion X-ray film (standard in most hospitals). This film is sensitive to X-rays and beta-particles and will not resolve between the two or even between betas of different energies. The Saxton, PA samples are known to contain naturally occurring ^{40}K and U and Th series daughters and anthropogenic ^{137}Cs in various proportions. Unfortunately, many of the above nuclides emit betas energetic enough to expose the film. In order to help resolve which nuclide is responsible for film exposure, five samples of varying ^{40}K/^{137}Cs ratios were used: FC-1, 0-2"(1:2); FC-3, 0-5" (15:1); FC-5, 0-1.5" (1:3); FC-6, 0-4" (1.5:1); and FC-10, 0-4" (~25:1). The samples were mounted in Kadex, an artificial Canadian balsam, and flattened (not cut and polished); they were then sealed in a pressure-backed, light-tight X-ray cartridge and exposed for fourteen days. This initial autoradiograph (enclosed in this report) shows images suggesting that the mounting medium either chemically exposed or phosphorescently exposed the film, leaving the sample grains in a shadow of relatively poor exposure. Six new samples (the five listed above plus FC-6, 0-4" 'sand fraction after selective extraction', ^{40}K/^{137}Cs-2.5:1) were mounted in Cold-seal, cut and polished and allowed to sit in the dark for 48 hrs. to let any residual phosphorescence to decay away. The samples were placed in the pressure-backed cartridge with single-emulsion hospital-grade film. The exposure time will be one month; meaningful results will be included in a following report.

REVIEW OF FLY ASH

The recognition that radioactivity at Saxton occurred in the surficial fly ash layer prompted an interest in this material. A very large amount of literature exists on fly ash, largely as a result of DOE-funded research in the 1970's and early 1980's. Only a small part of this has been examined, partly because of the voluminous quantity and partly because of the results of the research at Saxton have led to some question as to whether the radioactivity is actually in the fly ash particles.

Fly ash is the portion of ash formed in burning of coal or petroleum that is small enough, in terms of particle size, to be entrained in the flue gas and carried away from the site of combustion (Roy et al, 1981). Fly ash particles are typically derived from the melting of mineral matter or the partial combustion of coal. In general, about 70 to 80% of the solid waste derived from coal combustion is fly ash.

The particle size of fly ash is dominantly silt-size, with 65 to 90% of material recovered by fly ash collectors having a particle size less than 10µm, though the size depends on furnace characteristics. The fly ash at Saxton is predominantly coarser than this size, probably because the coarse particles are concentrated close to the stack, and fine particles travel farther.

Microscopic examination of fly ash shows a wide range of particle shapes and appearances. Some particles are spherical, others are irregular and angular to rounded. Some particles are opaque owing to being unburned to partially burned coal, and others are translucent glass, with a variety of forms and characters in between.

Mineralogically, quartz (SiO_2), mullite ($Al_6Si_2O_{13}$), hematite (Fe_2O_3) and magnetite (Fe_3O_4) are the most common crystalline phases. Amorphous material, in part glass, makes up 50 to 90% of typical fly ash. Chemical composition of typical fly ash is listed in Table 5, and additional data is in Turner et al (1982). SiO_2 and Al_2O_3 are the dominant constituents, with other important components being Fe_2O_3, CaO, MgO and K_2O. Minor Na and S are commonly present. Carbon can be present at levels up to at least 20%, and tends to be higher in products of older boilers. A wide variety of trace elements have been detected, some (mainly sulphophile metals) considerably enriched over levels for normal rock and soil and for input coal. Enrichment in cesium is not reported but may not have been looked for. Volatile elements (S, Hg, Se, As, Pb, Zn, Cd, etc.) tend to be particularly enriched in fly ash compared to coal. These volatiles include ^{210}Pb, U, Th and possibly other components of the natural U and Th decay series (Tadmor, 1986). The volatile trace metals tend to be enriched in the near-surface portion of fly ash particles (Stinespring et al, 1985) as a result of condensation in the cooler zone of the stack.

Initially, large amounts of relatively soluble or desorbable elements are present in fly ash. These include S, As, Cd, Pb, and other heavy metals. These eventually are leached away, and the fly ash then has a significant capacity to adsorb various metals (Liskowitz et al, 1986). Presumably the adsorption is caused by the unsatisfied surface charges of the glass, though no literature has been found on this topic. The glass probably devitrifies somewhat on exposure to lower temperatures and moisture, thereby redistributing constituents in the surface layer, and changing its adsorption characteristics.

Table 5.

A. Percentages of concentration of the major elements (in their oxide forms) in 13 fly ash samples. (from Roy et al., 1981)

	References cited												
	Hanson et al.[a] (1975)		Natusch et al.[b] (1977)	Smith et al.[c] (1979a)	Block and Dams[d] (1976)	Chu et al.[e] (1976, 1978)		Bickelhaupt[e] (1975)		Ondov et al.[f] (1975)	Page et al.[g] (1979)	Chang et al.[e] (1977)	Block and Dams[d] (1975)
SiO_2	23.32	50.49	23.50	47.06	-	49.70	18.26	57.27	22.00	44.92	21.39	2.14	53.70
TiO_2	0.27	1.61	0.79	1.33	0.50	1.27	1.07	1.05	0.60	1.23	-	-	0.75
Al_2O_3	12.79	26.64	-	20.78	10.96	31.19	18.52	27.16	14.80	24.00	34.01	32.50	22.67
Fe_2O_3	12.18	3.60	13.21	5.00	8.86	8.76	20.79	3.81	11.20	8.86	7.42	7.15	4.58
MnO	0.10	0.10	0.04	0.12	0.05	0.05	0.05	-	-	0.06	0.02	-	0.11
MgO	2.24	0.27	2.04	2.98	1.86	1.53	1.23	0.94	12.75	2.98	2.82	2.32	5.31
CaO	19.03	0.70	-	6.58	1.96	1.82	5.74	5.18	31.00	16.58	14.41	8.68	5.29
Na_2O	-	-	-	1.54	1.20	0.32	0.66	1.83	1.84	0.43	1.62	-	0.54
K_2O	0.79	3.09	7.06	2.55	0.56	4.34	3.37	1.19	0.20	2.93	0.98	-	6.09
P_2O_5	-	-	0.14	-	-	-	-	0.17	0.39	-	0.09	4.12	0.92
SO_3	-	-	1.77	1.30	-	0.40	1.55	0.33	1.83	-	1.83	-	2.75

[a] $NaOH-Na_2O_2$ fusion and atomic absorption spectroscopy.

[b] Spark source mass spectrometry.

[c] X-ray fluorescence and neutron activation.

[d] Neutron activation.

[e] Not stated.

[f] Neutron activation and photon activation gamma-ray detection.

[g] Na_2CO_3 fusion, spectroscopy, turbidemetrically, colorimetry, and neutron activation.

TABLE 5B Range and average chemical composition of fly ash (data from publications listed in Table 5C

Constituent	Range (%)	No. of data	Average (%)	Std. dev. (%)
SiO_2	2.19-68.1	58	44	13
TiO_2	0.5-2.55	39	1.3	0.5
Al_2O_3	3.39-39.4	60	23	6.5
Fe_2O_3	3.60-29.2	58	11	6.5
MnO	0.02-0.24	14	0.1	0.1
CaO	0.2-31.0	58	8.2	8.0
MgO	0.4-12.8	58	2.7	2.7
Na_2O	0.2-8.0	50	1.8	2.0
K_2O	0.2-8.1	49	2.0	1.8
P_2O_5	0.08-6.0	34	0.8	1.7
C	0.1-25.7	12	4.0	7.3
SO_3	0.1-7.28	47	1.6	1.9

TABLE 5C Bibliography of major studies containing results from chemical analyses of fly ashes.

Area of major concern	Reference
Major elements	Bickelhaupt, 1975; Funnell and Johnson, 1976; Nowak, 1974; Roy, Murtha, and Burnett, 1979; and Schuller et al., 1979.
Trace and minor elements	Coles et al., 1979; Fisher, Chrisp, and Raabe, 1979; Kaakinen et al., 1975; Lee et al., 1972, 1975; Lee and von Lehmden, 1973; Natusch et al., 1974a, 1974b; Ondov, Ragaini, and Biermann, 1979a, 1979b; Phung et al., 1979; and Theis and Wirth, 1977.
Detailed analytical studies	Block and Dams, 1975, 1976; Campbell et al., 1978; Chang, et al., 1977; Davison, 1974; Dvorak and Lewis, 1978; Furr et al., 1976a, 1977, 1978; Griffin et al., 1980; Hanson, Carpenter, and Henderson, 1975; Klein et al., 1975; Linton et al., 1976; Morse, 1979; Natusch et al., 1977; Nadkari, 1980; Ondov, Ragaini, and Biermann, 1978; Page, Elseewi, and Straughan, 1979; Ray and Parker, 1977; Santhanam and Ullrich, 1979; Smith, 1979; Smith, Campbell, and Felix, 1979; Smith, Campbell, and Nielson, 1979; and Torrey (ed.), 1978.

HOST AND FORM OF RADIOACTIVITY

The data discussed on the preceding pages show the following characteristics of the ^{137}Cs and other man-made radionuclides:

1. The activity is concentrated in the top few inches in nearly all drill holes.

2. The ^{137}Cs in drillholes outside the fence of the nuclear facility is at low levels, and could be derived largely from regional atmospheric fallout from weapons tests. Activities of ^{137}Cs beneath the surficial layer are negligible for these drillholes.

3. Within the facility fence, ^{137}Cs levels are considerably higher, up to 25 pCi/g, and extend to at least 2 ft. depth, though the concentration falls off with depth beneath the surface.

4. The ^{137}Cs is present in all particle sizes, but increases in activity (pCi/g) in the fine sizes. However, a large proportion typically occurs in the fine sand size (0.1-0.425 mm), because of its large mass fraction.

5. The samples with elevated ^{137}Cs contain dominantly fly ash, but they also contain smaller amounts of siltstone fragments and other materials.

6. Selective chemical extractions indicate very strong bonding of ^{137}Cs to solid particles; 53 to 75% of the ^{137}Cs resists extraction by 1:1 nitric acid. The ^{137}Cs appears to be slightly less strongly bonded than ^{40}K, a natural radionuclide, in the samples.

7. Activities of ^{137}Cs in the fine sieve fractions and in the clay fractions of the selective extraction series reach levels as high as 30 pCi/g.

8. The presence of ^{137}Cs in fly ash at FC-1 adjacent to the location where spent resin tanks were removed and above bottom ash used as fill for the former tank sites suggests that the radioactivity accumulated during or after removal of the tanks in 1972. One possibility is that some of the surficial material accumulated by wind action after 1972.

Three possible hosts for ^{137}Cs can be envisioned:

1. Illite clay occurring as a small proportion of siltstone and sandstone particles mixed with the fly ash.

2. Fly ash particles.

3. Trace amounts of unrecognized particles that are highly insoluble and contain relatively high ^{137}Cs activities.

Illite is a potassium-bearing clay mineral with a composition of (K, H_2O) $(Al, Mg, Fe)_2$ $(Si, Al)_4O_{10}$ $(OH)_2$. It has long been recognized as a strong scavenger of Cs, and the main host for ^{137}Cs in soils and stream sediments (Shulz et al., 1960; Jenne and Wahlberg, 1968). Cesium substitutes for potassium, another alkali metal with very similar ionic radius and identical charge, in illite. Illite is known to be the major clay mineral in sedimentary rocks of the region and in soils and stream sediments, and is detected by X-ray diffraction analysis of the samples (Appendix E). Research has shown that K and Cs can occupy three types of sites in illite (Bolt et al., 1963; Cremers et al., 1988):

1. Readily exchangeable K and Cs on the large exposed basal planes of the illite flakes. This type of site furnishes a large proportion of the ion exchange capacity of illite, but only a small proportion of the K and Cs are held on these sites (Cremers et al., 1988).

2. Interlayer sites binding the tetrahedral and octahedral sheets of the aluminosilicate structure together. K and Cs are bound extremely strongly into these sites because their large size fits very well and because these large ions are only weakly coordinated with water molecules, in contrast to Ca, Na, Mg, etc.

3. Edge or wedge sites, making up only a few percent of the exchange capacity of illite, but containing a high proportion of exchangeable K and Cs. The wedge sites represent weathered edges of the illite crystal structure,

where the interlayer sites have been opened up for a few unit cells and occupied by water and cations. Experiments show that these sites have very strong affinity for K and Cs, which enter and collapse the lattice to make further exchange very difficult (Lomenick and Tamura, 1983).

Research using ^{137}Cs and ^{41}K shows that they are initially adsorbed into wedge sites, but over periods of a year or more they diffuse further from the edge and become nonexchangeable (Jenne and Wahlberg,k 1968).

The very strong bonding of ^{137}Cs in the Saxton samples is consistent with adsorption on wedge sites of illite followed by partial migration into the structure so as to be non-exchangeable even in strong acid. Under this hypothesis, the small amounts of exchangeable and acid-extractable ^{137}Cs represent the fraction still in accessible wedge sites or on exposed basal surfaces.

Fly ash, being the major component of the radioactive surficial materials, clearly must be considered as a possible host. The major components of fly ash particles are aluminosilicate glass, carbonaceous material, and various fine-grained minerals (quartz, mullite, Fe-oxides). It has been suggested that the ^{137}Cs might have been on material that was burned in the coal-fired plant and thereby become incorporated in the fly ash. The main evidence against this hypothesis is the abrupt change in ^{137}Cs passing from within to outside the nuclear facility fence. Any emission from the power plant stack would be spread over a much larger area, with an approximately inverse square decrease away from the stack. The observed drop-off is much faster. Also, if the fly ash was completely melted and homogenized during the burning process, the ^{137}Cs would be uniformly distributed throughout the fly ash particles in a manner similar to the natural ^{40}K, but the data suggest that ^{137}Cs is somewhat more accessible to solvents than the ^{40}K.

Another possibility for incorporation of ^{137}Cs in fly ash is by adsorption on the surface followed by stronger fixation during devitrification of the glass. This process might be initiated by a spill of radioactive solution or solids on the surface, followed by migration of ^{137}Cs in solution until it was adsorbed by the glass. In this form, it would be expected that the Cs would be easily desorbed. However, glasses commonly devitrify, especially on exposure to the weather, and in this process the components are rearranged to form tiny crystallites. If Cs was incorporated into the crystallites during this stage, it might be further from the surface and incorporated in an insoluble crystal that would dissolve only with difficulty.

The third possibility is that the fly ash contains a very small amount of strongly radioactive particles, as a result of some contamination event. The particles could not be resin particles, since the Cs would be readily exchangeable from them. However, the incorporation of Cs into an insoluble oxide or other phase seems possible. This type of particle should show up on the autoradiographs, but was not detected. Therefore, such particles are either extremely rare, so that their detection is statistically improbable, or they do not exist.

With the evidence available, it is not possible to decide definitely among these alternatives. Indeed, it is quite likely that the ^{137}Cs occurs in more than one of these forms. If the contamination was released in a form that allowed mobility of ^{137}Cs in solution, then it seems certain that at least some of the ^{137}Cs occurs in both illite and glass, the question being the proportion of each. The limited depth extent of the ^{137}Cs shows that it is being rapidly immobilized by some interaction, and either of these forms seems possible.

Given the above state of knowledge, several further experiments might be conducted to establish the form of the ^{137}Cs:

1. Separation of illite-bearing particles from the fly ash, either by hand-picking of particles, by density, by magnetic separation of glass, or by size fractionation of clays, followed by radiometric analysis, should improve information on the form of the radioactivity. A large sample should be used for this study in order to acquire the needed counting statistics.

2. Further selective extraction experiments using HF to dissolve the outer layer of silicate minerals and glass, or moderate strength KOH to dissolve aluminosilicates, should allow a decision on whether the ^{137}Cs occurs on the surface of particles or is uniformly distributed.

3. Further autoradiography experiments, using liquid emulsions in combination with microscopic methods, might give better information on the host for ^{137}Cs, though the problem of distinguishing between ^{137}Cs and nuclides of the U, Th and K series remains a problem.

4. Collect and analyze more samples farther from the fence to determine if most of the activity outside the fence is fallout.

SUMMARY AND CONCLUSIONS

1. Based on materials recovered from eleven 2-foot split spoon auger drillholes (FC-series drillholes), plus previous drilling of 13 deeper drillholes, the following types of unconsolidated materials are present at the Saxton Nuclear Facility:

Materials related to nuclear and coal-fired power plants:

- Fly ash (surficial layer, locally buried)
- Coal (local component of surficial material)
- Bottom ash (fill and regraded surfaces)
- Crushed limestone (surface layer; base for asphalt)
- Red clay with siltstone fragments (fill)

Natural materials

- Sand, silty sand, gravel (flood plain deposits of a former stage of Raystown Branch)
- Boulder clay (former bed of Raystown Branch)

2. Man-made radionuclides detected are ^{137}Cs and ^{60}Co, of which ^{137}Cs is the only one exceeding the Minimum Detectable Concentration (MDC) in more than a few samples. Normal activities of natural radionuclides in the U, Th and K series exceed the activities of man-made radionuclides in most samples.

3. The ^{137}Cs is strongly concentrated in the top few inches in most drill holes. Outside the fence of the nuclear facility, it does not exceed 1.0 pCi/g, with a median of about 0.5 pCi/g. The concentrations in these samples may arise almost completely by regional atmospheric fallout from nuclear weapons tests, although a component from the nuclear facility is not precluded. Activities of ^{137}Cs in these samples are far lower than activities of natural radionuclides of the U, Th, and K series.

4. Activities of ^{137}Cs in surface layers of drillholes inside the fence all exceed 1.0 pCi/g, reaching 25, 8 and 4 pCi/g in materials rich in fly ash

in FC-5, -1, and -6, respectively. Activity of ^{137}Cs decreases downward at these sites but is still detectable in the bottom samples of these holes.

5. Activity of ^{137}Cs in 3 samples (FC-1, 0-1.5; FC-6, 0-4: FC-10, 0-4) consistently increases with decreasing grain size by a factor of as much as 10, reaching 13 pCi/g in the -140 mesh (0.1 mm) fraction of FC-1. However, 39 to 57% of the total ^{137}Cs activity is in the fine sand size (0.1-0.42 mm).

6. Selective sequential extractions for 2 samples rich in fly ash (FC-1, 0-1.5; FC-6, 0-4) show only 12 to 14% of the ^{137}Cs activity is in the exchangeable, organic and Fe-oxide fractions, 11 and 34% is extracted by 1:1 nitric acid, and 53 to 75% remains in the residual sand and silt-clay fractions. Activities reach 31 pCi/g in the silt-clay fraction of FC-1. The activity of the natural radionuclide ^{40}K appears to be even more concentrated in the residual solids, though the relatively high MDC for ^{40}K makes a firm conclusion impossible.

7. Autoradiographs of grain mounts for several samples show no obvious radioactive grains, but the method used led to exposures from the mounting plastic and is not entirely satisfactory. Samples mounted by improved methods are currently being exposed to a different film.

8. Possible hosts for ^{137}Cs in the samples rich in fly ash are illite (a clay mineral), fly ash particles, and unknown highly radioactive particles. The apparent lack of autoradiograph images argues against the last possibility. Illite is the major host for ^{137}Cs in soils and stream sediments, and is known to be present in the surficial materials in small amounts. Initial adsorption of Cs on edge sites followed by migration of Cs to interlayer sites could account for the resistance to acid leaching. Similarly, adsorption on glass in the fly ash particles followed by redistribution during devitrification of the glass can explain the data. It is likely that at least some Cs occurs in both of these two forms, but the

proportion is uncertain. Further experiments are suggested to help resolve this question.

9. The fly ash contains large amounts of carbonaceous material representing unburned or partially burned coal. The major portion has an aluminosilicate composition similar to fly ash reported in the literature.

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GLOSSARY

Alluvium A general term for clay, silt, sand and gravel deposited during recent geologic time by a stream or other body of running water.

Aquifer A body of rock that is sufficiently permeable to conduct ground water.

Bedded Formed or deposited in layers or beds; commonly true of sedimentary rocks.

Bedrock A general term for the rock, usually solid, that underlies soil, alluvium, or other unconsolidated superficial material.

Calcite A mineral composed of calcium carbonate.

Chlorite A group of platy, usually greenish minerals of the general formula $(Mg,Fe)_6AlSi_3O_{10}(OH)_8$. Chlorites resemble micas in cleaving into thin flakes, and are present in many sedimentary rocks and some soils.

Clay 1. A rock or mineral fragment or a detrital particle having diameter less than 0.004 mm. 2. An earthy, extremely fine-grained sediment or soft rock containing a high proportion of clay-size or colloidal particles and characterized by high plasticity and by a significant amount of clay minerals.

Clay mineral One of a group of finely crystalline aluminosilicate minerals with a layer structure, including kaolinite, illite and montmorillonite.

Clinker A rough jagged fragment found in ash from furnaces.

Detritus A collective term for loose rock and mineral material that is worn off or removed by mechanical means, especially sand, silt and clay that is derived from older rocks and moved from its place of origin.

Diamond drilling A variety of rotary drilling in which diamond bits are used as the rock cutting tool. In most instances a hollow cylindrical bit is used, so that a cylindrical core of the rock material is recovered.

Devitrification Conversion of a glass to crystalline material; a common process in nature.

Exchangeable ion An ion occurring on the surface of or within a solid and readily exchangeable for another ion from solution. Clay minerals, such as montmorillonite commonly contain exchangeable ions.

Feldspar A group of abundant rock-forming minerals with the general composition $MAl(Al,Si)_3O_8$ where M=K, Na or Ca. Common feldspars are orthoclase(K) and plagioclase(Na,Ca).

Formation A mappable body of rock identified by lithic characteristics and position relative to other formations.

Flood plain Any flat or nearly flat lowland that borders a stream and may be covered by its waters at flood stage. A flood plain is commonly constructed of alluvium deposited during past floods.

Gravel An unconsolidated natural accumulation of rock fragments resulting from erosion, consisting predominantly of particles larger than sand (i.e., larger than 2 mm).

Hematite An oxide of iron, Fe_2O_3, commonly with a bright red color.

Illite A clay mineral with a mica-type crystal structure. Chemically it is a potassium aluminosilicate, with an approximate composition $K_xAl_4(Si_{8-x}Al_x)O_{20}(OH)_4$ with x less than 2 and commonly 1 to 1.5. The crystal structure is formed of three types of repeating layers (see illustration next page). A strongly bonded sandwich of two tetrahedral layers and one octahedral layer forms the basis of the structure. The tetrahedral layers contain silicon and aluminum surrounded by oxygen in a tetrahedral arrangement. The octahedral layers contain Al, Mg, and Fe surrounded by oxygen in an octahedral arrangement. The three-layer sandwich is less strongly bonded to other such layers of potassium (or cesium) ions, termed interlayer cations.

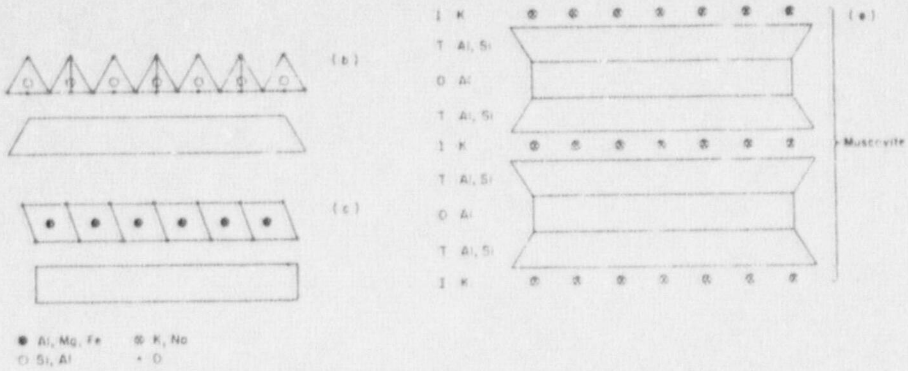


Fig. 6.3. Structure of clay minerals.
(b) side view of tetrahedral layer and schematic representation; (c) side view of octahedral layer and schematic representation;
(e) muscovite structure, schematic representation. T, tetrahedral layer; O, octahedral layer; I, interlayer cations.

Laminated Composed of thin visible layers, applied to fine-grained sedimentary deposits.

Lattice The 3-dimensional regularly repeating set of points that represent the periodicity of a crystal structure.

Limestone A sedimentary rock consisting chiefly of calcium carbonate with or without magnesium carbonate.

Limonite A general field term for a group of ferric oxides and hydroxides, including goethite (FeOOH) and hematite, and mixtures of these minerals; commonly brown in color, and formed by weathering of iron minerals.

Lithified Converted into a stone or solid rock, usually from a loose sediment to a solid rock.

Magnetite A mineral with the composition Fe_3O_4.

Mudstone An indurated mud having the texture and composition of a shale but lacking its fine lamination or fissility.

Member A sub-unit of a formation, with distinctive properties.

Mesh The size of a sieve or screen, or of the material passed by the sieve, derived from the number of meshes per inch; a 20-mesh sieve has 20 holes per linear inch (but because of the size of the wire, the opening is always less that the spacing of wires in the sieve).

Mullite A crystalline compound ($Al_6Si_2O_{13}$) occurring rarely as a mineral but commonly as a product of recrystallization of Al-rich rocks in furnaces.

Parting A thin layer of sedimentary rock separating two layers of another type of sedimentary material. Coal commonly contains partings of shale that form ash if not removed in mining or processing.

Pleistocene A subdivision of geologic time, characterized by glaciation, starting about 1 million years ago and extending up to the Recent, about 10,000 years ago.

Quartz A crystalline form of silica, SiO_2. A very common rock-forming mineral.

Sand A rock fragment or detrital particle with a diameter between 0.062 and 2.0 mm. Sands can be divided into very fine sand (0.062 to 0.125 mm), fine sand (0.125 to 0.25 mm), medium sand (0.25 to 0.5 mm), coarse sand (0.5 to 1 mm) and very coarse sand (1 to 2 mm).

Sandstone A lithified sedimentary rock composed dominantly of sand-sized particles.

Shale A lithified detrital sedimentary rock formed dominantly of silt and clay-sized particles, and having thin lamination or fissility (the ability to split into thin platy fragments along the layering).

Silt A rock fragment or detrital particle with a diameter between 0.004 and 0.062 mm.

Siltstone A lithified sedimentary rock composed dominantly of silt-size particles, but lacking the fine lamination and fissility of a shale.

Sorted Composed of particles of relatively uniform size, said of a sediment or sedimentary rock.

Split-spoon auger drilling A type of drilling normally used in unconsolidated or soft materials. The bit is a hollow cylinder sharpened on one end, and is attached to a hollow cylindrical sample holder 1 or 2 ft.

long. The sample holder splits in half to gain access to the sample. The sampler and bit are usually driven into the ground by a hammer or by dropping a weight.

Strike The direction (as measured by a compass) of a horizontal line on a dipping planar feature, such as the bedding of a sedimentary rock. The angle between the planar feature and a horizontal plane, in a direction normal to the strike, is termed the dip.

Sulphophile metals Metals that form strong bonds with sulfide, as CuS, FeS, ZnS, PbS, Ag_2S, etc.

Appendix A

Drill Logs of FC-Series Holes

Drill Hole FC-1 Drilled 8/11/88

Location: Near north edge of fenced area around containment structure.

Blow Count:

0 - 6 in.	2 blows
6 - 12	13
12 - 18	20
18 - 24	24

Recovery: 24" (100%)

Geologic Log:

1 - 1 3/4 in.	Fly ash and roots with minor red siltstone at base
1 3/4 - 2 1/2	Granular red siltstone fragments, 1-3 mm.
2 1/2 - 15	Reddish sandy silt with minor ash
15 - 24	Mostly black bottom ash, but 20-22" is red clay

Interpretation:

Probably the interval 1 3/4-24" is fill material, possibly of several ages. The top 1 3/4" of fly ash has at least partly blown into the area, because fly ash is present over the adjacent area from which the spent resin tanks were removed.

Drill Hole FC-2

This hole was not drilled, but was replaced by FC-12 as a replicate of FC-10.

Drill Hole FC-3 Drilled 8/11/88

Location: About 1/2 way up the north side of the earthen bunker on north side of the bunker. This bunker had already been stripped of a surface layer of slightly contaminated soil. The drill hole was drilled holding the drill by hand.

Blow Count:

0 - 6"	1 blow
6 - 12	2
12 - 18	3
18 - 24	7

Recovery: 24" (100%)

Geologic Log:

0 - 5"	Loose red clay with siltstone fragments and minor ash
5 - 13	Red clay, coherent, with very sparse rock fragments
13 - 24	Same as above, with sandstone fragments in the bottom 3".

Interpretation:

This material was piled up in order to form the bunker, apparently from a source outside the Power Plant area. The top few inches of this fill have been stripped, so the cored interval was several inches below the surface until recently.

Drill Hole FC-4 Drilled 8/11/88

Location: Within bunker, through hole in floor chopped through 6" of asphalt before starting hole.

Blow Count:

0 - 6	7 blows
6 - 12	10
12 - 18	9
18 - 24	17

Recovery: 21.5" (89.6%)

Geologic Log:

0 - 3	Asphalt and crushed limestone with some brown silt/clay
3 - 8 1/2	Bottom ash mixed with red clay
8 1/2 - 14 1/2	Orange brown clay, with minor ash at top
14 1/2 - 21 1/2	Orange brown clay with red sandstone fragments up to 2" at base

Interpretation: The 14 1/2 to 21 1/2 material and possibly most of 8 1/2 to 14 1/2, may be the original subsurface material at the site. The bottom ash (3 - 8 1/2) was apparently part of the base on which asphalt was laid to form the floor of the bunker.

Drill Hole FC-5 Drilled 8/11/88

Location: Near drain along fence around containment area

Blow Count:

0 - 6"	1 blow
6 - 12"	10
12 - 18"	10
18 - 24"	9

Recovery: 21" (87.5%)

Geologic Log:

0 - 1 1/2"	Fly ash with some roots
1 1/2 - 6	Mostly red clay with ~ 20% fly ash mixed in; also sparse pieces crushed limestone (2 cm)
6 - 21	Red clay with sparse bottom ash and crushed limestone fragments, also red and buff sandstone and siltstone

Interpretation:

The zone from 1 1/2 to 21 is probably all fill, perhaps of several different ages.

The fly ash is interpreted to have settled out during the last stages of coal plant operations, and/or blew in since that time. (See FC-1)

Drill Hole FC-6 Drilled 8/11/88

Location: Behind Radwaste Building

Blow Count:

0 - 6	5 blows
6 - 12	15
12 - 18	35
18 - 24	50

Recovery: 16 1/2" (69%)

0 - 2	Black fly ash and crushed limestone with roots
2 - 4	Buff sandy silt with red sandstone/siltstone fragments
4 - 6	Black fly ash with rock fragments
6 - 8	Reddish silt with some rock fragments
8 - 16 1/2	Buff to orangish silt with fragments of sandstone up to 2" diam. There appear to be bigger rock fragments beneath this point

Interpretation:

The zone below 6" may include original material at the site. The shallower material probably represents material redistributed at the time of constructing the Radwaste Building. The surface layer of fly ash may have accumulated during coal plant operation, but may include windblown material.

Drill Hole FC-7 Drilled 8/10/88

Location: "Westinghouse" fenced area to about 42 ft. north of north fence of main Saxton Facility.

Blow Count:

0 - 6"	7
6 - 12	17
12 - 18	17
18 - 24	13

Recovery: 22 1/2" (94%)

Geologic Log:

0 - 3"	Dark gray fine grained fly ash with grass roots
3 - 5	Fragments of fine grained buff sandstone in sandy matrix; probably essentially the original surface
5 - 22 1/2	Buff sandy silt with horizontal fractures; sparse weathered sandstone fragments

Interpretation:

The zone from 3" on down probably represents the original subsoil and parent material of the site (sandy deposits of a former river stage). The top unit of fly ash probably represents a combination of fly ash that settled out during coal plant operation plus a later component of wind blown ash.

Drill Hole FC-8 Drilled 8/11/88

Location: About 200 ft. south of the fence around the Saxton Nuclear Facility, in an area found to contain anomalous levels of radioactivity in an earlier gamma survey of the area. The drill hole was started in the bottom of a shallow depression.

Blow Count:

0 - 6"	4
6 - 12	8
12 - 18	12
18 - 24	15

Recovery: 16 1/2" (69%)

Geologic Log:

0 - 1 1/2"	Coarse black bottom ash
1 1/2 - 6	Mostly fine grained gray fly ash with some 1 - 10 mm fragments of bottom ash
6 - 12	Black ash, mostly bottom ash
12 - 16 1/2	Bottom ash mixed with about 20% red clay and red siltstone fragments

Interpretation:

All of this material appears to be fill or otherwise man-influenced. The zone from 1 1/2 to 6 may be dominantly fly ash from the main period of coal plant operation, but evidently bottom ash has been moved in at a later date.

Drill Hole FC-9

Drilled 8/11/8

Location: About 225' S50 W from the outer corner of the C and A building, in the area of the original coal-fired power plant (now demolished).

Blow Count:

0 - 6"	2
6 - 12	6
12 - 18	11
18 - 24	16

Recovery: 23 1/2" (98%)

Geologic Log:

0 - 4"	Loose gray bottom ash with roots
4 - 9	Slightly more coherent bottom ash
9 - 12	Fly ash
12 - 23 1/2	Orangish brown clay with siltstone and sandstone fragments

Interpretation:

The bottom unit (12 - 23 1/2) is probably fill moved into position when the coal plant was built. The fly ash at 9 - 12" is inferred to be deposited during coal plant operation. The shallower material was probably emplaced after removal of the coal plant.

Drill Hole FC-10 Drilled 8/11/88

Location: About 300 ft. east of the NE corner of the fence around the Saxton Nuclear Facility, in the vicinity of a power line, in an area of former coal/ash storage.

Blow Count:

0 - 6"	2
6 - 12	8
12 - 18	8
18 - 25	5

Recovery: 22" (92%)

Geologic Log:

0 - 4"	Mostly Fly ash with sparse coarser cinders
4 - 17	Bottom ash, 1 mm to 2 cm size
17 - 22	Bottom ash, less fine material, some pieces to 3 cm, appreciable efflorescence on surfaces

Interpretation:

Most of the core apparently represents bottom ash, possibly stored temporarily in this area. The top 4" represents a significant period of fly ash fallout during coal plant operation, plus possible windblown transport of fly ash.

Drill Hole FC-11 Drilled 8/11/88

Location: About 200' N of the NW corner of the fence around the Saxton Nuclear Facility (containment area), about 15' outside the outer fence of the coal plant facility. The area has small (15') trees within 20 - 30' of hole.

Blow Count:

0 - 6"	4
6 - 12	27
12 - 18	16
18 - 24	18

Recovery: 22" (92%)

Geologic Log:

0 - 4"	Soil containing considerable fly ash, grading downward into crushed limestone
4 - 17 1/2	Crushed limestone in a fine gray matrix, plus local buff sandstone
17 1/2 - 22	Black and orangish bottom ash with some red siltstone fragments

Interpretation:

The deeper material indicates that this area was disturbed during operation of the coal-fired plant, and that crushed stone was brought in at some time, possibly for a road. The top layer is fly ash accumulated during the later stages of coal plant operation, or by later wind-transport.

Drill Hole FC-12 Drilled 8/11/88

Location: About 325 ft. east of the NE corner of the fence around the Saxton Nuclear Facility, about 50 ft. SW of hole FC-10. This hole was intended to evaluate replication of drillholes.

Blow Count:

0 - 6 "	1
6 - 12	7
12 - 18	20
18 - 24	30

Recovery: 17 1/2" (73%)

Geologic Log:

0 - 3"	Fly ash, gray-black, with some cinders and roots
3 - 9 1/2	Black ash and coal, mostly fine grained
9 1/2 - 17 1/2	Bottom ash, some pieces up to 3" diam.

Interpretation:

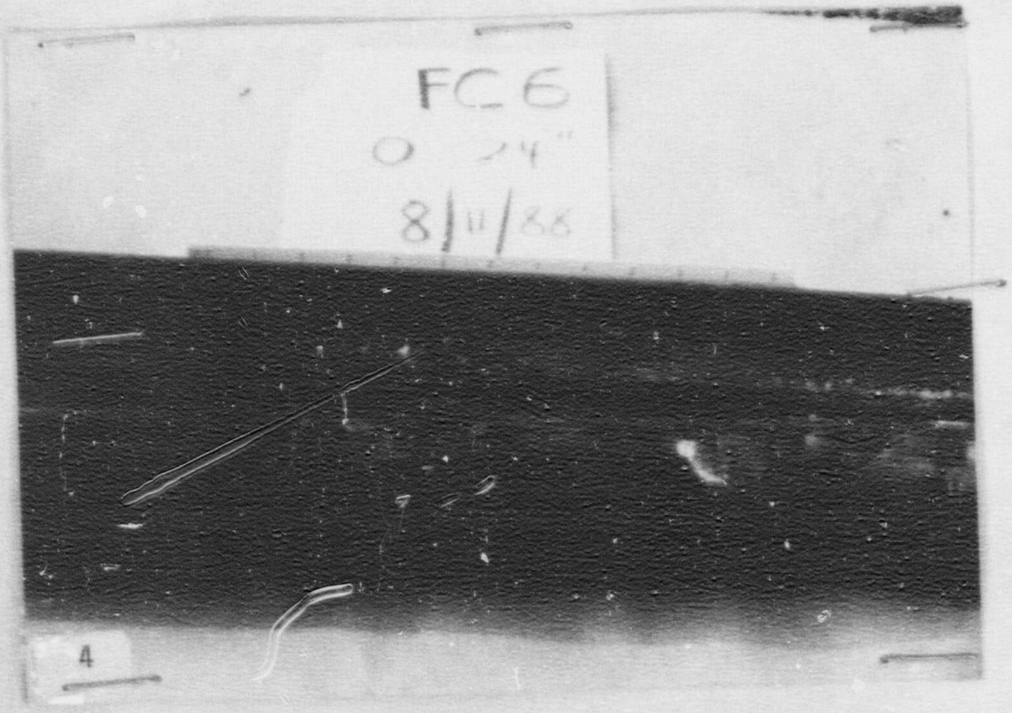
The material below 9 1/2" appears to represent bottom ash stored in the area during coal plant operation. At a later date, still during coal plant operation, coal was stored in the vicinity or was dozed into this spot from adjacent areas. The top layer is fly ash from the late stages of plant operation plus later wind-blown contributions.

Appendix B

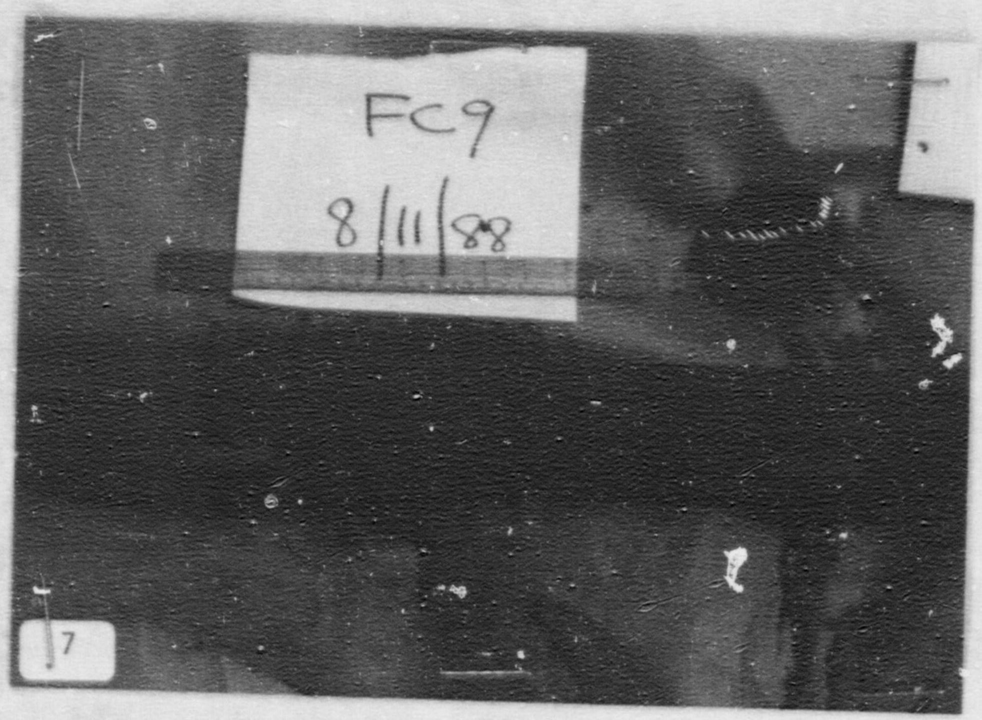
Photographs


FC-5
8/11/88
3


FC1
0" To 24"
8/11/88
1


FC6
0 24"
8/11/88
4


FC-3
8-11-88
2


FC9
8/11/88
7

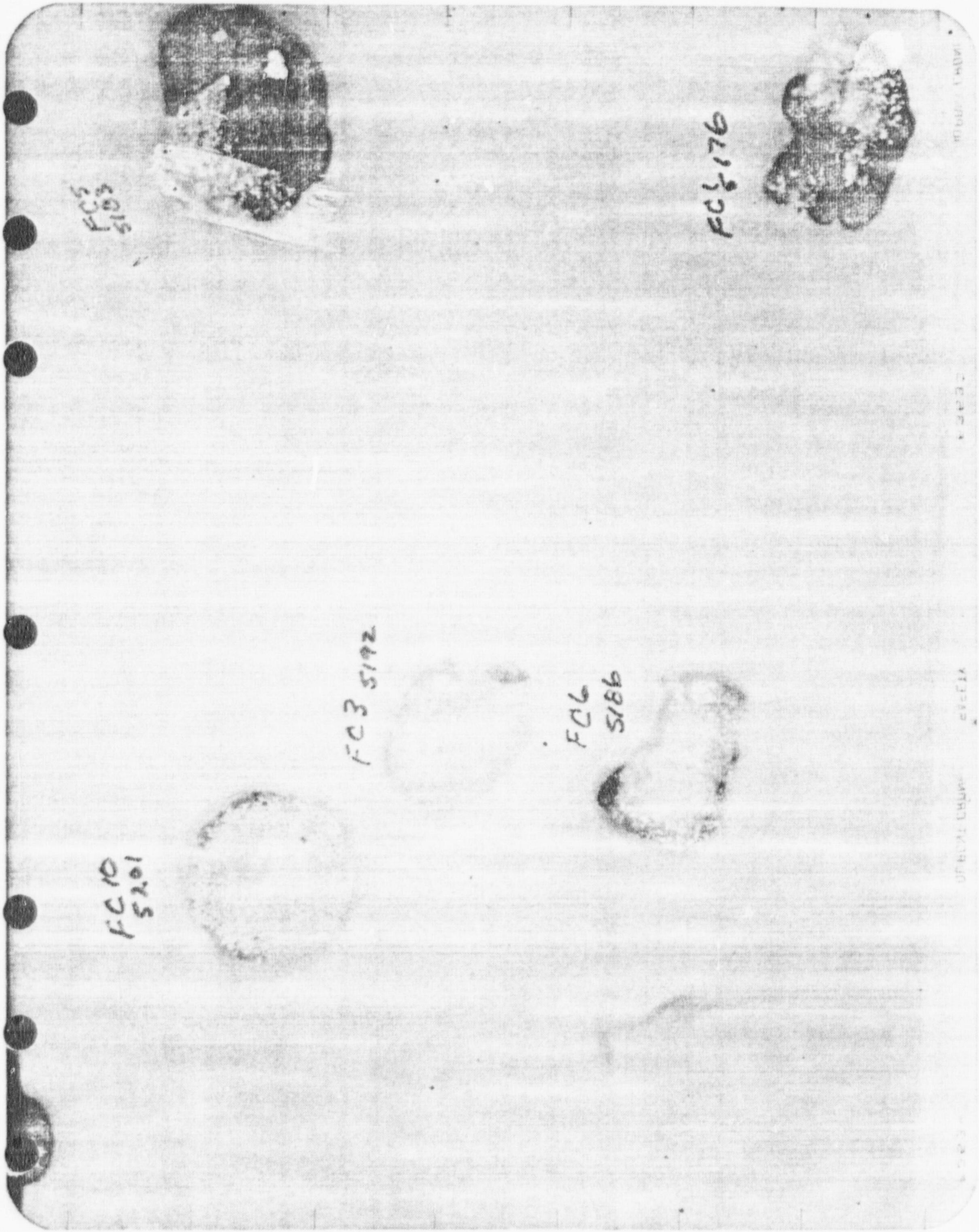

FC-7
8-10-88
5


FC10
8/11/88
8

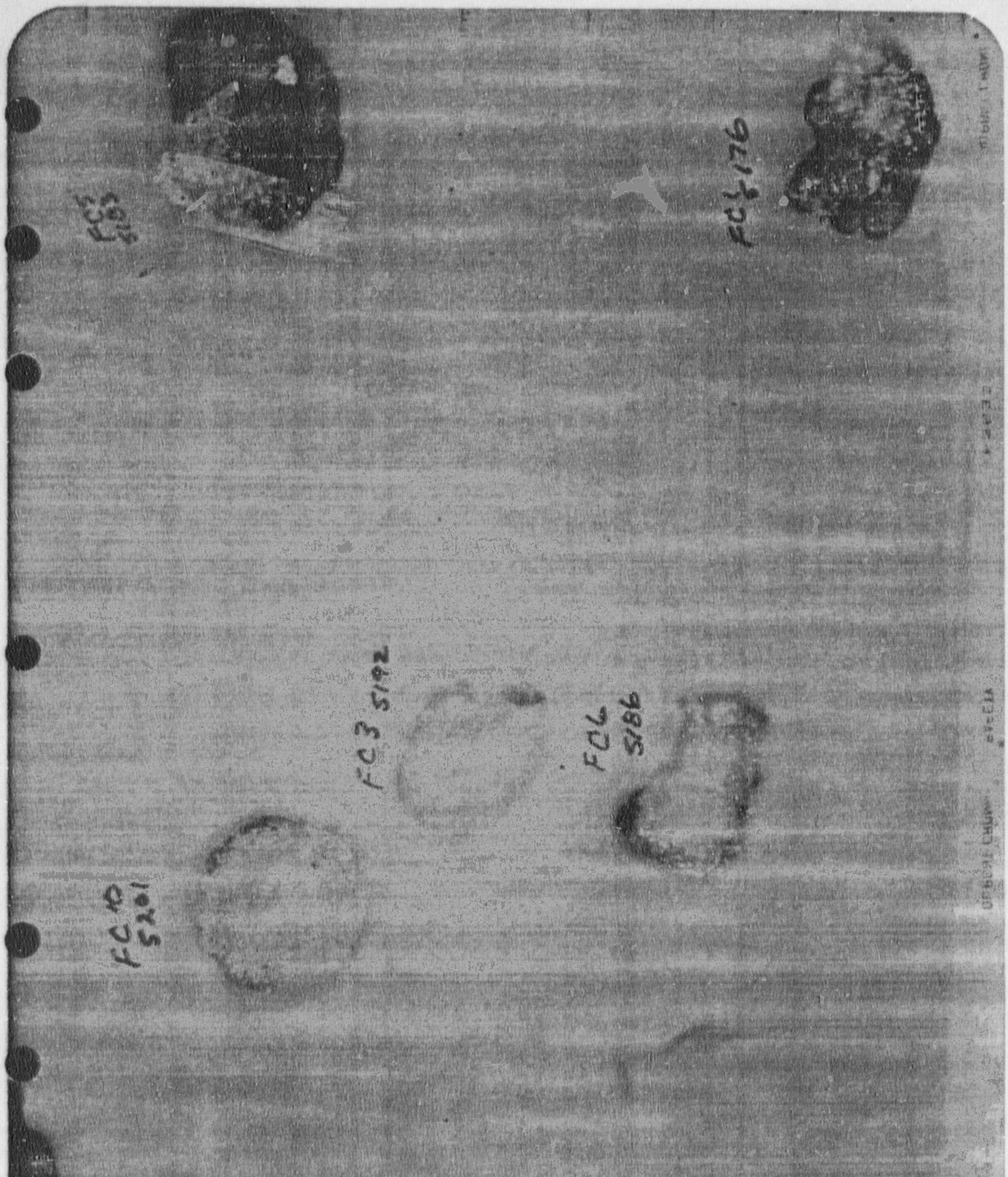

FC8
8/11/88
6

9

10



Autoradiograph



Autoradiograph

Appendix C

Equations Used to Calculate Gamma Spectroscopy Results

EQUATIONS USED TO CALCULATE GAMMA SPECTROSCOPY RESULTS

Symbols used in calculations:

A = sample peak area above continuum (counts)
B = branching ratio for the gamma ray of the particular isotope in question (gammas/disintegration)
C = sample peak area below continuum (counts)
D = background peak area above continuum (counts)
E = fractional detector efficiency at photopeak energy (counts/gamma)
F = background peak area below continuum (counts)
S = sample size (grams)
BT = background counting time (seconds)
CT = sample counting time (seconds)
DC = decay correction factor; corrects for radioactive decay of the sample from the time of collection to the time of counting
2.22 = conversion factor; disintegrations per minute per picocurie
4.65 = $2\sqrt{2}k$, where k is the value for the upper percentile of the standardized normal variate corresponding to the preselected risk that the present activity will be detected 95% of the time.

For radioisotopes which are found in the sample but not in the background the following equations are used to calculate concentration, error and minimum detectable concentration.

$$\text{Isotopic concentration (pCi/gram)} = \frac{A}{2.22 \times B \times E \times S \times DC \times (CT/60)}$$

$$\text{1-sigma counting error (pCi/gram)} = \frac{\sqrt{A + 2C}}{2.22 \times B \times E \times S \times DC \times (CT/60)}$$

$$\text{Minimum detectable concentration (pCi/gram)} = \frac{4.65\sqrt{C}}{2.22 \times B \times E \times S \times DC \times (CT/60)}$$

For radioisotopes which are found in both the sample and background the following equations are used to calculate concentration, error and minimum detectable concentration.

$$\text{Isotopic concentration (pCi/gram)} = \frac{(A/CT)-(D/BT)}{2.22 \times B \times E \times S \times DC} \times 60$$

$$\text{1-sigma counting error (pCi/gram)} = \frac{\sqrt{((A + 2C)/CT^2) + ((D + 2F)/BT^2)}}{2.22 \times B \times E \times S \times DC} \times 60$$

$$\text{Minimum detectable concentration (pCi/gram)} = \frac{3.29\sqrt{(C/CT^2) + ((D + 2F)/BT^2)}}{2.22 \times B \times E \times S \times DC} \times 60$$

Appendix D

Microscopic Observations and Sieve Analyses

List of abbreviations used in FC-series descriptions

frags - fragments
ss - sandstone
Ls - limestone
cind. - cinders
clink. - clinkers or bottom ash
spher. - spherules
qtz - quartz
concr. - concrete
NA - not applicable
poss. - possible
crush. - crushed
yell. - yellow
slg. - slag

Drill Hole FC-1, 0-2" (PSU# 5176)

Weight: 74.5 g (field moist), 67.5 g (dry)

Bulk color: Dark gray (N3)

Description: Almost entirely fly ash, very minor reddish ss frags (~1-4 mm), few twigs etc...

>1 cm (0%)

2-10 mm (10%) red ss frags (well rounded), twigs, some coarser fly ash, poss. coal frags

1-2 mm (40%) fly ash, very vesicular, round, shiny to earthy in lustre; some spherules of greasy slag, light to black in color.

<1 mm (50%) fly ash, as above; more abundant spherules; very small particles of ash, coal?, and clay coat on larger particles

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	0	0	NA
4-10	0.8	1.2	twigs, red ss
10-40	3.7	5.5	fly ash, ss
40-60	10.2	15.1	fly ash, spher.
60-140	26.7	39.6	" "
140-200	21.1	31.3	fly ash, dust
<200 mesh	5.0	7.4	spher., ash, dust

Drill hole FC-1, 2-15" (PSU#5177)

Weight: 1642.0 g (field moist), 1601.1 g (dry)

Bulk color: Fly ash: Dark gray N3; Clay 1): Grayish orange 10YR 7/4;
Clay 2): Moderate brown 5YR 4/4

Description: Orangish clay 20%, Brownish clay 60%, Ash 20%, some smooth reddish slag

>1 cm (10%) reddish and whitish ss chips (well-rounded) some crushed Ls (angular)

2-10 mm (40%) same as above except no crushed stone, cinders, fly ash, and slag

1-2 mm (10%) cinders, fly ash, and some spherules

<1 mm (40%) half clay and silt fines from ss, and fly ash and greasy spherules

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	353.2	22.1	ss frags, crush. Ls
4-10	192.1	12.0	" "
10-20	83.4	5.2	ss frags, cind., ash
20-40	66.1	4.1	fly ash, cin., ss silt
40-60	148.9	9.3	" "
60-140	359.6	22.5	ss silt, fly ash
140-200 mesh	194.5	12.1	" "
75-5 microns	87.7	5.5	silts, fly ash
5-1.3 microns	54.0	3.4	" "
<1.3 microns	61.6	3.8	clay fines

Drill hole FC-1, 15-24" (PSU# 5178)

Weight: 1109.0 g (field moist), 1039.5 g (dry)

Bulk color: Fly ash + cinders: Dark gray N3, Clay: Pale brown 5YR 5/2

Description: Silty clay, brown, 30%; Grayish smooth slag 20%; Cinders 20%; Fines: fly ash, cinders, ss frags, spherules 30%

>1cm (40%) clay clods, some cinders, and smooth slag
2-10 mm (20%) ss frags, cinders, coarse ash, and slag
1-2 mm (20%) red and whitish ss frags, fine cinders, and ash
<1 mm (20%) clay fines, fly ash and spherules of greasy slag

Sieve fractions	wt. (g)	wt. (%)	Descrption
>4 mesh	381.0	36.7	crushed Ls, slag
4-10	154.7	14.9	slag, cinders, ss
10-20	38.8	3.7	cind., ash, ss frags
20-40	66.3	6.4	" "
40-60	74.8	7.2	ash, ss frags, cind.
60-140	133.5	12.8	ss fines, ash
140-200	73.4	7.1	" "
75-5 microns	79.6	7.7	spherules, ash, clay
5-1.3 microns	12.2	1.2	clays, ash
<1.3 microns	21.9	2.1	clay fines

Drill hole FC-3, 0-5" (PSU# 5192)

Weight: 473.3 g (field moist), 412.7 g (dry)

Bulk color: Orange-pink 5YR 7/2 - Light brown 5YR 6/4

Descritpion: Mostly (90%) fine silt and clay aggregates, some weathered reddish ss frags; (10%) angular, vesicular slag

>1cm (10%) weathered ss frags, coarse cinders
2-10 mm (20%) same as above except fewer cinders
1-2 mm (30%) silts and sands of weathered ss, cinders, slag
<1 mm (40%) silts and clays from above, ash, and cinders, slag

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	42.8	10.4	red ss chips, cind.
4-10	76.9	18.6	ss, cind., slag
10-20	6.3	1.5	ss, slag, ash
20-40	12.2	3.0	" "
40-60	21.4	5.2	" "
60-140	80.8	19.6	ash, ss frags
140-200 mesh	76.2	18.5	ss silts, ash
75-5 microns	56.6	13.7	" "
5-1.3 microns	12.3	3.0	silts + clays
<1.3 microns	27.2	6.6	clay fines

Drill hole FC-3, 5-13" (PSU# 5193)

Weight: 1177.8 g (field moist), 1101.3 g (dry)

Bulk color: Grayish-orange pink 5YR 7/2, Light brown 5YR 6/4

Description: Almost entirely silt and clay from ss frags with above color. Some ss frags (well-rounded ~1 cm), minor vesicular, angular slag frags ~1 cm

>1 cm (15%) oblong rounded ss frags, smooth slag
2-10 mm (10%) smooth ss chips,
1-2 mm (15%) ss frags, sands mostly reddish in color
<1 mm (60%) silts and clays from above

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	198.5	18.0	ss frags, slag
4-10	131.3	11.9	ss frags
10-20	8.5	0.8	ss frags
20-40	34.9	3.2	" "
40-60	20.2	1.8	" "
60-140	272.2	24.7	ss sands
140-200 mesh	238.6	21.7	silts + sands
75-5 microns	124.6	11.3	silts
5-1.3 microns	28.4	2.6	silts + clays
<1.3 microns	43.9	4.0	clay fines

Drill hole FC-3, 13-24" (PSU# 5194)

Weight: 1946.5 g (field moist), 1744.8 g (dry)

Bulk color: Light brown 5YR 6/4

Desription: 68% clays, fines, and ss frags of above color some 5YR 5/2 ss frags. 32% ash and slag with orange coatings; a few clinkers (bottom ash)

>1 cm (25%) coarse coal ash, coarse slag, subrounded ss frags
2-10 mm (5%) ss frags, some ash, some cooked shaley partings
1-2 mm (20%) mostly brownish clay aggregates, very minor ash
<1 mm (50%) clays and silts from ss frags

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	417.1	23.9	large ss, slag
4-10	182.1	10.4	red ss, slag
10-20	34.6	1.8	ss, ash
20-40	49.7	2.8	" "
40-60	79.9	4.6	ss, stained qtz
60-140	508.9	29.2	sands, some ash
140-200 mesh	272.2	15.6	sands, ash, qtz
75-5 microns	120.4	6.9	sands, silts
5-1.3 microns	35.4	2.0	silts, clays
<1.3 microns	52.5	3.0	clay fines

Drill hole FC-4, 0-3" (PSU# 5180)

Weight: 342.3 g (field moist), 341.4 g (dry)

Bulk color: Med. light gray N6 (crushed Ls); Dark gray N3 ash

Description: 90% crushed Ls, 10% fines: qtz, ash, and slag

>1 cm (75%) crushed Ls
2-10 mm (10%) crushed Ls, and slag
1-2 mm (5%) slag and qtz and ash
<1 mm (10%) dust, ash and minor spherules

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	268.5	78.5	crushed Ls
4-10	32.4	9.5	crushed Ls, ash
10-20	12.2	3.6	ash, Ls, slag
20-40	8.5	2.5	slag and ash
40-60	6.1	1.8	" "
60-140	6.1	1.8	quartz, ash, slag
140-200 mesh	1.9	0.6	spherules, qtz, ash
<75 microns	5.7	1.7	fines, spherules

Drill hole FC-4, 3-8.5" (PSU# 5179)

Weight: 673.8 g (field moist), 648.6 g (dry)

Bulk color: Dark gray N3

Description: Bottom ash: earthy to glassy in lustre, brownish to brown-orange coatings, oblong to equant, very angular, mostly vesicular. Minor glassy slag, whitish ss frags and crushed Ls

>1 cm (60%) ash, as described above
2-10 mm (20%) as above except more slag and ss
1-2 mm (10%) more ss than above
<1 mm (10%) fine ash and very minor ss frags

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	361.0	55.7	bottom ash
4-10	143.3	22.1	ash, some crush. Ls
10-20	16.2	2.5	ash, ss, crushed Ls
20-40	20.7	3.2	" "
40-60	19.5	3.0	fine ash, ss, slag
60-140	29.7	4.6	" "
140-200 mesh	18.7	2.9	sands, and ash
75-5 microns	24.4	3.8	silts, ash
5-1.3 microns	4.3	0.7	" "
<1.3 microns	10.8	1.7	fines

Drill hole FC-4, 8.5-14.5" (PSU# 5181)

Weight: 1018.4 g (field moist), 931.3 g (dry)

Bulk color: Grayish orange 5YR 6/4

Description: 95% silty clay and reddish ss chips; minor vesicular cinders, some coal frags and slag

>1 cm (~5%) cinders and slag
2-10 mm (~5%) ss frags and cinders
1-2 mm (30%) ss frags and sands, very minor cinders
<1 mm (60%) sands and silts and clays from ss, coal dust

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	42.1	4.5	ash, and cinders
4-10	10.1	1.1	ss chips, and ash
10-20	6.2	0.7	" "
20-40	27.6	3.0	sands and cinders
40-60	75.3	8.1	sands and ash
60-140	233.4	25.1	sand, mostly
140-200 mesh	163.6	17.6	silts and coal dust
75-5 microns	197.5	21.2	silts
5-1.3 microns	55.0	5.9	dust and silts, etc...
<1.3 microns	116.7	12.5	clays and fines

Drill hole FC-4, 14.5-21.5" (PSU# 5182)

Weight: 1223.2 g (field moist), 1167.1 g (dry)

Bulk color: Moderate yellowish brown 10YR 5/4, Dark yellowish orange 10YR 6/6

Description: Mostly weathered, rounded ss frags with above color; size: 0.5-4 cm. Fines consist of sands of same and stained quartz

>1 cm (40%) well-rounded fine-grained ss frags, white and brown
2-10 mm (10%) same as above
1-2 mm (20%) mostly ss chips and stained quartz
<1 mm (30%) sands and stained quartz and fines

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	498.2	42.7	round ss frags
4-10	68.2	5.8	" "
10-20	20.8	1.8	sands, stained qtz
20-40	54.0	4.6	" "
40-60	105.7	9.1	reddish sands, qtz
60-140	170.3	14.6	brown and red sand
140-200 mesh	106.4	9.1	sands and qtz
75-5 microns	77.3	6.4	sands and silts
5-1.3 microns	22.1	1.9	silts and clays
<1.3 microns	44.1	3.8	clay fines

Drill hole FC-5, 0-1.5" (PSU# 5183)

Weight: 157.3 g (field moist), 148.5 g (dry)

Bulk color: Dark gray N3

Description: Sample is mostly fly ash, some crushed Ls, few twigs

>1 cm (30%) one large (~8 cm) piece crushed Ls
2-10 mm (10%) coarse ash, twigs
1-2 mm (30%) coarse fly ash
<1 mm (30%) fly ash

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	47.9	29.3	crushed Ls
4-10	7.2	4.8	twigs, ash
10-20	7.3	4.9	ash, fly ash
20-40	26.1	17.6	fly ash
40-60	24.4	16.4	" "
60-140	23.3	15.7	" "
140-200 mesh	5.9	4.0	fly ash
75-5 microns	5.5	3.7	fly ash
<5 microns	5.3	3.6	fines

Drill hole FC-5, 1.5-6" (PSU# 5184)

Weight: 401.3 g (field moist), 376.5 g (dry)

Bulk color: Pale red 10R 6/2, Pale reddish brown 10R 5/4

Description: 80% pale red silty clay with above colors, 15% vesicular fly ash, some crushed Ls

>1 cm (15%) angular slag, crushed Ls, and ss frags
2-10 mm (10%) mostly ss frags, some slag
1-2 mm (25%) ss frags, fly ash
<1 mm (50%) ss frags, fly ash, silts

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	50.6	13.4	slag, Ls, ss frags
4-10	32.4	8.6	ss frags, slag
10-20	3.7	1.0	fly ash, ss frags
20-40	23.5	6.2	" "
40-60	39.0	10.4	some ash, ss frags
60-140	86.6	23.0	sands, some ash
140-200 mesh	57.9	15.4	sand, spherules
75-5 microns	49.5	13.1	" "
5-1.3 microns	10.5	2.8	silts
<1.3 microns	23.3	6.2	clay fines

Drill hole FC-5, 6-21 (PSU# 5185)

Weight: 2274.6 g (field moist), 2195.0 g (dry)

Bulk color: Grayish orange pink 5YR 7/2, Light brown 5YR 6/4

Description: Mostly clays and silts from ss frags with above colors, some crushed Ls, very minor angular dark slag

>1 cm (15%) yellowish and brownish rounded ss frags, Ls
2-10 mm (10%) ss frags as above, some slag and minor Ls
1-2 mm (30%) ss frags, sands, and slag
<1 mm (45%) silts and sands

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	389.5	17.7	red ss, Ls, slag
4-10	183.6	8.4	ss, slag
10-20	34.3	1.6	whitish ss frags
20-40	26.8	1.2	white and red ss
40-60	117.0	5.3	" "
60-140	642.3	29.3	sands, and ss frags
140-200 mesh	355.3	16.2	sands and frags
75-5 microns	232.5	10.6	sands and silts
5-1.3 microns	72.8	3.3	silts and clays
<1.3 microns	141.0	6.4	clay fines

Drill hole FC-6, 0-4" (PSU# 5186)

Weight: 337.6 g (field moist), 324.5 g (dry)

Bulk color: Fly ash: Dark gray N3, crushed Ls: Light olive gray 5Y 4/1

Description: 35% Large angular chunks of grayish crushed Ls; 65% blackish, vesicular, earthy to shiny, fly ash, fine cinders, and some spherules, possible coal dust

>1 cm (35%) gray limestone
2-10 mm (~5%) coarse fly ash and cinders
1-2 mm (20%) fly ash
<1 mm (40%) fly ash

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	96.8	29.8	crushed Ls
4-10	47.3	14.6	crushed Ls, ash
10-20	10.1	3.1	fly ash and cinders
20-40	33.8	10.4	" "
40-60	53.8	16.6	fly ash, spherules
60-140	33.7	10.4	" "
140-200	16.4	5.1	fine ash
<200 mesh	32.6	10.0	very fine ash

FC-6, 4-8" (PSU# 5187)

Weight: 605.3 g (field moist), 581.8 g (dry)

Bulk color: Pale reddish brown 10R 5/4 - 10R 4/6, Dark yellowish orange 10YR 6/6

Desription: 35% silty clay with above colors, 25% gray crushed Ls, 20% fly ash, slag and coal dust-black in color (N2), 20% bottom ash, and cooked shaley partings. Fines consist of some pale ss frags, fly ash, greasy spherules, qtz

>1 cm (25%) cooked shaley partings, slag, crushed Ls
2-10 mm (15%) Ls, slag, ash, ss frags
1-2 mm (30%) slag, ash, ss frags
<1 mm (30%) silty clay, ash

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	146.7	25.2	crushed Ls, clinkers
4-10	86.9	14.9	angular slag, ash
10-20	16.9	2.9	ash, slag, ss frags
20-40	29.3	5.0	" "
40-60	35.7	6.1	fly ash, spherules
60-140	113.4	19.5	spherules, ash
140-200 mesh	41.1	7.1	" "
75-5 microns	76.1	13.1	dust, spherules, ash
5-1.3 microns	12.4	2.1	dust, ash, fines
<1.3 microns	23.4	4.0	fines

Drill hole FC-6, 8-16" (PSU# 5188)

Weight: 1328.6 g (field moist), 1269.4 g (dry)

Bulk color: Mostly Moderate yellowish brown 10YR 5/4

Description: 70% silty clay of above color, derived from whitish gray well-rounded ss (3-10 cm) 20%, and fine-grained, reddish, flat ss. Very minor cinders and ash in fines

>1 cm (50%) White-pink and red-olive ss frags
2-10 mm (5%) same as above
1-2 mm (15%) sands and stained quartz
<1 mm (30%) silty clay and minor ash, cinders

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	506.7	39.9	rounded ss frags
4-10	40.4	3.2	ss frags
10-20	23.0	1.8	" "
20-40	64.1	5.0	ss, qtz sand, ash
40-60	52.0	4.1	" "
60-140	149.9	11.8	sand, ash
140-200 mesh	220.4	17.4	slag flakes, sand
75-5 microns	116.5	9.2	ash, dust, sand
5-1.3 microns	37.7	3.0	sands, silts
<1.3 microns	58.8	4.6	clay fines

Drill hole FC-7, 0-4" (PSU# 5189)

Weight: 397.8 g (field moist), 366.8 g (dry)

Bulk color: Composite: Olive gray 5Y 4/1 + Grayish orange 10YR 7/4

Description: Mostly ss frags, (angular 0.5-4 cm), with above colors, roots and humus 30%, some crushed Ls, very minor fly ash (very fine)

>1 cm (35%) orangish ss frags, some crushed Ls
2-10 mm (10%) ss frags, humus, cinders, crushed Ls
1-2 mm (25%) ss frags, twigs, ash
<1 mm (30%) sands, ash

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	136.3	37.2	ss frags
4-10	41.9	11.4	ss frags, Ls, humus
10-20	2.4	0.7	twigs, ss, Ls, ash
20-40	5.4	1.5	" "
40-60	27.2	7.4	ss, fly ash
60-140	52.8	14.4	fly ash, ss frags
140-200 mesh	31.8	8.7	ash, sands
75-5 microns	20.1	5.5	sands, ash
5-1.3 microns	31.6	8.6	silts,ash
<1.3 microns	17.2	4.7	fines

Drill hole FC-7, 4-13" (PSU# 5190)

Weight: 1217.9 g (field moist), 1159.3 g (dry)

Bulk color: Moderate yellowish brown 10YR 5/4

Description: 95% silty clay with above color, few ss frags, fines: quartz+cinders+silt
>1 cm (~5%) angular frags of fine-grained ss
2-10 mm (~5%) subrounded frags of ss
1-2 mm (35%) sands, cinders
<1 mm (55%) sands, silts clays, and some cinders

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	51.4	4.2	ss frags
4-10	15.7	1.3	ss frags, rounded
10-20	8.2	0.7	ss frags, ash
20-40	23.8	2.1	ss frags, sand, ash
40-60	88.5	7.6	sand, cinders
60-140	335.1	28.9	sands, ss frags
140-200 mesh	344.0	29.7	sands, silts
75-5 microns	159.5	13.8	silts
5-1.3 microns	43.4	3.7	silts and clays
<1.3 microns	89.8	7.7	clay fines

Drill hole FC-7, 13-22" (PSU# 5191)

Weight: 1485.1 g (field moist), 1404.0 g (dry)

Bulk color: Grayish orange 10YR 7/4

Description: 90% fines: 1-2 mm red ss and yellow-gray ss frags, 10% coarse frags of angular ss. Sample has very minor ash.
>1 cm (25%) gray-orange ss frags
2-10 mm (<1%) ss frags
1-2 mm (30%) ss frags and minor ash
<1 mm (45%) sands and silts, qtz, ash

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	329.1	23.4	coarse ss frags
4-10	17.9	1.3	less coarse ss frags
10-20	5.0	0.4	ss frags, sands
20-40	39.4	2.8	ss, sand, ash
40-60	119.0	8.5	" "
60-140	384.7	27.4	ss frags, qtz, ash
140-200 mesh	281.7	20.1	" "
75-5 microns	122.8	8.7	sands, qtz, silt
5-1.3 microns	37.4	2.7	sand, silt
<1.3 microns	66.4	4.7	fines

Drill hoie FC-8, 0-6" (PSU# 5198)

Weight: 481.7 g (field moist), 462.3 g (dry)

Bulk color: Dark gray N3

Description: 35% dark, vesicular slag; 5% shiny clinkers; 60% fines: fly ash, coal dust, spherules, glassy slag and common roots

>1 cm (15%) slag and clinkers
2-10 mm (45%) vesicular slag, ash, and coal
1-2 mm (20%) ash, coal, and clinker frags
<1 mm (20%) ash, spherules, coal dust

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	73.1	15.8	slag and clinkers
4-10	244.1	52.8	slag and sh. parting
10-20	25.4	5.5	ash, slag, partings
20-40	30.8	6.7	" "
40-60	25.4	5.5	coal dust, ash
60-140	30.7	6.6	spherules, ash
140-200 mesh	9.8	2.1	coal dust, spherules
75-5 microns	8.1	1.8	dust ,ash, spherules
5-1.3 microns	7.9	1.7	dust, fines
<1.3 microns	8.1	1.8	fines

Drill hole FC-8, 6-12" (PSU# 5199)

Weight: 559.1 g (field moist), 514.7 g (dry)

Bulk color: Dark gray N3

Description: 60% clinkers 0.5-6 cm, subangular, earthy in lustre, vesicular. 30% fines: silt, clay, fly ash, dust, spherules. 10% glassy to ceramic-like reddish-brown vesicular slag

>1 cm (45%) clinkers, slag
2-10 mm (25%) clinkers, slag, fly ash
1-2 mm (10%) fly ash, slag
<1 mm (30%) fly ash, silt, clay, spherules

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	256.1	49.8	clinkers, slag
4-10	92.8	18.0	" "
10-20	32.5	6.3	ash, slag
20-40	39.8	7.7	fly ash , slag
40-60	30.2	5.9	" "
60-140	33.6	6.5	spherules, fly ash
140-200 mesh	10.2	2.0	dust, spherules
75-5 microns	10.9	2.1	dust, ash
5-1.3 microns	3.4	0.7	dust
<1.3 microns	5.4	1.0	fines

Drill hole FC-8, 12-16.5" (PSU# 5200)

Weight: 550.1 g (field moist), 508.5 g (dry)

Bulk color: Pale reddish brown 10R 5/4, Grayish orange 10YR 7/4

Description: 60% orangish subrounded, friable ss frags 0.3-4 cm; 10% reddish rounded coarse-grained ss frags; 30% angular, vesicular to smooth slag, cinders, ash

>1 cm (40%) ss frags, clinkers
2-10 mm (15%) ss frags, slag, ash, clinkers
1-2 mm (15%) ash, ss, slag frags
<1 mm (30%) silts and clays and ash

Sieve fractions	wt. (g)	wt. (%)	Description
.4 mesh	228.0	44.8	ss frags, slag
4-10	61.7	12.1	slag, clinkers, ss
10-20	56.9	11.2	ash, ss, slag
20-40	60.1	11.8	" "
40-60	41.8	8.2	ash, slag, ss
60-140	35.7	7.0	sands, ash
140-200 mesh	9.0	1.8	ash, silts
75-5 microns	7.1	1.4	dust, silt
5-1.3 microns	0.7	0.1	silt and clay
<1.3 microns	7.5	1.5	fines

Drill hole FC-9, 0-9" (PSU# 5195)

Weight: 661.3 g (field moist), 540.4 g (dry)

Bulk color: Dark gray N3

Description: 10% slag, angular, vesicular, reddish brown; 30% ash and cinders, subrounded; 60% finer ash and cinders, some spherules, some twigs, crushed Ls

>1 cm (65%) slag, ash and crushed Ls, some twigs
2-10 mm (15%) ash, cinders, slag, minor twigs
1-2 mm (10%) ash, cinders
<1 mm (10%) fine ash, spherules

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	357.1	66.1	slag, ash
4-10	110.3	20.4	ash, cinders
10-20	17.1	3.2	twigs, ash
20-40	18.9	3.5	ash, cinders
40-60	12.1	2.2	" "
60-140	12.2	2.3	spherules, ash
140-200 mesh	4.0	0.7	" "
75-5 microns	6.4	1.2	fine ash
5-1.3 microns	0.4	0.1	very fine ash
<1.3 microns	2.2	0.4	fines

Drill hole FC-9, 9-12" (PSU# 5196)

Weight: 124.4 g (field moist), 112.0 g (dry)

Bulk color: Grayish black N2 - Dark gray N3

Description: 90% granular fly ash, 10% coarser clinkers: angular vesicular with glassy fringes

- >1 cm (20%) clinkers
- 2-10 mm (10%) clinkers, some slag
- 1-2 mm (45%) fly ash
- <1 mm (25%) finer fly ash

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	25.0	22.6	clinkers
4-10	7.6	6.9	clinkers, slag
10-20	11.4	10.3	slag, clink., ash
20-40	22.9	20.7	coarse fly ash
40-60	17.6	15.9	fly ash
60-140	15.1	13.7	fly ash
140-200 mesh	3.2	2.9	fly ash
<75 microns	7.6	6.9	fine fly ash

Drill hole FC-9, 12-23.5" (PSU# 5197)

Weight: 1827.5 g (field moist), 1644.8 g (dry)

Bulk color: Clay: Pale yellowish brown 10YR 6/2, Concrete: White N9, Siltstone: Light olive gray 5Y 6/1, Clinkers: Black N1

Description: 40% 4mm reddish ss chips and gray ss chips, 40% silt of similar color, some angular chunks of concrete, some angular slag

>1 cm (30%) ss frags, red and gray; concrete
2-10 mm (20%) ss frags, slag
1-2 mm (25%) ss frags, slag, ash
<1 mm (25%) same as above

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	454.4	27.6	ss frags, slag
4-10	210.5	12.8	ss, slag, concr.
10-20	41.2	2.5	ss frags, ash
20-40	94.8	5.8	" "
40-60	129.3	7.9	ss frags
60-140	274.7	16.7	silt, sand, ss
140-200 mesh	205.2	12.5	sand, silt
75-5 microns	122.4	7.4	sand, silt
5-1.3 microns	48.1	2.9	silt
<1.3 microns	64.0	3.9	clay fines

Drill hole FC-10, 0-4" (PSU# 5201)

Weight: 339.2 g (field moist), 318.6 g (dry)

Bulk color: Dark gray N3/N4

Description: Mostly fine (<2 mm) slag, fly ash, clinkers, spherules. About 10% coarse subangular vesicular slag, cooked shaley partings, clinkers

>1 cm (25%) slag, slatey partings, clinkers
2-10 mm (30%) ash, slag, clinkers
1-2 mm (15%) ash, slag, clinkers
<1 mm (30%) fly ash, slag, and spherules

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	72.5	22.8	ash, slag
4-10	29.5	9.3	" "
10-20	35.4	11.1	slag, ash
20-40	39.3	12.3	fly ash, slag
40-60	37.1	11.6	root hairs, ash
60-140	49.4	15.5	spherules, ash
140-200 mesh	18.3	5.7	glassy slag, ash
75-5 microns	31.1	9.8	spherules, dust
5-1.4 microns	2.1	0.7	dust, ash
<1.4 microns	3.6	1.1	fines

Drill hole FC-10, 4-17" (PSU# 5202)

Weight: 1063.5 g (field moist), 973.0 g (dry)

Bulk color: Dark gray N3

Description: 10% large angular chunks of clinkers and slag, 90% finer glassy slag, ash, clinkers, coal dust and spherules

>1 cm (20%) slag, ash
2-10 mm (20%) ash, cinders, glassy slag
1-2 mm (25%) ash, cinders, some slag
<1 mm (35%) ash, slag fines, spherules, coal dust

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	347.5	35.7	slag, cinders
4-10	168.8	17.3	slag, ash, cind.
10-20	104.3	10.7	" "
20-40	86.4	8.9	coal dust, ash
40-60	64.0	6.6	spherules, ash
60-140	88.6	9.1	dust, ash, spher.
140-200 mesh	35.1	3.6	" "
<75 microns	78.1	8.0	fines, dust

Drill hole FC-10, 17-22" (PSU# 5203)

Weight: 394.6 g (field moist), 349.9 g (dry)

Bulk color: Dark gray N3, Medium gray N4

Description: 80% angular vesicular red-orange stained slag 0.4-3 cm
20% finer ash, elongate cinders, whitish glassy slag,
fine silt, some vesicular glassy, greasy slag
>1 cm (55%) slag and ash
2-10 mm (20%) slag, ash, cinders,white glassy slag
1-2 mm (10%) ash, cinders, slag frags
<1 mm (15%) ash fines, spherules

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	165.4	47.3	slag, cinders
4-10	69.7	19.9	cinders, slag
10-20	35.3	10.1	slag, ash
20-40	24.4	7.0	ash, white slag
40-60	15.5	4.4	ash, wh. slag, ash
60-140	18.8	5.4	cinders, spherules
140-200 mesh	6.9	2.0	ash, spherules
75-5 microns	6.4	1.8	spherules, dust
<5 microns	8.6	2.5	fines

Drill hole FC-11, 0-4" (PSU# 5204)

Weight: 264.5 g (field moist), 261.5 g (dry)

Bulk color: Fines: Olive gray 5Y 4/1, Coarse: Light olive gray 5Y 6/1

Description: 20% crushed limestone, 80% fine dust, peat, twigs, a few land mollusks, minor fly ash, cinders, spherules

- >1 cm (50%) crushed Ls
- 2-10 mm (20%) weathered pink ss, crushed Ls
- 1-2 mm (15%) sand, cinders, ash
- <1 mm (15%) ash, spherules, glassy slag

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	134.5	51.4	crushed Ls
4-10	36.5	14.0	Ls, ss, ash
10-20	13.8	5.3	ash, cinders
20-40	16.7	6.4	" "
40-60	17.7	6.8	glassy slag, ash
60-140	25.4	9.7	as above w/spher.
140-200 mesh	7.6	2.9	dust, spher., ash
<75 microns	9.5	3.6	fines

Drill hole FC-11, 4-17.5" (PSU# 5205)

Weight: 2052.3 g (field moist), 2015.6 g (dry)

Bulk color: Medium gray N6

Description: 95% angular, blocky, fine-grained crushed Ls 0.2-6 cm, ave. 4 cm. 5% fines: mostly quartz, soil grains, reddish ss chips, crushed Ls

>1 cm (70%) crushed Ls as above
2-10 mm (15%) Ls frags, ss frags, sand
1-2 mm (~5%) sand, ss frags, soil
<1 mm (10%) qtz, sand, rare ash

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	1246.3	61.8	crushed Ls
4-10	259.4	12.9	" "
10-20	75.5	3.7	ss frags, Ls
20-40	63.6	3.2	ss frags, sand
40-60	66.2	3.3	sand, soil
60-140	117.8	5.8	ash, ss, sand
140-200 mesh	66.6	3.3	soil, ash
75-5 microns	69.4	3.4	sand, silt
5-1.3 microns	13.7	0.7	silt and clay
<1.3 microns	37.1	1.8	clay fines

Drill hole FC-11, 17.5-22" (PSU# 5206)

Weight: 538.5 g (field moist), 509.9 g (dry)

Bulk color: Moderate yellow brown 10YR 5/4

Description: Almost entirely slag and ash; minor soil particles, ss frags
some yellowish glassy slag, spherules, clinkers common
>1 cm (35%) orange-stained slag
2-10 mm(15%) slag, clinkers, ss frags
1-2 mm (25%) ss frags, coal?, clinkers
<1 mm (25%) ss frags, sand, fines, ash

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	148.8	29.2	slag, clinkers
4-10	129.9	25.5	ss frags, slag
10-20	36.4	7.3	ss frags, yell. slg.
20-40	42.2	8.5	ss, glassy slag
40-60	35.3	7.1	sand, ash, slag
60-140	43.7	8.6	sand, spherules
140-200	16.0	3.2	spher., sand, ash
75-5 microns	39.2	7.9	sand, silt
5-1.4 microns	4.6	0.9	silt
<1.4 microns	8.5	1.7	clays and fines

Drill hole FC-12, 0-3" (PSU# 5207)

Weight: 171.8 g (field moist), 159.2 g (dry)

Bulk color: Black N1

Description: Mostly fine vesicular shiny fly ash. Some coarser clinkers and ash, fine root hairs, clay

> 1 cm (15%) coarse ash, clinkers
2-10 mm (10%) same as above
1-2 mm (20%) fly ash some sand, root hairs
<1 mm (55%) fly ash, clay, and some glassy spherules

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	18.9	11.9	ash, clinkers
4-10	8.4	5.3	ash, sand
10-20	20.3	12.8	coarse fly ash
20-40	25.3	15.9	fly ash, rt. hairs
40-60	21.3	13.4	" "
60-140	23.7	14.9	spherules, ash
140-200 mesh	11.1	7.0	" "
75-5 microns	9.3	5.8	silt, fine ash
5-1.3 microns	14.1	8.9	silt, ash
<1.3 microns	6.9	4.3	fines

Drill hole FC-12, 3-9.5" (PSU# 5208)

Weight: 562.1 g (field moist), 491.2 g (dry)

Bulk color: Black N1 (shiny)

Description: Mostly shiny black, very angular, vesicular ash, some coarse coal pieces, some spherules

>1 cm (15%) coarse clinkers
2-10 mm (20%) clinkers, ash, coal
1-2 mm (25%) same as above
<1 mm (40%) spherules, ash, coal flakes

Sieve fractions	wt. (g)	wt. (%)	Description
>4 mesh	61.8	12.6	ash, clinkers
4-10	128.5	26.1	same plus coal
10-20	67.0	13.7	ash, coal, clink.
20-40	68.1	13.9	" "
40-60	46.3	9.4	coal flakes, ash
60-140	61.4	12.5	spherules, ash
140-200 mesh	33.2	6.8	" "
75-5 microns	14.7	3.0	flakes, spherules
5-1.3 microns	2.0	0.4	fine ash
<1.3 microns	7.3	1.5	very fine ash

Drill hole FC-12, 9.5-17" (PSU# 5209)

Weight: 708.1 g (field moist), 658.8 g (dry)

Bulk color: Black N1

Description: Mostly fine ~2 mm very angular shiny to glassy ash, some clinkers, some yellowish brown slag (coarse); coal

>1 cm (60%) slag
2-10 mm (15%) slag, ash, coal
1-2 mm (10%) ash
<1 mm (15%) ash, coal dust

Sieve fractions	wt. (g)	wt. (%)	Desrciption
>4 mesh	367.6	55.8	slag
4-10	99.8	15.1	slag, ash
10-20	32.9	5.0	" "
20-40	34.7	5.3	coal dust, ash
40-60	27.3	4.1	" "
60-140	40.7	6.2	coal dust, ash
140-200 mesh	18.1	2.7	ash, dust
75-5 microns	28.1	4.3	fine ash
5-1.3 microns	1.4	0.3	very fine ash
<1.3 microns	8.1	1.2	fines

Appendix E

Chemical and Mineralogical Analyses

THE PENNSYLVANIA STATE UNIVERSITY
INTER-OFFICE CORRESPONDENCE

Date: December 1, 1988

From: N. H. Suhr

To: A. Rose

Subj: Spectrochemical Analysis of Soils (Ash Basis)

Our No.	88-1038	88-1039	88-1040	88-1041	88-1042	88-1043
Your PSU No.	5176	5786	5187	5188	5201	5202
HTA (750°C)	58.5%	69.1%	76.1%	96.0%	63.4%	52.9%
SiO_2	66.5%	49.1%	63.5%	83.3%	53.8%	53.4%
Al_2O_3	17.7	9.20	11.2	7.92	29.3	32.9
TiO_2	1.13	0.55	0.74	0.67	1.56	1.75
Fe_2O_3	8.79	5.53	5.50	5.68	11.1	7.82
MgO	0.85	1.83	1.17	0.54	0.84	0.72
CaO	1.35	31.8	15.3	<0.05	0.97	0.76
MnO	0.077	0.042	0.035	0.014	0.015	0.013
Na_2O	0.22	0.17	0.19	0.20	0.21	0.26
K_2O	2.16	1.51	1.87	1.09	1.89	2.15
P_2O_5	0.25	0.23	0.15	0.07	0.28	0.19
SO_3	0.4	0.4	0.5	<0.05	0.3	<0.05
TOTALS	99.4%	100.4%	100.2%	99.5%	100.3%	100.0%

NHS/vc

cc: H. Gong

THE PENNSYLVANIA STATE UNIVERSITY
INTER-OFFICE CORRESPONDENCE

Date: October 27, 1988

From: J. B. Bodkin, Mineral Constitution Labs, 308 Mineral Sciences

To: Dr. Arthur Rose, 332 Deike

Subj: C, H, N Determinations

Our Number	Your Identification	C	H	N
88-1038	FC 1 Top 0-2" PSU#5176	34.76%	0.82%	0.86%
88-1039	FC 6 Top 0-4" PSU#5786	15.69	0.36	0.35
88-1040	FC 6 4"-8" PSU#5187	14.55	0.60	0.36
88-1041	FC 6 8"-16" PSU#5188	0.41	0.37	0.14
88-1042	FC 10 0-4" PSU#5201	33.25	0.44	0.68
88-1043	FC 10 4"-17" PSU#5202	43.84	0.25	0.71

Analyst: J. B. Bodkin

Joseph B. Bodkin

Joseph B. Bodkin
Chief Analytical Chemist

JBB/vc
cc: N. H. Suhr

Appendix E-3. Mineralogy of samples, based on X-ray diffraction patterns

Patterns run with Cu radiation from 5 to 65 degrees, at 4 deg./min. Minerals are listed in approximate order of abundance.

Sample 5176, FC-1, 0-4 in.

Glass	Major
Quartz	"
Mullite	"
Illite	Minor
Chlorite or kaolinite	"

Sample 5186, FC-6, 0-4 in.

Quartz	Major
Calcite	"
Glass	Moderate
Illite	Minor
Magnetite(?)	"

Sample 5187, FC-6, 4-8 in.

Quartz	Major
Calcite	Moderate
Illite	"
Glass	"
Chlorite or kaolinite	Minor

Sample 5188, FC-6, 8-16 in.

Quartz	Major
Illite	Moderate
Chlorite or kaolinite	"
Albite(?)	Minor
Zeolite(?)	"

Sample 5201, FC-10, 0-4 in.

Glass	Major
Mullite	"
Quartz	Minor

Sample 5202, FC-10, 4-17 in.

Glass	Major
Mullite	"

Major, moderate, and minor are judged from the intensity of x-ray peaks. Major indicates peak or peaks are offscale (except for glass, for which the broad peak from 20 to 30 degrees, peaked at about 26 degrees, has an amplitude about half the chart width). Moderate indicates a distinct peak or peaks reaching 10% of full scale or more. Minor indicates a smaller peak. Query indicates uncertain mineral identification