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Prepared by
Oak Ridge Associated Universities

Prepared for
Division of Industrial and Medical Nuclear Safety

U.S. Nuclear Regulatory Commission

RADIOLOGICAL IMPACTS OF EFFLUENT RELEASES TO THE SANITARY SEWER FROM INTERSTATE NUCLEAR SERVICE CORPORATION ROYERSFORD, PENNSYLVANIA (PHASE I)

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Radiological Site Assessment Program
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FINAL REPORT
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FINAL REPORT

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RADIOLOGICAL IMPACTS OF EFFLUENT RELEASES TO THE SANITARY SEWER FROM INTERSTATE NUCLEAR SERVICES CORPORATION ROYERSFORD, PENNSYLVANIA (PHASE I)

INTRODUCTION AND SITE HISTORY

Interstate Nuclear Service Corporation (INS) of Royersford, Pennsylvania operates a laundry facility under Nuclear Regulatory Commission (NRC) license No. 37-23341-0, authorizing the collection and laundering of clothing and other items potentially contaminated with low-level radioactive material. INS receives items for laundering from customers engaged in the production of nuclear energy and the utilization and/or disposal of radioactive materials. The liquid wastes from laundering operations are filtered to remove suspended solids, and monitored. If the radionuclide concentrations are within the NRC limits for release, the contents are discharged to the sanitary sewer. INS typically releases 57,000 liters each day, five days per week to the sewer. Analyses of the water released from the tanks have identified a variety of radionuclides, including tritium, mixed fission products, activation products, uranium, and thorium.

The Royersford Wastewater Treatment Facility handles about 2 million liters per day, including the discharge from INS. Sludges from the treatment process accumulate in the secondary digestor from approximately October to May each year. Beginning in May the sludge is withdrawn and spread on land, as fertilizer, throughout a number of farms comprising a large area west of Philadelphia. During 1986 a total of approximately 7.1×10^5 liters of sludge was removed from the Royersford Wastewater Treatment Facility and spread for this purpose. Clear water from the plant is chlorinated and discharged to the Schuykill River.

Analyses of sludge from the secondary digestor has indicated measurable concentrations of most radionuclides being discharged from INS. Concentrations in the liquid effluent released to the river are much lower than those in the sludge. Considering the levels being released from INS, and the dilution available before reaching the waste treatment plant, it appears that the waste treatment process is concentrating many of the radionuclides released from INS in the sludge.

The Nuclear Regulatory Commission's Division of Industrial and Medical Nuclear Safety (formerly the Division of Fuel Cycle and Material Safety) has requested that Oak Ridge Associated Universities evaluate the potential exposure pathways from surface application of low-level radioactively-contaminated sewage sludge from the Royersford Wastewater Treatment Facility. This project was initiated in early 1986 (Phase I) and is expected to continue through 1987 (Phase II) and, possibly, into 1988 (Phase III). Activities during 1986 included: evaluating liquid effluent discharges from the INS laundry; measuring radiological conditions within the sewage treatment facility; determining concentrations in sewage sludge; establishing concentrations of radionuclides in several treated fields; and conducting preliminary estimates of potential dose commitments from such sludge application. Additional measurements during 1987 will enable evaluation of effects of repeated long-term sludge applications and uptake of various radionuclides by vegetation, grown on treated areas. These additional data will then be used to estimate the maximum radionuclide concentrations, which could be present in the sludge, to assure satisfying current population dose limits.

SITE DESCRIPTION

The Interstate Nuclear Services Corporation, operates its laundry service at North Third Avenue in Royersford, PA (Figures 1 and 2). Potentially contaminated items are water-washed in commercial laundry units, dried, surveyed, and then folded. The liquid wastes from the laundering process are collected in two 1.9×10^4 liter tanks and the pH is adjusted to 6 - 9. The wastewater is recirculated for approximately 30 minutes in the discharge tank prior to release to the sanitary sewer system. Approximately 57,000 liters are discharged to the sewer each work day.

The Borough of Royersford, Pennsylvania, Wastewater Treatment Facility consists of two pumping stations, approximately 20 km of sewer, and a secondary treatment plant. The facility was originally constructed in 1937 and was upgraded to secondary treatment in 1952. The secondary treatment plant (Figure 3) is located at the end of 1st Avenue in Royersford and is a two-stage biofiltration plant with a design capacity of 2 million liters per day. Primary and secondary sludges settle in the primary settling tanks. Periodically, the sludge is pumped to the primary anaerobic digestor, where the organic content of the sludge is

stabilized. Excess water is decanted to the plant raw sewage wetwalls and the thicker digested sludge is pumped to the secondary digestor where it is allowed to accumulate from October to May. Approximately 9.5×10^3 liters of the sludge, with a solids content of 3 - 5%, is transferred to the secondary digestor each week. Beginning in May the sludge is withdrawn in 2.3×10^4 liter truckloads by a commercial sludge spreader. The sludge is spread on agricultural land, as fertilizer, throughout a number of farms, west of Philadelphia. The majority of the sludge is spread early in the growing season; spreading is reduced during the late summer and early fall.

The sludge application sites selected for this study consist of two farmland areas near Royersford (Figure 2). Both sites 1 and 2 have received sludge application in past years; however, the application frequencies and amounts are unknown. Site 1 is a 10 m x 10 m plot located on farmland in Limerick Township, approximately 5 km north of the Borough of Royersford. Site 2 (Providence Township) is located in Upper Providence, approximately 6.5 km east of Royersford and 0.3 km north of the Pottstown Phoenixville-Collegeville (Rt 29) exchange. Sludge from the Royersford Wastewater Treatment Facility was spread on both sites in June and July 1986. Sludges were applied at an approximate rate of 11.5 l/m^2 (12,000 gal/acre). The soil was tilled to a depth of 7 to 10 cm immediately following sludge application. Prior to planting feed crops, the soil was disked/plowed to a depth of 30 cm. Wheat was planted on site 2 in late October 1986. No crops were planted on site 1 during 1986; however, corn was planted in the spring of 1987.

SURVEY PROCEDURES

INS Sampling

1. ORAU personnel reviewed records of data for effluent releases from September 1985 through September 1986.

2. During the week of June 23-27, 1986, ORAU collected two 4 liter samples of each batch of liquid effluent released to the sanitary sewer system. A total of 17 water samples was collected. Lint and other particulate matter removed by the laundry screen filters, was also collected for determination of the types and quantities of radionuclides handled by the INS laundry process.

3. A sediment sample was collected from the sewer main within the INS facility compound.

Wastewater Treatment Facility

1. ORAU personnel performed a walkover survey of the facility property using NaI(Tl) gamma scintillation detectors cross calibrated onsite with a pressurized ion chamber. Direct measurements at the surface and at 1 meter above the surface were made at the settling ponds, bio-filters, and primary and secondary digestors (Figure 4).

2. Composited samples (1/2 hour intervals) of the Wastewater Treatment Facility influent were collected on June 25 and 26, 1986, coinciding with INS plant discharge sampling, to determine if fluctuations in radionuclide levels could be traced to INS release times.

3. ORAU personnel collected samples of sludge being transferred from the primary digestor to the secondary digestor, and at various depths and locations within the secondary digestor, prior to the initial withdrawal for sludge spreading.

4. Royersford Wastewater Treatment Facility workers obtained samples of every batch of sludge as it was being withdrawn from the secondary digestor by the commercial spreader, during the 1986 sludge spreading season, for analyses.

5 Water and sediment samples were collected at the Wastewater Treatment facilities outfall to the Schuylkill River.

6. A sediment sample was collected from the sewer line on Main Street, midway between INS and the Wastewater Treatment Facility.

Sludge Application Sites

Site 1 (Limerick Township)

1. A 10 m x 10 m grid was established at the site on April 15, 1986. The grid origin was referenced to existing surface features.

2. One sediment and one water sample were obtained from a small runoff stream, just south of the site.

3. On June 23, 1986, before initial sludge application of the 1986 season, baseline soil samples were collected at nine randomly selected locations within the gridded area. Soil samples were obtained using a shelby tube driven to a depth of 22.5 cm. Samples were composited to represent depths of 0-2.5, 2.5-7.5, and 7.5-22.5 cm. Direct gamma radiation levels were measured at the surface and one meter above the surface at the nine sampling locations. Surface beta-gamma measurements were also performed at each sampling location.

4. During sludge spreading and tilling on June 24, 1986, hi-volume air samplers were operated upwind and downwind of the site to determine levels of airborne radionuclides.

5. On June 24, 1986, following the initial sludge application and tilling, soil was resampled from the 100 m^2 plot, following the same procedure described in step 3 above. Direct measurements were obtained at individual sampling locations.

6. On August 26, 1986, the soil sampling and direct measurement procedures were repeated on the 100 m^2 plot. Soil was composited into 4 segments representing depths of 0-2.5, 2.5-7.5, 7.5-15, and 15-30 cm. No crops have been planted on this site, therefore vegetation sampling was not performed.

7. Soil sampling and direct measurements were repeated on the study plot on October 28, 1986. Soil sample composites were prepared for depths of 0-2.5, 2.5-7.5, 7.5-15, and 15-30 cm. Vegetation was not sampled, because crops were never planted.

Site 2 (Providence Township)

1. A 10 m x 10 m grid was established on the site on April 15, 1986. The grid origin was referenced to existing surface features.

2. On April 15, samples of soil were obtained at nine randomly selected locations within the gridded area. Soil samples were obtained using a shelby tube driven to a depth of 22.5 cm. Samples were composited to represent depths of 0-2.5, 2.5-7.5, and 7.5-22.5 cm. Direct gamma radiation levels were measured at the surface and one meter above the surface at the nine sampling locations. Surface beta-gamma were also performed at each sampling location.

3. Two samples of sediment and water were obtained from small runoff streams adjacent to the site.

4. During initial sludge spreading and tilling on June 24, 1986, hi-volume air samples were obtained upwind and downwind of the site to determine levels of airborne activity.

5. On June 24, 1986, following the initial sludge application and tilling, soil was resampled from a selected 100 m^2 plot, following the same procedure described in step 2 above. Direct measurements were obtained at individual sampling locations.

6. On August 26, 1986, the soil sampling and direct measurement procedures were repeated on the 100 m^2 plot. Soil was composited into 4 segments representing depths of 0-2.5, 2.5-7.5, 7.5-15, and 15-30 cm. No crops have been planted on this site, therefore vegetation sampling was not performed.

7. Soil sampling and direct measurements were repeated on the study plot on October 28, 1986. Soil sample composites were prepared for depths of 0-2.5, 2.5-7.5, 7.5-15, and 15-30 cm. Vegetation was not sampled, because winter wheat had recently been planted.

Background Samples and Measurements

Surface soil samples were collected from three locations within the Royersford and Upper Providence townships to provide baseline concentrations of radionuclides of interest for comparison purposes (Figure 5). Background exposure levels were measured at each of the baseline sample locations. Three water and

three sediment samples were collected from area streams and rivers for baseline purposes. A sample of city tap water was collected for radionuclide concentration determination. Vegetation samples were collected from four locations and composited for determination of baseline concentrations.

Sample Analysis and Interpretation of Data

Soil and sludge samples were analyzed by gamma spectrometry. In addition, H-3, Sr-89/90, isotopic uranium, and isotopic plutonium concentrations were determined using established radiochemistry procedures. Water, residue samples, and air filters were analyzed for gross alpha and beta concentrations. Selected water samples were analyzed for Sr-89/90, uranium, and plutonium. Vegetation samples were analyzed by gamma spectrometry and wet chemistry procedures.

Additional information concerning analytical equipment and procedures is presented in Appendices A and B.

SURVEY RESULTS

Background Levels and Baseline Concentrations

Background exposure rates and beta-gamma dose rates are presented in Table 1. Exposure rates at one meter above the surface ranged from 8 to 12 μR/h. Beta-gamma dose rates ranged from 22 to 30 μrad/h.

Baseline radionuclide concentrations measured in surface soil, sediment, and vegetation samples are presented in Table 2. Radionuclide concentrations measured in these samples are typical of radionuclide concentrations normally observed in similar sample media.

Table 3 presents gross alpha and gross beta concentrations measured in water samples from baseline sample locations. These values are typical of concentrations normally detected in surface/run-off water.

Gross alpha and gross beta concentrations measured in a sample of Royersford city tap water were 3 pCi/l and 4 pCi/l, respectively, and the H-3 concentration was <230 pCi/l.

Interstate Nuclear Services

Sampling records maintained by INS from September 1985 through August 1986 are complete and indicate compliance with 10CFR20.303.[1] Average monthly releases to the sewer system, based on gross activity measurements, are 21.1 mCi.

Table 4 presents the results of analysis of the water samples collected by ORAU prior to tank release during the week of June 23-27, 1986. Cobalt 60, Co-58, and Cs-137 concentrations averaged 500 pCi/l, 1600 pCi/l, and 2600 pCi/l, respectively. Tritium (H-3) concentrations measured in seven of the samples averaged 3.0×10^4 pCi/l. Smaller amounts of several other radionuclides were detected. The total activity level in liquid releases from the facility during the week calculated to be approximately 1.1 mCi. This is less than the INS calculated value of 3.2 mCi; however, the INS values are based on gross activity measurements and therefore may overestimate the release.

Radionuclide concentrations measured in three aliquots from the particulate matter, collected on the INS washwater filter during the week of June 23-27, 1986, are presented in Table 5. The major contributing radionuclides were Cr-51, Co-58, Co-60, Zn-65, and Cs-137, and the total activity calculated for the entire quantity of filtered material was 0.32 mCi. Assuming that the laundering process removes essentially all contamination from the clothing and that all of the removed contamination enters the wash and rinse water, the total activity throughput for the facility during the week of June 23-27, 1986, is estimated at about 1.4 mCi (i.e. 1.1 mCi in the liquid plus 0.32 mCi of filtered particulate).

The radionuclide concentrations measured in a sediment sample collected from the sewer at INS are presented in Table 6. The maximum concentration was measured to be 1.2×10^5 pCi/g of Co-60. Phase II of this study will address a direct exposure pathway for an individual working in the sewer system.

Wastewater Treatment Facility

Exposure Rate Measurements

Gamma exposure rates (Table 7) measured over most of the wastewater facility, generally ranged from 7 to 17 μR/h, which are typical of background exposure rates

for the Royersford area. Measurements made at the surface of the liquid in the secondary digestor ranged from 390 to 470 μR/h. The values dropped to 360 to 430 μR/h when measured at one meter above the opening to the secondary digestor in the early spring when the tanks were full. Gamma exposure levels at one meter above the tanks were reduced to 20 to 30 μR/h by the fall of 1986, probably because of the lower level of liquid remaining in the tanks.

Wastewater Influent

Table 8 presents gross alpha and gross beta concentrations measured in primary influents to the Royersford facility, collected at one-half hour intervals. Specific radionuclide concentration measurements performed on samples composited from 9:30 am to midnight on June 25, 12:30 am to 9:00 am and 9:30 am to midnight on June 26, and 12:30 am to 9:00 am on June 27, are presented in Table 9. Tank release times at INS during the sampling period were:

June 25	7:15 am
	10:10 am
	2:30 pm
June 26	7:00 am
	8:30 am
	10:45 am
	2:40 pm
June 27	7:45 am

Digestor Sludge Concentrations

Radionuclide concentrations measured in sludge samples taken from the secondary digestor in April, 1986, are presented in Table 10. Table 11 contains concentration information from samples collected from May through September, as the sludge spreading truck was being filled. Cobalt 60 was noted to have the greatest average concentration (59,000 pCi/l).

Wastewater Effluent

A sample of effluent discharged from the Wastewater Treatment Facility to the Schuylkill River, was analyzed and found to contain no identifiable gamma emitters

and less than 2 pCi/l of total uranium. The tritium concentration in this sample was 2510 pCi/l and the Sr-90 concentration was 23.7 pCi/l. These levels of measurable radionuclides are at least an order of magnitude less than the concentrations discharged from INS. The differences are the result of dilution by other Treatment Facility influent and the uptake of the radionuclides by biological activity occurring in the sewage digestion process.

Sludge Application Sites

Direct Radiation Levels

Tables 12 and 13 summarize the direct radiation levels measured on Sites 1 and 2, respectively, before 1986 sludge applications and at three successive dates following the applications. Radiation levels measured before sludge application averaged 3-4 μR/h higher than background levels determined for the Royersford area. The reason for this may be slightly elevated concentrations of radionuclides from previous soil treatment with phosphate fertilizers and/or sewage sludge. Following sludge application and initial tilling, the direct radiation levels increased. At Site 1 the average exposure rate at one meter above the surface increased from 13.7 to 15.2 μR/h. At surface contact the changes in exposure and dose rates were 14.6 to 15.9 μR/h and 28.1 to 33.3 μrad/h, respectively. In August and October, the radiation levels had decreased to slightly below the baseline levels, measured before the sludge application in June.

Direct radiation levels on Site 2 after sludge applications were increased by a greater amount than those on Site 1. The average exposure rate at one meter above the surface increased from 13.6 to 20.1 μR/h. Exposure rate and dose rate averages at surface contact increased from 13.8 to 21.0 μR/h and 24.0 to 34.1 μrad/h, respectively. The direct radiation levels were lower on subsequent surveys but did not return to the baseline levels, measured prior to sludge application.

Radionuclide Concentrations in Soil

Radionuclide concentrations measured in composite soil samples from the study sites are presented in Tables 14-17. On Site 1 prior to sludge application the

only non-naturally occurring radionuclide noted above minimum detection levels was Cs-137; the concentration of this radionuclide was, however, comparable to levels present in baseline soils. Following sludge application, increased levels of Mn-54, Co-60, and Cs-137 were measured in the samples representing the upper 2.5 cm and 2.5 to 7.5 cm soil layers. The radionuclide with the highest concentration measured was Co-60 at 4.0 pCi/g in the top 2.5 cm of soil. All soil concentrations decreased on subsequent sampling dates. By October, only Co-60 and Cs-137 were still present at levels above the detection limits for the analytical procedures. The highest Co-60 level at this time was 0.7 pCi/g at the 2.5-7.5 cm depth, and the highest Cs-137 concentration was 0.7 pCi/g at the same depth.

The sampling on Site 2 before sludge application identified elevated levels of Co-60; the highest concentration was 1.8 pCi/g in the upper 2.5 cm of soil. Other radionuclides were at naturally occurring levels or below the measurement sensitivities. After application of sludge, Mn-54, Co-60, and Cs-137 concentrations were elevated. The major radionuclide was Co-60 with a concentration of 27 pCi/g in the top 2.5 cm of soil. The concentrations decreased to baseline levels below 7.5 cm. Subsequent measurements indicated decreasing concentrations of these radionuclides. By October, the highest Co-60 level was 4.0 pCi/g at the 2.5 to 7.5 cm depth. The only other radionuclides, measured at other than baseline concentration at this time, were Cs-137 and uranium. The maximum Cs-137 concentration in the October samples was 1.1 pCi/g in the upper 2.5 cm of soil at study Site 2. Highest uranium concentrations were on Site 1, and were: U-234, 27 pCi/g at 2.5 to 7.5 cm depth; U-235, 1.0 pCi/g at 2.5 to 7.5 cm depth; and U-238, 4.2 pCi/g in the upper 2.5 cm. Because other samples contained uranium-234 levels averaging about 1/10 of these values, ORAU suspects that a small area containing enriched uranium was sampled for this composite, and that the resulting uranium concentration is probably not representative of the average for the entire study site.

Airborne Radioactivity During Spreading Operations

Table 18 summarizes the results of air sampling, conducted during sludge-spreading and surface-tilling operations at the two study sites. At both sites, there was no significant difference between the upwind and downwind sample. The maximum alpha and beta concentrations were 4.3×10^{-14} μCi/ml and 3.5×10^{-13} μCi/ml, respectively. These concentrations are within the

unrestricted area guideline values presented in 10CFR20, Appendix B, Table II, Column 1, for major radionuclides which have been identified as being present in the sewage sludge.[1]

Radionuclide Concentrations in Sediments from Runoff Ditches

Radionuclide concentrations in sediment samples from runoff ditches adjacent to the study sites are presented in Table 19. As noted in this table, the only man-made radionuclide exceeding the measurement sensitivities of the analytical procedure was Cs-137. This radionuclide had a maximum concentration of 0.3 pCi/g in the sample from the ditch near Site 1; such a concentration does not differ significantly from baseline soil levels.

PATHWAY ANALYSIS AND DOSE COMMITMENT ESTIMATES

Pathway Identification

The exposure pathways identified as plausible for this study were:

1. Direct radiation from the sludge-fertilized fields.
2. Inhalation of dust emissions from the sludge-fertilized fields.
3. Ingestion of produce from sludge-fertilized fields.
4. Ingestion of beef from cows fed vegetation from sludge-fertilized fields.
5. Ingestion of milk from cows fed vegetation from sludge-fertilized fields.
6. Ingestion of soil (pica).

Pathway Analysis and Dose Estimates

Pathway analyses and dose estimates were performed for the maximally exposed individual, two special case situations involving potential exposures of children, and the population. Five radionuclides were selected for dose calculations, based on their positive concentrations in soil samples from the treated sites; these are Co-60, Cs-137, U-234, U-235, and U-238. In addition, calculations were performed for Sr-90, because of that radionuclide's importance in several of the food chains - particularly vegetation and milk. Methodology was that of ICRP 26, using parameters from NUREG/CR-150, Vol 3; NUREG/CR-4628; NUREG/CR-3535 and NRC Regulatory Guides 1.109 and 3.51.[2-7] A description of the dose estimation procedures is provided in Appendix C.

Maximally Exposed Individual

The maximally exposed individual is assumed to be a farmer, who spends an average of 4 hours per day, 240 days per year working on or in the immediate vicinity of a land area treated with sewage sludge. Soil concentrations during the entire year are assumed to be the average levels measured during the 1986 sampling. In addition to the direct exposure and inhalation exposure while working the treated land, it is assumed that 10% of the produce (vegetables) eaten by the farmer is grown on this land; 50% of the farmer's meat intake is from livestock, fed crops from treated land; and 100% of the milk is from cattle fed from treated land. At the present time the sludge is not being spread on agriculture lands growing crops used for human consumption.

Highest dose equivalent commitments to major organ systems from 1 year's exposure to sludge-treated areas were estimated to be:

Endostial cells on bone surfaces	8.2 mrem
Kidneys	5.4 mrem
Lung	4.6 mrem
Red Marrow	4.1 mrem
Effective	4.0 mrem

With exception of the endostial cells, over half of the dose equivalents were due to external, direct radiation. The dose equivalent to endostial cells was primarily due to uranium isotopes in the vegetation ingestion pathway.

Dose to Child From Ingestion of Soil

People with a condition known as pica have a craving for ingesting non-food materials, such as chalk, clay, soil, etc. If, during a year, a child were to ingest 100 g of soil from the surface of a treated site the dose equivalent commitments from this pathway would be approximately:

Endostial cells	13 mrem
Kidneys	5.8 mrem
LLI Wall	0.6 mrem
Effective	0.8 mrem

Dose equivalent commitments are primarily due to uranium isotopes.

Dose to Child From Ingestion of Milk

An annual ingestion of 330 liters of milk, contaminated with radionuclides as a result of cows consuming forage grown on sludge-treated land, was assumed for a child. Dose equivalent commitments from this pathway were estimated to be:

Endostial cells	3.0 mrem
Kidneys	1.2 mrem
Effective	0.25 mrem

Population Dose

The total number of sludge-application areas occupy only about 10 hectares. For population-dose estimates, it was assumed that treated areas are on 20 different farms; two individuals work on the treated areas for 4 hours per day, 240 days per year; half of the treated areas are planted in vegetation crops for direct human consumption; and half of the areas are used to raise livestock forage crops. The resulting population dose equivalent commitment for the total body was 1.2 person-rem.

DISCUSSION

Interstate Nuclear Services

A review of the discharge records from INS indicates compliance with 10CFR20.303. ORAU analyses of samples of water discharged by INS, indicates that INS is slightly overestimating their discharge quantities, due to measurement techniques which are based on gross activity. The total activity reported by INS as discharged to the sanitary sewer, September 1985 through August 1986, was 242 mCi. Based on the comparison of ORAU isotopic analyses with INS gross analyses, the INS values may be overestimating discharge by a factor of approximately 2.9; the recalculated discharge would be 83.4 mCi for this time period. The total volume of sludge withdrawn from the Treatment Facility during the same time period was 7.1×10^5 liters; the average total concentration in the sludge, determined by ORAU, was about 1.04×10^5 pCi/l. This results in a total activity of 73.8 mCi. Considering the uncertainties in beginning and ending digestor tank contents and other potential uncertainties inherent with the various

data used for these determinations, there appears to be good agreement between the total activity released from INS and the total activity collecting in the secondary digestor.

Wastewater Treatment Facility

Exposure rate measurements performed at several locations around the facility were comparable to background levels, with the exception of the openings (2) to the Imhoff tanks (secondary digestors). Full-time occupancy of the open area over the Imhoff tanks would result in 5.1 mrem/y from direct exposure. However, the tank openings are very small, and situated such that continual total body exposure is very unlikely. A more reasonable estimate is 15 minutes per day exposure which would result in approximately 0.2 mrem per year. Direct exposure resulting from radionuclide concentrations in the wastewater treatment facility is negligible.

The analysis of the influent to the wastewater treatment facility indicates low alpha emitter concentrations. Gross beta concentrations vary widely; however, peaks in gross beta concentrations typically occur approximately three hours after discharge is made from the INS facility. Gross comparisons of INS release concentrations to influent concentrations indicate a reduction in concentration by approximately one order of magnitude, due to dilution from other wastewater sources.

Sludge Application Sites

Direct radiation levels at the sludge application sites are slightly elevated above background initially after sludge application and tilling. The measured levels present no hazard to individuals occupying the sites under the scenarios described.

Monitoring for airborne radioactivity was conducted during sludge application and tilling. The results indicate that the airborne contamination is within the guideline values presented in 10CFR20, Appendix B, Table II, column 1.

Samples collected from drainage ditches and runoff streams did not contain detectable radionuclide concentrations which could be attributed to sludge spread on the site.

Pathway Analysis

In determining the exposure pathways and defining the maximally exposed individual, conservative assumptions were used throughout, resulting in an overestimate of dose equivalent commitment.

The effective (weighted) committed dose equivalents are summarized below for one year's exposure to the maximally exposed individual, a child from ingestion of soil, a child from ingestion of milk, and the population:

Effective Dose Equivalent Commitment

Maximally Exposed Individual	4.0 mrem
Child (Soil)	0.8 mrem
Child (Milk)	0.25 mrem
Population Dose	1.2 rem

ICRP 26 recommends a lifetime dose equivalent to an individual member of the public be limited to 100 mrem per year life-long whole body exposure, and the whole body dose-equivalent limit for critical groups be limited to 500 mrem. The maximally exposed individual would receive approximately 4% of the recommended dose equivalent commitment, under the assumptions used in the analyses.

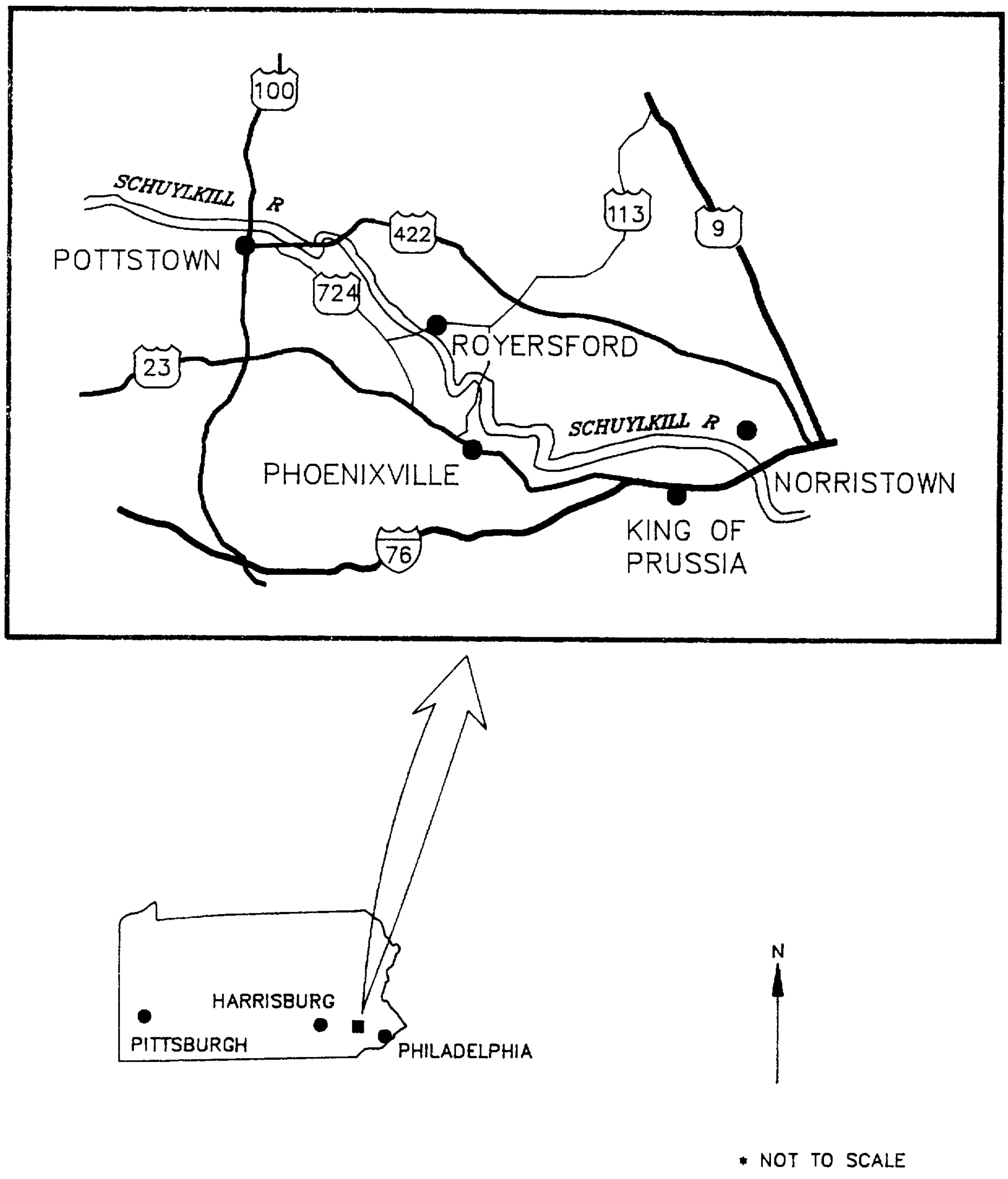

FIGURE 1: Map of Pennsylvania Indicating Location of the Borough of Royersford

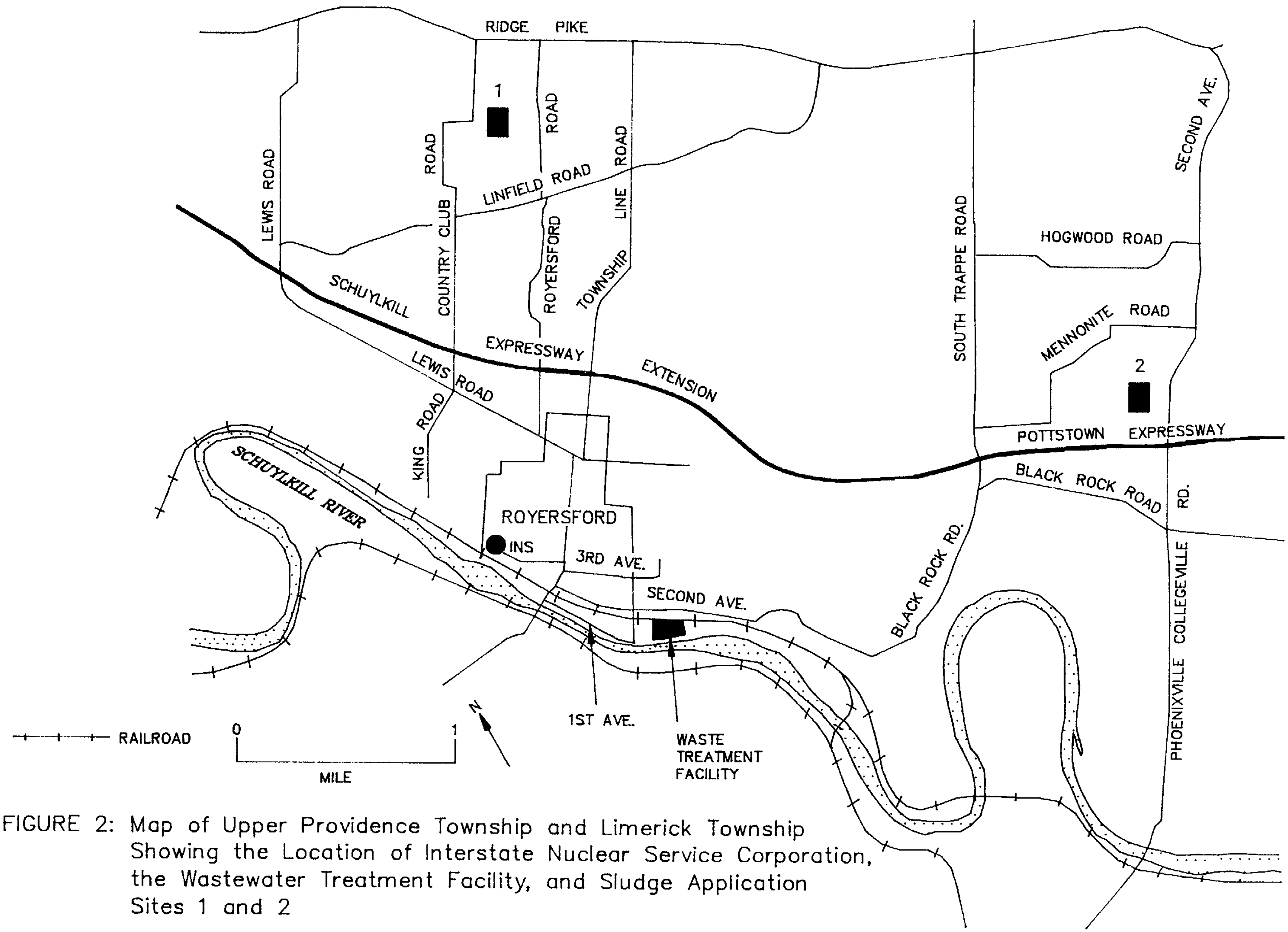

FIGURE 2: Map of Upper Providence Township and Limerick Township Showing the Location of Interstate Nuclear Service Corporation, the Wastewater Treatment Facility, and Sludge Application Sites 1 and 2

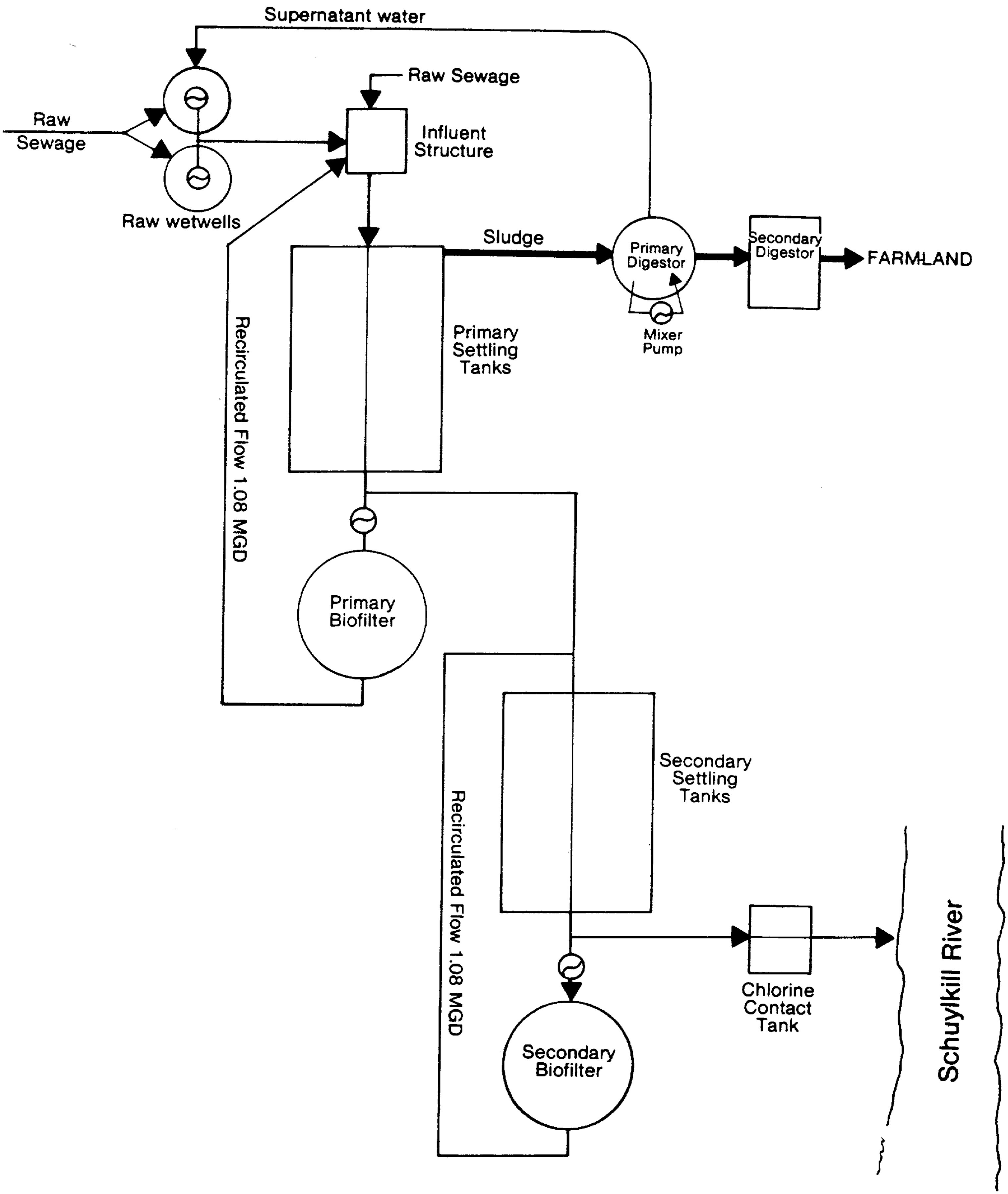

FIGURE 3: Flow Diagram of the Royersford Wastewater Treatment Facility

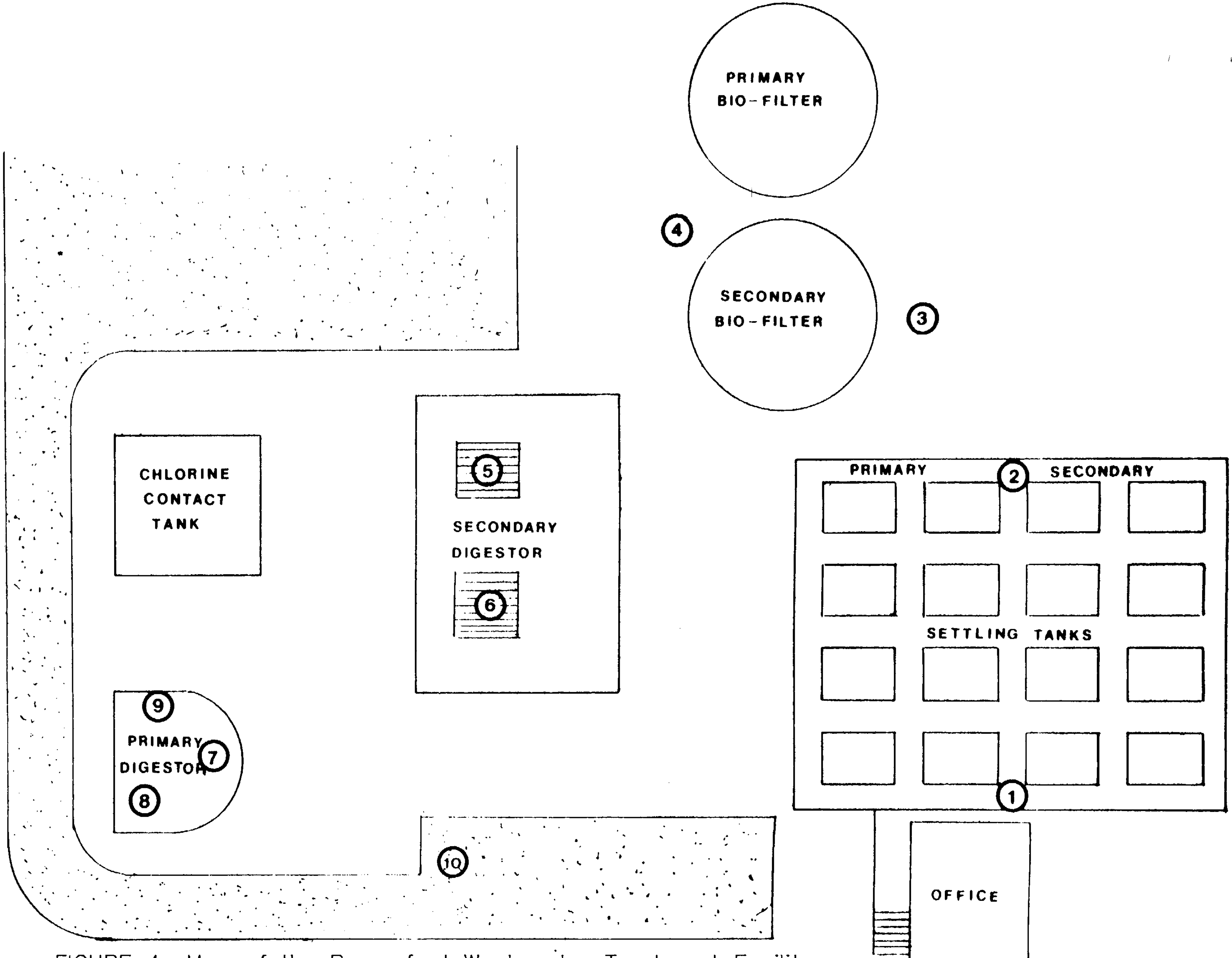

FIGURE 4: Map of the Royersford Wastewater Treatment Facility Indicating Locations of Direct Gamma Measurements

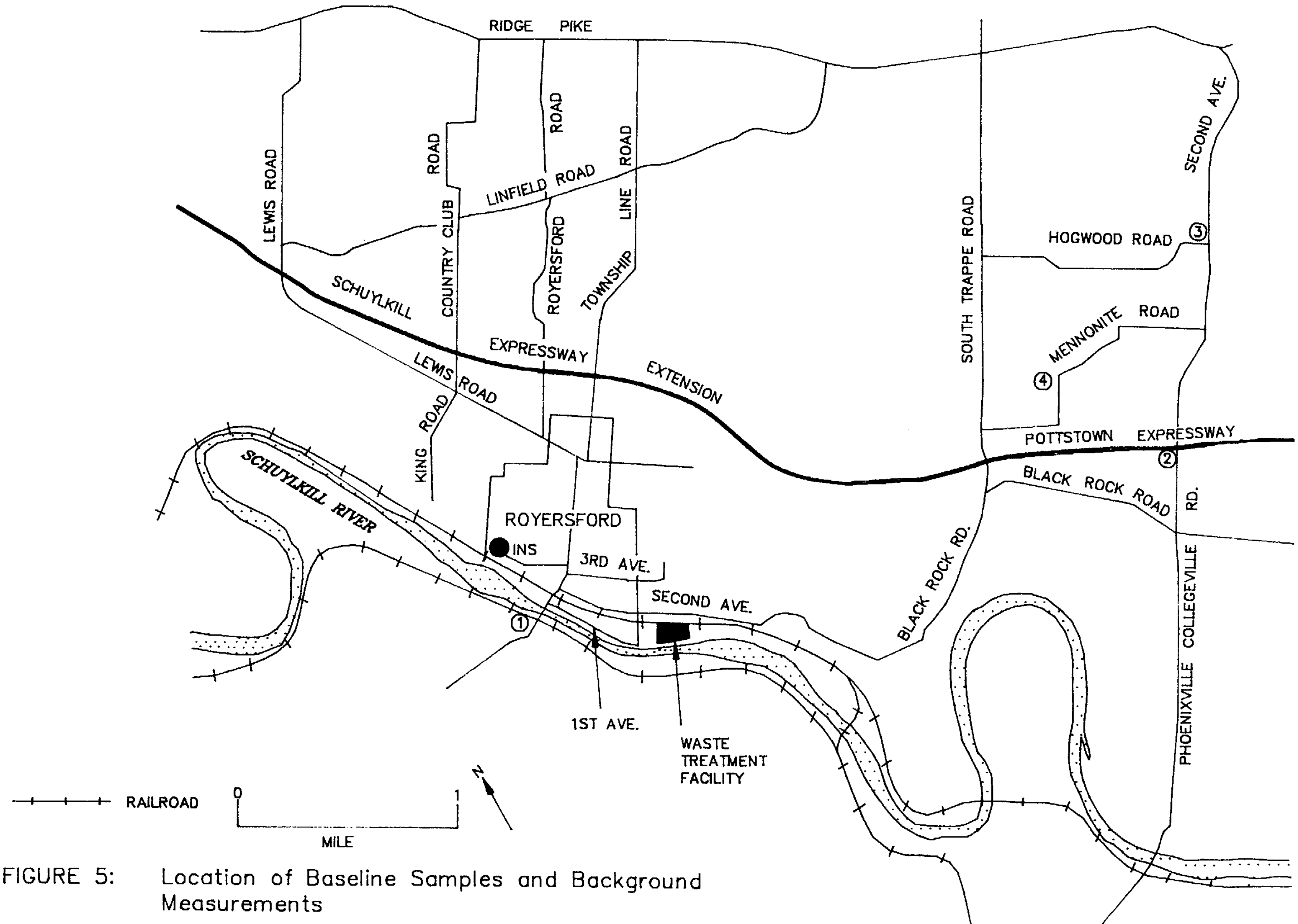

FIGURE 5: Location of Baseline Samples and Background Measurements

TABLE 1

DIRECT RADIATION LEVELS MEASURED AT BASELINE SAMPLE LOCATIONS
ROYERSFORD, PENNSYLVANIA

Location[a]	Gamma Exposure Rates at 1 m Above the Surface (μR/h)	Gamma Exposure Rates at the Surface (μR/h)	Beta-Gamma Dose Rates at 1 cm Above the Surface (μrad/h)
1	8	9	22
2	12	12	29
3	10	10	30
4	b	b	b

[a]Refer to Figure 5.
[b]No data collected.

TABLE 2

RADIONUCLIDE CONCENTRATIONS (pCi/g) IN BACKGROUND SOIL, SEDIMENT AND VEGETATION
INTERSTATE NUCLEAR SERVICES
ROYERSFORD, PENNSYLVANIA

Radionuclide	Location 1[a]		Location 2[a]	Location 3[a]		Location 4[a]	Vegetation Composite From All Locations (Activity/Ashed Weight)
	Soil	Sediment	Soil	Soil	Sediment	Sediment	
Cr-51	<1.0	<1.0	<0.7	<1.0	<0.6	<0.7	<0.1
Mn-54	<0.1	<0.1	<0.2	<0.1	<0.2	<0.1	<0.1
Co-58	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Fe-59	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1
Co-60	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1
Zn-65	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sr-89	b	b	b	b	b	b	<0.1
Sr-90	<0.46	<0.32	0.49 ± 0.60	<0.37	<0.38	<0.42	0.16 ± 0.02[c]
Zr-95	<1.2	<0.1	<0.1	<1.1	<0.1	<0.1	<0.1
Nb-95	<0.1	<0.1	0.4 ± 0.3	<0.1	<0.1	<0.1	<0.1
Ag-110m	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sb-125	<0.2	<0.2	<0.1	<0.2	<0.1	<0.1	<0.1
Cs-134	<0.1	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1
Cs-137	0.4 ± 0.2	0.4 ± 0.2	<0.1	<0.1	<0.1	<0.2	0.03 ± 0.009
U-234	2.25 ± 0.20	2.37 ± 0.22	1.69 ± 0.17	1.97 ± 0.18	1.81 ± 0.20	2.06 ± 0.18	b
U-235	0.06 ± 0.04	0.10 ± 0.05	0.10 ± 0.04	0.05 ± 0.03	0.03 ± 0.03	0.10 ± 0.05	b
U-238	1.92 ± 0.91	2.19 ± 0.21	1.70 ± 0.17	1.58 ± 0.17	1.46 ± 0.17	1.88 ± 0.18	b
Pu-238	<0.01	0.03 ± 0.02	<0.01	0.02 ± 0.02	0.02 ± 0.02	0.01 ± 0.01	b
Pu-239/240	<0.01	0.02 ± 0.02	<0.01	0.02 ± 0.02	0.01 ± 0.01	0.02 ± 0.02	b

[a]Refer to Figure 5.
[b]Analysis not performed.
[c]Uncertainties are 2σ based only on counting statistics.

TABLE 3

RADIONUCLIDE CONCENTRATIONS MEASURED IN BASELINE
WATER SAMPLES
INTERSTATE NUCLEAR SERVICES
ROYERSFORD, PENNSYLVANIA

Sample Location[a]	Radionuclide Concentrations (pCi/l)	
	Gross Alpha	Gross Beta
1	<1.1	<4.2
2	b	b
3	<0.7	3.1 ± 1.6[c]
4	<2.0	<5.3

[a]Refer to Figure 5.
[b]Water not available for sampling.
[c]Uncertainties are 2σ based only on counting statistics.

TABLE 4

RADIONUCLIDE CONCENTRATIONS IN WASTE WATER SAMPLES COLLECTED AT INS
PRIOR TO DISCHARGE TO SANITARY SEWER
INTERSTATE NUCLEAR SERVICES
ROYERSFORD, PENNSYLVANIA

Radionuclide	Radionuclide Concentrations (pCi/l)								
	Sample #1	Sample #2	Sample #3	Sample #4	Sample #5	Sample #6	Sample #7	Sample #8	Sample #9
H-3	17000 ± 700[a]	b	15000 ± 200	69000 ± 1000	57000 ± 1000	b	b	b	b
Cr-51	1100 ± 400	<180	<600	<240	<200	<190	<290	<200	<160
Mn-54	450 ± 12	260 ± 9	280 ± 8	200 ± 8	730 ± 13	270 ± 8	200 ± 41	170 ± 9	130 ± 6
Co-58	85 ± 8	1600 ± 25	1400 ± 23	1100 ± 21	700 ± 18	870 ± 19	1600 ± 41	880 ± 20	1100 ± 19
Fe-59	<11	<13	<14	<13	<14	<14	<25	<14	<9.0
Co-60	130 ± 8	570 ± 12	440 ± 10	380 ± 9	540 ± 11	600 ± 12	430 ± 18	380 ± 11	230 ± 7
Zn-65	<4.0	<5.1	<5.3	7.3 ± 5.6	<5.6	11 ± 9	22 ± 20	32 ± 13	<3.9
Sr-89	b	b	b	b	b	b	b	b	b
Sr-90	260 ± 4	b	240 ± 5	b	800 ± 9	b	b	b	b
Zr-95	<8.1	<8.3	<9.0	<9.0	<8.7	<8.1	<16	<8.8	<6.5
Nb-95	<10	<9.6	<10	<11	<10	<10	43 ± 37	<10	<7.2
Ag-110m	<4.9	<3.4	4.5	<4.6	<4.5	<3.9	<6.6	<4.9	<3.3
Sb-125	<12	<9.3	<12	<13	<12	<11	<18	<12	<9.3
Cs-134	530 ± 13	300 ± 9	800 ± 13	870 ± 13	570 ± 11	360 ± 9	400 ± 14	360 ± 12	390 ± 9
Cs-137	1500 ± 18	1000 ± 14	2500 ± 21	3200 ± 24	2500 ± 22	2100 ± 19	2000 ± 29	1400 ± 18	1400 ± 16
U-234	2.4 ± 0.5	b	2.4 ± 0.5	b	2.0 ± 0.5	b	b	b	b
U-235	<0.2	b	<0.3	b	<0.2	b	b	b	b
U-238	2.6 ± 0.6	b	2.3 ± 0.5	b	1.9 ± 0.4	b	b	b	b
Pu-238	<0.1	b	<0.1	b	<0.1	b	b	b	b
Pu-239/240	<0.1	b	<0.1	b	<0.1	b	b	b	b

TABLE 4 (Continued)

RADIONUCLIDE CONCENTRATIONS IN WASTE WATER SAMPLES COLLECTED
PRIOR TO DISCHARGE TO SANITARY SEWER
INTERSTATE NUCLEAR SERVICES
ROYERSFORD, PENNSYLVANIA

	Radionuclide Concentrations (pCi/l)							
Radionuclide	Sample #10	Sample #11	Sample #12	Sample #13	Sample #14	Sample #15	Sample #16	Sample #17
H-3	44000 ± 1000	b	b	b	b	b	15000 ± 600	14000 ± 900
Cr-51	<250	<250	<220	<260	<460	<230	<300	<93
Mn-54	220 ± 11	130 ± 12	100 ± 6	93 ± 11	220 ± 17	79 ± 7	140 ± 9	38 ± 2
Co-58	3300 ± 37	920 ± 33	880 ± 17	1200 ± 37	6100 ± 76	2900 ± 36	<56	660 ± 9
Fe-59	<21	<23	<12	58 ± 45	<33	<15	660 ± 15	<6.4
Co-60	1100 ± 19	470 ± 20	390 ± 10	350 ± 19	1100 ± 29	500 ± 13	46 ± 17	160 ± 4
Zn-65	25 ± 18	28 ± 17	<4.6	<34	47 ± 28	<6.3	b	<7.6
Sr-89	b	b	b	b	b	b	b	b
Sr-90	190 ± 4	b	b	b	b	b	<12	300 ± 7
Zr-95	<13	<14	<7.0	<14	<19	<49	<13	<3.3
Nb-95	<15	<15	<8.8	<15	<22	<12	<7.6	<4.8
Ag-110m	<6.4	<6.5	<4.0	<6.4	<12	<5.1	<51	<2.9
Sb-125	<14	<18	<12	44 ± 32	86 ± 49	<13	510 ± 15	7.3 ± 4.5
Cs-134	320 ± 13	310 ± 12	240 ± 8	210 ± 14	600 ± 23	200 ± 8	3800 ± 30	90 ± 3
Cs-137	1200 ± 18	2900 ± 35	3600 ± 24	2,800 ± 37	10000 ± 68	1600 ± 19	b	500 ± 5
U-234	1.9 ± 0.4	b	b	b	b	b	b	1.8 ± 0.4
U-235	<0.2	b	b	b	b	b	b	<0.3
U-238	1.9 ± 0.4	b	b	b	b	b	b	1.8 ± 0.4
Pu-238	<0.1	b	b	b	b	b	b	<0.1
Pu-239/240	<0.1	b	b	b	b	b	b	<0.1

[a]Uncertainties are 2σ based only on counting statistics.
[b]Analysis not performed.

TABLE 5

RADIONUCLIDE CONCENTRATIONS (pCi/g) MEASURED IN LINT FROM THE LIQUID FILTER COLLECTED AT INS FROM JUNE 23 - 27, 1986
INTERSTATE NUCLEAR SERVICES
ROYERSFORD, PENNSYLVANIA

Radionuclide	Sample #1	Sample #2	Sample #3
Cr-51	6900 ± 1800[a]	5300 ± 1700	11000 ± 2100
Mn-54	800 ± 110	1100 ± 110	1100 ± 100
Co-58	1700 ± 140	1200 ± 140	1800 ± 190
Fe-59	<180	<130	<200
Co-60	4700 ± 200	3500 ± 190	5900 ± 250
Zn-65	2200 ± 230	1700 ± 240	2300 ± 314
Sr-89	b	b	b
Sr-90	b	240 ± 13	b
Zr-95	<400	<85	1100 ± 300
Nb-95	250 ± 180	<80	3200 ± 310
Ag-110m	110 ± 48	<40	150 ± 60
Sb-125	210 ± 160	<90	210 ± 200
Cs-134	1300 ± 86	580 ± 82	980 ± 101
Cs-137	4100 ± 160	4000 ± 164	4700 ± 170
U-234	1.7 ± 0.5	1.74 ± 0.49	b
U-235	0.1 ± 0.2	0.13 ± 0.23	b
U-238	1.7 ± 0.5	0.71 ± 0.49	b
Pu-238	2.3 ± 0.3	0.29 ± 0.29	b
Pu-239/240	1.7 ± 0.6	1.66 ± 0.58	b

Total weight of lint collected = 12,900 grams.
Average radionuclide concentration = 24,000 pCi/g.
Average total activity = 0.316 mCi.

[a]Uncertainties are 2σ based only on counting statistics.
[b]Analysis not performed.

TABLE 6

RADIONUCLIDE CONCENTRATIONS MEASURED IN SEWER SEDIMENT
INTERSTATE NUCLEAR SERVICES
ROYERSFORD, PENNSYLVANIA

Radionuclide	Radionuclide Concentrations (pCi/g) INS Manhole	Main Street Manhole	Schuylkill River at Sewage Plant Outfall
Cr-51	<620	<26	<3.1
Mn-54	14000 ± 580[a]	16 ± 2	1.0 ± 0.2
Co-58	1600 ± 700	6.2 ± 3.8	0.6 ± 0.2
Fe-59	<1500	<10	<0.2
Co-60	120000 ± 1300	9.0 ± 4.7	1.4 ± 0.2
Zn-65	15000 ± 1500	9.0 ± 4.6	0.7 ± 0.3
Sr-89	b	c	c
Sr-90	b	7.3 ± 0.9	1.9 ± 0.7
Zr-95	<600	<2.5	<0.2
Nb-95	2600 ± 910	<3.1	<0.2
Ag-110m	<180	<0.7	<0.1
Sb-125	2700 ± 680	1.9 ± 3.3	<0.2
Cs-134	2100 ± 190	5.1 ± 1.7	2.0 ± 0.2
Cs-137	14000 ± 470	20 ± 2	10 ± 1
U-234	180 ± 5	2.2 ± 0.3	2.0 ± 0.3
U-235	6.1 ± 1.2	<0.1	<0.2
U-238	99 ± 4	1.8 ± 0.3	1.0 ± 0.2
Pu-238	16 ± 1	<0.1	<0.1
Pu-239/240	65 ± 1	<0.1	<0.1

[a]Uncertainties are 2σ based only on counting statistics.
[b]Insufficient sample for analysis.
[c]Analysis not performed.

TABLE 7

DIRECT RADIATION LEVELS MEASURED AT ROYERSFORD
WASTEWATER TREATMENT FACILITY
ROYERSFORD, PENNSYLVANIA

Location[a]	Gamma Exposure Rates at 1 m Above the Surface (μR/h)	Gamma Exposure Rates at the Surface (μR/h)
1	9	9
2	7	b
3	14	14
4	13	b
5	360	390
6	430	470
7	17	18
8	16	18
9	15	16
10	12	12

[a]Refer to Figure 5.
[b]No measurement made.

TABLE 8

GROSS ACTIVITY CONCENTRATIONS IN PRIMARY INFLUENT TO THE WASTEWATER TREATMENT FACILITY COLLECTED AND COMPOSITED IN ONE HALF HOUR INTERVALS
ROYERSFORD, PENNSYLVANIA

	Sampling Time[a]	Gross Alpha (pCi/l)	Gross Beta (pCi/l)
June 25	9:30a - 10:00a	<1.3	98.8 ± 5.9[b]
	10:30 - 11:00a	1.4 ± 2.0	408 ± 10
	11:30a - 12:00	<1.3	247 ± 9
	12:30p - 1:00p	<1.3	55.4 ± 4.8
	1:30 - 2:00p	<1.5	437 ± 12
	2:30 - 3:00p	<2.0	389 ± 13
	3:30 - 4:00p	<1.8	84.4 ± 6.8
	4:30 - 5:00p	<1.4	64.9 ± 5.1
	5:30 - 6:00p	<1.3	488 ± 12
	6:30 - 7:00p	<1.3	553 ± 12
	7:30 - 8:00p	1.9 ± 2.0	142 ± 7
	8:30 - 9:00p	<1.3	98.0 ± 5.8
	9:30 - 10:00p	<1.2	76.7 ± 5.3
	10:30 - 11:00p	<1.3	135 ± 7
	11:30p - 12:00	<1.2	28.7 ± 4.0
June 26	12:30a - 1:00a	<1.2	32.5 ± 4.1
	1:30 - 2:00a	<1.2	44.1 ± 4.5
	2:30 - 3:00a	<1.2	38.7 ± 4.3
	3:30 - 4:00a	<1.5	14.9 ± 4.2
	4:30 - 5:00a	<2.2	8.42 ± 5.76
	5:30 - 6:00a	<2.4	33.2 ± 7.5
	6:30 - 7:00a	2.8 ± 3.9	33.2 ± 7.5
	7:30 - 8:00a	<2.8	9.77 ± 7.5
	8:30 - 9:00a	<2.1	41.3 ± 7.0
	9:30 - 10:00a	<1.8	1022 ± 20
	10:30 - 11:00a	<1.1	626 ± 13
	11:30a - 12:00	<1.5	636 ± 14
	12:30p - 1:00p	<1.5	925 ± 18
	1:30 - 2:00p	<1.9	130 ± 9
	2:30 - 3:00p	2.2 ± 2.6	1035 ± 19
	3:30 - 4:00p	7.4 ± 3.5	201 ± 11
	4:30 - 5:00p	2.9 ± 2.5	168 ± 8
	5:30 - 6:00p	2.1 ± 2.2	1430 ± 21
	6:30 - 7:00p	<1.5	647 ± 15
	7:30 - 8:00p	<1.5	203 ± 11
	8:30 - 9:00p	5.2 ± 2.4	178 ± 8
	9:30 - 10:00p	<1.8	128 ± 9
	10:30 - 11:00p	<1.1	95.2 ± 5.7
	11:30p - 12:00	<2.1	59.7 ± 7.6

TABLE 8 (Continued)

GROSS ACTIVITY CONCENTRATIONS IN PRIMARY INFLUENT TO THE WASTEWATER TREATMENT FACILITY COLLECTED AND COMPOSITED IN ONE HALF HOUR INTERVALS ROYERSFORD, PENNSYLVANIA

	Sampling Time[a]	Gross Alpha (pCi/l)	Gross Beta (pCi/l)
June 27	12:30a - 1:00a	<1.9	77.8 ± 7.5
	1:30 - 2:00a	<2.0	69.0 ± 7.8
	2:30 - 3:00a	<2.6	17.6 ± 7.8
	3:30 - 4:00a	4.3 ± 3.8	40.6 ± 7.7
	4:30 - 5:00a	2.7 ± 2.9	49.1 ± 6.6
	5:30 - 6:00a	<1.7	50.6 ± 6.1
	6:30 - 7:00a	<1.3	18.1 ± 3.6
	7:30 - 8:00a	<1.3	46.6 ± 4.6
	8:30 - 9:00a	<1.3	2497 ± 26

[a]Sample composites consist of 2 samples collected on the half hour.
[b]Uncertainties are 2σ based only on counting statistics.

TABLE 9

RADIONUCLIDE CONCENTRATIONS IN COMPOSITED WATER SAMPLES FROM THE TIMED SAMPLING OF THE WASTEWATER TREATMENT FACILITY INFLUENT
ROYERSFORD, PENNSYLVANIA

Radionuclide	Radionuclide Concentration (pCi/l)			
	DATE/TIME			
	6-25/9:30a-12:00m	6-26/12:30a-9:00a	6-26/9:30a-12:00m	6-27/12:30a-9:00a
H-3	760 ± 340[a]	<230	1100 ± 340	650 ± 340
Cr-51	<300	<200	<350	<230
Mn-54	81 ± 8	<2.9	50 ± 9	<19
Co-58	140 ± 22	<19	180 ± 22	110 ± 18
Fe-59	<28	<19	<26	<21
Co-60	160 ± 12	17 ± 6	160 ± 12	63 ± 7
Zn-65	<10	<6.6	<8.8	<6.9
Sr-89	5.9 ± 0.5	<1.4	55 ± 2	24 ± 1
Sr-90	230 ± 130	<1.4	410 ± 200	510 ± 220
Zr-95	<14	<10	<14	<11
Nb-95	<21	<14	<20	<62
Ag-110m	<4.2	<5.8	<5.7	<3.2
Sb-125	<9.2	<6.5	<11	<7.8
Cs-134	45 ± 6	<28	50 ± 6	24 ± 4
Cs-137	170 ± 12	23 ± 4	530 ± 17	280 ± 11
U-234	b	b	b	b
U-235	b	b	b	b
U-238	b	b	b	b
Pu-238	b	b	b	b
Pu-239/240	b	b	b	b

[a]Uncertainties are 2σ based only on counting statistics.
[b]Insufficient sample for analysis.

TABLE 10

RADIONUCLIDE CONCENTRATIONS MEASURED
IN SLUDGE SAMPLES FROM SECONDARY DIGESTOR TANKS AT THE ROYERSFORD
WASTEWATER TREATMENT FACILITY
APRIL 1986
ROYERSFORD, PENNSYLVANIA

Radionuclide	Radionuclide Concentration (pCi/l)		
	East Tank (Middle)	West Tank (Top)	West Tank (Middle)
Cr-51	<1050	2390 ± 930[a]	2470 ± 2760
Mn-54	4400 ± 430	20100 ± 170	19800 ± 760
Co-58	310 ± 310	1890 ± 140	1930 ± 540
Fe-59	290 ± 740	1060 ± 310	2750 ± 1150
Co-60	45000 ± 980	131000 ± 340	118000 ± 1630
Zn-65	7180 ± 960	24900 ± 370	25700 ± 1750
Sr-89	440 ± 30	850 ± 40	900 ± 40
Sr-90	670 ± 70	2100 ± 120	2020 ± 110
Zr-95	<260	650 ± 180	<430
Nb-95	<170	150 ± 110	1150 ± 360
Tc-99	<20	74 ± 36	16 ± 24
Ag-110m	<140	850 ± 70	<240
Sb-125	380 ± 660	1060 ± 190	870 ± 880
Cs-134	790 ± 270	2250 ± 90	2430 ± 300
Cs-137	10200 ± 470	299000 ± 140	28700 ± 910
Th-228	7.4 ± 0.9	14 ± 2	10 ± 1
Th-230	14 ± 1	24 ± 2	14 ± 1
Th-232	6.4 ± 0.9	13 ± 2	7.5 ± 0.9
U-234	110 ± 10	230 ± 10	210 ± 10
U-235	1.9 ± 1.1	6.0 ± 1.0	7.7 ± 2.0
U-238	47 ± 5	86 ± 6	85 ± 6
Pu-238	21 ± 4	39 ± 5	3.7 ± 1.6
Pu-239/240	11 ± 4	40 ± 6	2.4 ± 2.0
Am-241	6.8 ± 1.0	8.5 ± 1.2	2.0 ± 0.6

Detectable, but much smaller, levels of Be-7, Co-57, and Sb-124 are also present in the sludge.

[a]Uncertainties are 2σ based only on counting statistics.

TABLE 11

RADIONUCLIDE CONCENTRATIONS MEASURED IN
SLUDGE SAMPLES COLLECTED WHILE SPREADER TRUCK WAS BEING FILLED
ROYERSFORD, PENNSYLVANIA

Radionuclide	DATES (1986)							
	5/28	5/28	5/28	5/30	5/30	5/30	5/30	6/2
	Radionuclide Concentrations (pCi/l)							
H-3	3200 ± 940[a]	400 ± 1300	1900 ± 550	2100 ± 450	1900 ± 530	b	b	b
Cr-51	<72	<120	3500 ± 1400	1700 ± 1100	2600 ± 2000	<2300	<8700	<2600
Mn-54	21000 ± 590	21000 ± 170	21000 ± 150	21000 ± 130	16000 ± 450	15000 ± 410	20000 ± 610	18000 ± 490
Co-58	2300 ± 550	2300 ± 160	2400 ± 130	2600 ± 120	1800 ± 400	2100 ± 370	3200 ± 770	2600 ± 440
Fe-59	<880	1500 ± 430	1900 ± 408	1600 ± 300	1100 ± 100	1800 ± 950	<860	1800 ± 1100
Co-60	90000 ± 1000	89000 ± 290	95000 ± 260	89000 ± 240	77000 ± 820	73000 ± 770	92000 ± 1000	82000 ± 850
Zn-65	<460	<130	<110	<97	<340	<310	<640	<350
Sr-89	3500 ± 240	2700 ± 25	2600 ± 26	2900 ± 34	2500 ± 230	2400 ± 22	1800 ± 20	2700 ± 230
Sr-90	2500 ± 20	5100 ± 270	4800 ± 290	5300 ± 370	2600 ± 20	4400 ± 240	4400 ± 240	2700 ± 20
Zr-95	17000 ± 1100	18000 ± 370	19000 ± 300	18000 ± 260	15000 ± 900	12000 ± 810	18000 ± 1200	17000 ± 890
Nb-95	<460	540 ± 200	680 ± 180	520 ± 160	<330	970 ± 480	2200 ± 1400	740 ± 580
Ag-110m	<180	<52	540 ± 57	550 ± 46	320 ± 140	<130	<180	650 ± 200
Sb-125	1100 ± 630	1100 ± 190	900 ± 150	900 ± 140	890 ± 510	620 ± 420	1000 ± 650	800 ± 480
Cs-134	2600 ± 330	2700 ± 62	2800 ± 53	2800 ± 44	2300 ± 170	2100 ± 200	2500 ± 360	2600 ± 240
Cs-137	23000 ± 560	25000 ± 160	26000 ± 120	24000 ± 100	20000 ± 360	18000 ± 370	23000 ± 540	21000 ± 370
U-234	400 ± 19	590 ± 19	420 ± 15	460 ± 17	440 ± 17	450 ± 17	380 ± 16	320 ± 15
U-235	12 ± 4	21 ± 4	14 ± 4	14 ± 4	12 ± 3	15 ± 4	12 ± 3	11 ± 3
U-238	170 ± 12	160 ± 10	180 ± 10	180 ± 11	170 ± 11	190 ± 11	140 ± 10	140 ± 10
Pu-238	8.0 ± 2.1	14 ± 4	13 ± 2	8.7 ± 1.0	9.5 ± 1.4	11 ± 1	9.6 ± 1.3	9.6 ± 1.4
Pu-239/240	23 ± 4	34 ± 6	16 ± 2	15 ± 1	17 ± 2	17 ± 2	21 ± 2	18 ± 2
Column Total[c]	166813.0	170159.0	183663.0	173647.7	144658.5	133073.0	168662.6	153088.6

TABLE 11 (Continued)

RADIONUCLIDE CONCENTRATIONS MEASURED IN
SLUDGE SAMPLES COLLECTED WHILE SPREADER TRUCK WAS BEING FILLED
ROYERSFORD, PENNSYLVANIA

Radionuclide	DATES (1986) 6/6	6/17	6/24	6/24	7/8	7/8	7/10	7/15
	Radionuclide Concentrations (pCi/l							
H-3	b	b	b	b	<230	<230	1500 ± 350[a]	b
Cr-51	<1300	<1600	<1700	<1400	<9800	<2200	<1400	<8700
Mn-54	5600 ± 260	5300 ± 310	16000 ± 450	16000 ± 420	16000 ± 950	840 ± 270	17000 ± 1200	18000 ± 1000
Co-58	620 ± 230	1100 ± 200	1500 ± 350	1700 ± 330	2400 ± 1200	360 ± 310	1700 ± 1400	2300 ± 1000
Fe-59	<370	<390	<500	<1000	<2000	<460	<2400	<1900
Co-60	37000 ± 550	33000 ± 620	110000 ± 1000	99000 ± 900	110000 ± 1800	4650 ± 400	100000 ± 2200	97000 ± 1900
Zn-65	<200	<230	<310	<270	<1000	<190	<1200	<910
Sr-89	1000 ± 110	350 ± 64	4000 ± 220	3600 ± 190	410 ± 270	20000 ± 1500	1700 ± 1800	22000 ± 1800
Sr-90	450 ± 9	160 ± 5	2300 ± 25	1900 ± 21	105 ± 4	2700 ± 21	2500 ± 27	3100 ± 28
Zr-65	12000 ± 640	4200 ± 660	18000 ± 980	17000 ± 880	15000 ± 1900	750 ± 430	18000 ± 2700	16000 ± 1900
Nb-95	<180	<190	<240	<210	<1100	<280	<1400	<1000
Ag-110m	<82	<100	620 ± 190	500 ± 170	350 ± 310	<60	<390	<300
Sb-125	<170	<230	820 ± 540	1600 ± 480	1700 ± 1000	<140	<83	<660
Cs-134	900 ± 150	970 ± 190	2700 ± 280	2300 ± 220	2400 ± 310	280 ± 130	2600 ± 670	3200 ± 540
Cs-137	6600 ± 190	6600 ± 330	27000 ± 420	26000 ± 370	28000 ± 780	1400 ± 220	26000 ± 1200	28000 ± 970
U-234	68 ± 5	64 ± 4	160 ± 7	630 ± 13	18 ± 3	560 ± 12	560 ± 12	360 ± 16
U-235	2.9 ± 1.1	1.8 ± 0.8	4.1 ± 1.4	27 ± 3	<1.0	20 ± 3	27 ± 3	12 ± 4
U-238	29 ± 3	27 ± 3	76 ± 5	240 ± 8	6.2 ± 1.6	210 ± 8	220 ± 8	140 ± 10
Pu-238	1.4 ± 0.6	1.9 ± 0.7	11 ± 2	11 ± 2	<0.3	12 ± 2	10 ± 2	7.6 ± 1.9
Pu-239/240	3.7 ± 1.0	4.9 ± 1.1	17 ± 2	16 ± 2	<0.4	16 ± 2	16 ± 2	11 ± 2
Column Total	64275	51779.6	183208.1	170524	176389.2	31848	171833	190130.6

TABLE 11 (Continued)

RADIONUCLIDE CONCENTRATIONS MEASURED IN
SLUDGE SAMPLES COLLECTED WHILE SPREADER TRUCK WAS BEING FILLED
ROYERSFORD, PENNSYLVANIA

Radionuclide	DATES (1986) 7/15	7/15	7/17	7/17	7/22	8/14	8/15	8/15
	Radionuclide Concentrations (pCi/l)							
H-3	<230	650 ± 340[a]	<660	<230	440 ± 330	440 ± 330	<660	440 ± 330
Cr-51	<8900	<3000	<8800	<7600	<3800	<2200	<2900	<8800
Mn-54	19000 ± 1000	2300 ± 330	12000 ± 950	7400 ± 730	4500 ± 500	3900 ± 440	4100 ± 510	11000 ± 660
Co-58	2000 ± 1300	420 ± 560	2500 ± 980	1400 ± 860	990 ± 510	1300 ± 510	1700 ± 480	4300 ± 640
Fe-59	<1900	<700	<1600	<1300	<760	<580	<630	<2200
Co-60	110000 ± 2000	12000 ± 610	55000 ± 1600	36000 ± 1300	2200 ± 870	20000 ± 850	19000 ± 920	50000 ± 1300
Zn-65	<910	<320	<830	<690	<400	<290	<350	<430
Sr-89	15000 ± 1100	5200 ± 550	7500 ± 810	16000 ± 1100	5100 ± 640	5200 ± 480	2100 ± 400	11000 ± 800
Sr-90	2500 ± 18	890 ± 11	1500 ± 14	2200 ± 17	1100 ± 12	900 ± 11	700 ± 10	2600 ± 20
Zr-95	15000 ± 2100	2000 ± 800	8700 ± 2000	6400 ± 1700	4200 ± 1000	3700 ± 840	3200 ± 1100	9900 ± 1300
Nb-95	<1100	<350	<910	<710	<440	<280	<340	<1300
Ag-110m	<320	<100	<300	<250	<140	<380	<170	<1300
Sb-125	1800 ± 1100	<210	860 ± 970	<490	<320	<300	<380	490 ± 760
Cs-134	3000 ± 520	540 ± 180	1700 ± 520	1300 ± 420	800 ± 260	760 ± 240	740 ± 280	1600 ± 360
Cs-137	28000 ± 1000	3600 ± 280	15000 ± 870	9800 ± 690	6300 ± 450	6500 ± 400	5600 ± 560	13000 ± 540
U-234	550 ± 17	110 ± 7	240 ± 12	220 ± 10	160 ± 8	100 ± 5	110 ± 6	250 ± 10
U-235	20 ± 4	3.1 ± 1.3	9.2 ± 2.7	6.3 ± 1.8	4.3 ± 1.6	3.1 ± 1.1	2.8 ± 1.2	9.7 ± 2.3
U-238	210 ± 10	45 ± 4	99 ± 8	96 ± 6	63 ± 5	40 ± 3	39 ± 4	110 ± 7
Pu-238	11 ± 3	2.2 ± 1.0	4.4 ± 1.5	7.1 ± 1.9	3.0 ± 1.2	3.1 ± 0.9	2.9 ± 0.9	7.1 ± 1.8
Pu-239/240	19 ± 3	7.5 ± 1.8	12 ± 3	19 ± 3	4.4 ± 1.4	4.5 ± 1.1	7.6 ± 1.5	16 ± 3
Column Total	197100	27767.8	105124.6	80848.4	25864.7	42850.7	37302.3	105162.8

TABLE 11 (Continued)

RADIONUCLIDE CONCENTRATIONS MEASURED IN
SLUDGE SAMPLES COLLECTED WHILE SPREADER TRUCK WAS BEING FILLED
ROYERSFORD, PENNSYLVANIA

Radionuclide	DATES (1986)						
	8/15	9/4	9/4	9/10	9/15	9/17	9/18
	Radionuclide Concentrations (pCi/l)						
H-3	b	b	b	b	b	b	b
Cr-51	<37000	<21000	<24000	<19000	<20000	<17000	<43000
Mn-54	2100 ± 360	1600 ± 270	1900 ± 330	1800 ± 350	3700 ± 440	2800 ± 380	19000 ± 9000
Co-58	1600 ± 1100	<410	1100 ± 720	<430	1600 ± 600	<400	7000 ± 1800
Fe-59	<3300	<2000	<2400	<2000	<2300	<2000	<4800
Co-60	8900 ± 550	7700 ± 510	9200 ± 570	8100 ± 520	14000 ± 670	9600 ± 590	60000 ± 1400
Zn-65	2000 ± 660	<410	1800 ± 700	1800 ± 670	2200 ± 880	1700 ± 920	12000 ± 1800
Sr-89	230 ± 5	250 ± 6	300 ± 6	190 ± 5	620 ± 9	210 ± 5	2900 ± 19
Sr-90	800 ± 290	990 ± 240	740 ± 250	1000 ± 210	1300 ± 320	800 ± 190	9500 ± 640
Zr-95	<890	<560	<730	<580	<740	<680	<1700
Nb-95	<2500	<1700	<1700	<1200	<1600	<1400	<3600
Ag-110m	<180	<140	<180	<170	<220	<190	<440
Sb-125	<220	<200	<220	<220	<280	<230	<610
Cs-134	440 ± 180	450 ± 150	400 ± 170	410 ± 270	590 ± 200	580 ± 210	1900 ± 420
Cs-137	3000 ± 290	2100 ± 240	3200 ± 320	2500 ± 320	4300 ± 360	2900 ± 320	16000 ± 720
U-234	28 ± 3	22 ± 3	43 ± 5	31 ± 4	46 ± 5	36 ± 3	300 ± 11
U-235	<1.4	<1.3	1.5 ± 1.1	1.0 ± 0.9	1.2 ± 1.0	1.0 ± 0.7	8.3 ± 2.2
U-238	15 ± 3	10 ± 2	18 ± 3	13 ± 3	19 ± 3	16 ± 2	120 ± 7
Pu-238	1.4 ± 0.7	<1.2	0.6 ± 0.5	0.9 ± 0.6	2.1 ± 1.1	0.6 ± 0.5	7.4 ± 1.7
Pu-239/240	5.5 ± 1.3	1.4 ± 0.9	1.3 ± 0.7	1.7 ± 0.8	5.4 ± 1.6	1.9 ± 0.8	29 ± 3
Column Totals	19119.9	13123.4	18704.4	15847.6	28383.7	18645.5	128764.7

[a]Uncertainties are 2σ based only on counting statistics.
[b]Analysis not performed.
[c]Radionuclides with concentrations below the detection sensitivities are not included in totals.

TABLE 12

DIRECT RADIATION LEVELS AT SITE 1
ROYERSFORD, PENNSYLVANIA

Measurement	Dates (1986)			
	June 23 (before application)	June 24	August 26	October 28
Exposure Rate at 1m above surface				
Range (μR/h)	13-15	15-17	11-15	12-15
Average (μR/h)	13.7	15.2	12.3	13.1
Exposure Rate at surface contact				
Range (μR/h)	13-15	15-19	11-15	12-15
Average (μR/h)	14.6	15.9	13.0	13.8
Beta-Gamma Dose Rate at Surface				
Range (μR/h)	13-49	19-44	19-33	16-37
Average (μR/h)	28.1	33.3	25.6	26.6

TABLE 13

DIRECT RADIATION LEVELS AT SITE 2
ROYERSFORD, PENNSYLVANIA

Measurement	Dates (1986)			
	June 23 (before application)	June 24	August 26	October 28
Exposure Rate at 1m above surface				
Range (μR/h)	11-15	19-23	13-17	14-19
Average (μR/h)	13.6	20.1	15.4	15.9
Exposure Rate at surface contact				
Range (μR/h)	12-15	19-23	14-21	13-19
Average (μR/h)	13.8	21.0	17.7	16.0
Beta-Gamma Dose Rate at Surface				
Range (μR/h)	15-33	21-58	31-43	13-42
Average (μR/h)	24.0	34.1	35.2	27.7

TABLE 14

RADIONUCLIDE CONCENTRATIONS MEASURED IN SOIL COMPOSITES
PRIOR TO SLUDGE APPLICATION - SITE 1
ROYERSFORD, PENNSYLVANIA

Radionuclide	Radionuclide Concentrations (pCi/g)		
	0-2.5 cm	2.5-7.5 cm	7.5-22.5 cm
Cr-51	<1.3	<0.8	<0.5
Mn-54	<0.1	<0.1	<0.1
Co-58	<0.1	<0.1	<0.1
Fe-59	<0.3	<0.2	<0.1
Co-60	<0.2	<0.1	<0.1
Zn-65	<0.2	<0.1	<0.1
Sr-89	a	a	a
Sr-90	<0.4	<0.4	<0.4
Zr-95	<0.2	<0.1	<0.1
Nb-95	<0.2	<0.1	<0.1
Ag-110m	<0.2	<0.1	<0.1
Sb-125	<0.3	<0.2	<0.1
Cs-134	<0.1	<0.1	<0.2
Cs-137	0.4 ± 0.3[b]	0.4 ± 0.2	0.3 ± 0.1
U-234	3.1 ± 0.4	1.8 ± 0.3	1.7 ± 0.2
U-235	0.3 ± 0.1	<0.2	<0.1
U-238	1.9 ± 0.2	1.7 ± 0.2	1.5 ± 0.2
Pu-238	<0.1	<0.1	<0.1
Pu-239/240	<0.1	<0.1	<0.1

[a]Analysis not performed.
[b]Uncertainties are 2σ based only on counting statistics.

TABLE 15

RADIONUCLIDE CONCENTRATIONS MEASURED IN
SOIL COMPOSITES AT VARIOUS INTERVALS FOLLOWING SLUDGE APPLICATION
SITE 1
ROYERSFORD, PENNSYLVANIA

	Radionuclide Concentrations (pCi/g)										
	June 1986[a]			August 1986				October 1986			
Radionuclide	0-2.5 cm	2.5-7.5 cm	7.5-22.5 cm	0-2.5 cm	2.5-7.5 cm	7.5-15 cm	15-30 cm	0-2.5 cm	2.5-7.5 cm	7.5-15 cm	15-30 cm
Cr-51	<1.7	<1.1	<0.7	<3.7	<1.8	<2.2	<1.0	<6.5	<10.0	<5.9	<5.0
Mn-54	1.0 ± 0.7[b]	0.3 ± 0.2	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1
Co-58	<0.2	<0.2	<0.1	<0.3	<0.1	<0.2	<0.1	<0.2	<0.3	<0.1	<0.1
Fe-59	<0.4	<0.2	<0.1	<0.7	<0.4	<0.3	<0.2	<0.8	<0.7	<0.4	<0.5
Co-60	4.0 ± 1.0	1.0 ± 0.5	<0.1	1.0 ± 0.8	<0.8	<0.1	<0.1	<0.8	0.7 ± 0.3	<0.1	<0.1
Zn-65	0.6 ± 1.0	<0.2	<0.1	<0.4	<0.2	<0.2	<0.1	<0.2	<0.3	<0.2	<0.1
Sr-89	c	c	c	c	c	c	c	c	c	c	c
Sr-90	<0.4	<0.4	<0.4	<0.5	<0.4	<0.4	<0.4	<0.4	<0.5	<0.4	<0.4
Zr-95	<0.6	<0.3	<0.1	<0.4	<0.3	<0.2	<0.1	<0.4	<0.5	<0.3	<0.2
Nb-95	<0.2	<0.2	<0.1	<0.4	<0.2	<0.2	<0.4	<0.6	<0.7	<0.4	<0.3
Ag-110m	<0.2	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sb-125	<0.6	<0.4	<0.1	<0.4	<0.3	<0.3	<0.1	<0.3	<0.3	<0.2	<0.1
Cs-134	<1.0	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1
Cs-137	1.2 ± 0.6	0.8 ± 0.3	0.2 ± 0.1	0.9 ± 0.4	0.4 ± 0.2	<0.7	<0.1	<0.5	0.7 ± 0.3	0.4 ± 0.2	<0.1
U-234	4.2 ± 0.4	2.2 ± 0.3	1.8 ± 0.3	2.5 ± 0.4	1.9 ± 0.3	1.9 ± 0.3	3.3 ± 0.4	26 ± 1	27 ± 1	1.9 + 0.3	1.9 ± 0.3
U-235	0.2 ± 0.1	<0.2	<0.1	<0.2	<0.1	<0.1	0.2 ± 0.1	0.9 ± 0.2	1.0 ± 0.2	<0.1	<0.1
U-238	2.2 ± 0.3	1.9 ± 0.3	2.1 ± 0.3	1.7 ± 0.3	1.9 ± 0.3	1.6 ± 0.3	2.2 ± 0.3	4.2 ± 0.4	3.9 ± 0.4	1.8 ± 0.3	2.0 ± 0.3
Pu-238	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pu-239/240	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

[a]Sludge applied to plot on June 24, 1986.

[b]Uncertainties are 2σ based only on counting statistics.

[c]Analysis not performed.

TABLE 16

RADIONUCLIDE CONCENTRATIONS MEASURED IN SOIL COMPOSITES
PRIOR TO SLUDGE APPLICATION - SITE 2
ROYERSFORD, PENNSYLVANIA

Radionuclide	Radionuclide Concentrations (pCi/g)			
	0-2.5 cm	2.5-7.5 cm	7.5-15.0 cm	15-30 cm
Cr-51	<5.8	<3.3	<3.3	<1.4
Mn-54	<0.2	<0.2	<0.1	<0.1
Co-58	<0.3	<0.2	<0.1	<0.1
Fe-59	<1.2	<0.6	<0.3	<0.2
Co-60	1.8 ± 0.8[a]	1.6 ± 0.6	0.6 ± 0.4	0.2 ± 0.2
Zn-65	<2.5	<0.8	<0.4	<0.2
Sr-89	b	b	b	b
Sr-90	<0.33	<0.42	2.13 ± 0.72	<0.31
Zr-95	<0.7	<0.8	<0.3	<0.1
Nb-95	<0.5	<1.1	<0.3	<0.2
Ag-110m	<0.2	<0.1	<0.1	<0.1
Sb-125	<0.7	<0.3	<0.2	<0.1
Cs-134	<0.3	<0.2	<0.2	<0.1
Cs-137	<1.4	<0.3	0.5 ± 0.3	<0.3
U-234	1.9 ± 0.1	1.7 ± 0.1	1.7 ± 0.1	1.6 ± 0.1
U-235	0.09 ± 0.03	0.08 ± 0.02	0.07 ± 0.02	0.09 ± 0.03
U-238	1.9 ± 0.1	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1
Pu-238	<0.1	<0.1	<0.1	<0.1
Pu-239/240	<0.1	<0.1	<0.1	<0.1

[a]Uncertainties are 2σ based only on counting statistics.
[b]Analysis not performed.

TABLE 17

RADIONUCLIDE CONCENTRATIONS MEASURED IN
SOIL COMPOSITES AT VARIOUS INTERVALS FOLLOWING SLUDGE APPLICATION
SITE 2
ROYERSFORD, PENNSYLVANIA

	Radionuclide Concentrations (pCi/g)										
	June 1986[a]			August 1986				October 1986			
Radionuclide	0-2.5 cm	2.5-7.5 cm	7.5-22.5 cm	0-2.5 cm	2.5-7.5 cm	7.5-15 cm	15-30 cm	0-2.5 cm	2.5-7.5 cm	7.5-15 cm	15-30 cm
Cr-51	<2.1	<1.0	<0.6	<3.8	<2.1	<2.3	<0.8	<8.4	<8.5	<5.9	<5.9
Mn-54	2.0 ± 0.8[b]	<0.7	<0.1	1.0 ± 0.4	0.7 ± 0.4	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1
Co-58	<0.3	<0.1	<0.1	<0.3	<0.2	<0.1	<0.1	<0.2	<0.3	<0.1	<0.1
Fe-59	<0.8	<0.2	<0.1	<0.7	<0.4	<0.1	<0.1	<0.8	<1.2	<0.6	<0.5
Co-60	27 ± 2	2.5 ± 0.5	<0.3	6.7 ± 1.2	3.9 ± 0.6	0.6 ± 0.3	<0.1	1.8 ± 0.5	4.0 ± 0.6	0.6 ± 0.2	<0.1
Zn-65	<5.0	<4.8	<0.1	<0.6	0.7 ± 0.5	<0.2	<0.1	<0.3	<0.4	<0.2	<0.1
Sr-89	c	c	c	c	c	c	c	c	c	c	c
Sr-90	<0.4	<0.5	c	<0.4	<0.4	<0.4	<0.4	<0.5	<0.5	<0.5	<0.4
Zr-95	<0.6	<0.1	<0.1	<0.5	<0.3	<0.2	<0.1	<0.4	<0.5	<0.3	<0.2
Nb-95	<0.3	<0.1	<0.1	<0.4	<0.3	<0.2	<0.1	<0.5	<0.8	<0.5	<0.4
Ag-110m	<0.3	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1
Sb-125	<2.4	<0.3	<0.1	<0.6	<0.4	<0.3	<0.1	<0.3	<0.3	<0.2	<0.1
Cs-134	<1.8	<0.7	<0.1	<1.1	<3.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cs-137	3.9 ± 0.9	0.9 ± 0.3	0.2 ± 0.1	1.8 ± 0.7	1.5 ± 0.4	<0.9	<0.1	1.1 ± 0.4	0.8 ± 0.3	0.4 ± 0.2	<0.1
U-234	2.0 ± 0.3	2.2 ± 0.3	3.1 ± 0.3	2.5 ± 0.4	3.2 ± 0.4	2.2 ± 0.3	1.6 ± 0.3	1.9 ± 0.3	1.9 ± 0.3	2.0 ± 0.3	1.9 ± 0.3
U-235	<0.2	<0.2	0.2 ± 0.1	<0.1	0.3 ± 0.2	0.3 ± 0.1	1.1 ± 0.3	<0.1	<0.2	<0.1	<0.1
U-238	3.1 ± 0.3	1.9 ± 0.3	11 ± 1	2.6 ± 0.4	2.3 ± 0.4	1.8 ± 0.3	1.4 ± 0.3	1.6 ± 0.2	1.4 ± 0.3	1.7 ± 0.2	1.8 ± 0.3
Pu-238	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pu-239/240	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

[a]Sludge applied on June 24, 1986.
[b]Uncertainties are 2σ based only on counting statistics.
[c]Analysis not performed.

TABLE 18

RESULTS OF AIR SAMPLING DURING SLUDGE SPREADING AND TILLING ROYERSFORD, PENNSYLVANIA

Sample Location	Gross Alpha (μCi/ml)	Gross Beta (μCi/ml)
SITE 1		
Upwind	$2.2 \pm 3.7 \times 10^{-14}$[a]	$3.1 \pm 0.9 \times 10^{-13}$
Downwind	$4.3 \pm 2.9 \times 10^{-14}$	$3.5 \pm 0.7 \times 10^{-13}$
SITE 2		
Upwind	$3.8 \pm 3.1 \times 10^{-14}$	$3.0 \pm 0.7 \times 10^{-13}$
Downwind	b	b

[a]Uncertainties are 2σ based only on counting statistics.
[b]Electrical generator failure during sampling period.

TABLE 19

RADIONUCLIDE CONCENTRATIONS MEASURED IN SEDIMENT SAMPLES COLLECTED FROM DRAINAGE DITCHES BELOW SITES 1 AND 2 ROYERSFORD, PENNSYLVANIA

Radionuclide	Radionuclide Concentration (pCi/g)		
	Site 1	Site 2A	Site 2B
H-3	a	a	a
Cr-51	<6.3	<6.5	<5.5
Mn-54	<0.1	<0.1	<0.1
Co-58	<0.1	<0.1	<0.1
Fe-59	<0.5	<0.5	<0.5
Co-60	<0.1	<0.1	<0.1
Zn-65	<0.1	<0.1	<0.1
Sr-89	a	a	a
Sr-90	a	<0.36	a
Zr-95	<0.3	<0.3	<0.2
Nb-95	<0.4	<0.4	<0.4
Ag-110m	<0.1	<0.1	<0.1
Sb-125	<0.1	<0.1	<0.1
Cs-134	<0.1	<0.1	<0.1
Cs-137	0.3 ± 0.1[b]	<0.1	0.2 ± 0.1
U-234	a	1.7 ± 0.1	a
U-235	a	0.08 ± 0.03	a
U-238	a	1.9 ± 0.1	a
Pu-238	a	<0.1	a
Pu-239/240	a	<0.1	a

[a]Analysis not performed due to small sample size.
[b]Uncertainties are 2σ based only on counting statistics.

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4. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.109, Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10CFR Part 50, Appendix I, October 1977.

5. U.S. Nuclear Regulatory Commission, Regulatory Guide 3.51, Calculational Models for Estimating Radiation Doses to Man from Airborne Radioactive Materials Resulting from Uranium Mining Operations, April 1982.

6. M. Cristy et al, Age-Dependent Dose-Conversion Factors for Selected Bone-Seeking Radionuclides, NUREG/CR-3535 (ORNL/TM-8929), Oak Ridge National Laboratory, May 1984.

7. M. Cristy et al, Relative Age-Specific Radiation Dose Commitment Factors for Major Radionuclide Released from Nuclear Fuel Facilities, NUREG/CR-4628 (ORNL/TM-9890), Oak Ridge National Laboratory, August 1986.

APPENDIX A

MAJOR SAMPLING AND ANALYTICAL EQUIPMENT

APPENDIX A

Major Sampling and Analytical Equipment

The display or description of a specific product is not to be construed as an endorsement of that product or its manufacturer by the authors or their employer.

A. Direct Radiation Measurements

Eberline "RASCAL"
Portable Ratemeter-Scaler
Model PRS-1
(Eberline, Santa Fe, NM)

Eberline PRM-6
Portable Ratemeter
(Eberline, Santa Fe, NM)

Eberline Beta-Gamma "Pancake" Detector
Model HP-60
(Eberline, Santa Fe, NM)

Reuter-Stokes Pressurized Ionization Chamber
Model RSS-111
(Reuter-Stokes, Cleveland, OH)

Victoreen NaI Scintillation Detector
Model 489-55
(Victoreen, Cleveland, OH)

High Volume Air Sampler
Model 650-CRP-R-PT
(Sierra-Misco, Berkeley, CA)

B. Laboratory Analyses

Low Background Alpha-Beta Counter
Model LB-5110
(Tennelec, Oak Ridge, TN)

Ge(Li) Detector
Model LGCC2220SD, 23% Efficiency
(Princeton Gamma-Tech, Princeton, NJ)

used in conjunction with:
Lead Shield Model SPG-16
(Applied Physical Technology, Atlanta, GA)

High Purity Germanium Detector
Model IGC25, 25% Efficiency
(Princeton Gamma-Tech, Princeton, NJ)

used in conjunction with:
Lead Shield
(Nuclear Data, Schaumburg, IL)

Multichannel Analyzer
ND66/680 System
(Nuclear Data, Schaumburg, IL)

Alpha Spectrometry System
Tennelec Electronics
(Tennelec, Oak Ridge, TN)

Surface Barrier Detectors
(EG&G ORTEC, Oak Ridge, TN)

Multichannel Analyzer
Model ND-66
(Nuclear Data, Schaumburg, IL)

Liquid Scintillation Counter
Model Tri-Carb 300
(Packard Instruments Company, Downers Grove, IL)

APPENDIX B

MEASUREMENT AND ANALYTICAL PROCEDURES

APPENDIX B

MEASUREMENT AND ANALYTICAL PROCEDURES

Gamma Scintillation Measurement

Walkover surface scans and measurements of gamma exposure rates were performed using Eberline Model PRM-6 portable ratemeters with Victoreen Model 489-55 gamma scintillation probes containing 3.2 cm x 3.8 cm NaI(Tl) scintillation crystals. Count rates were converted to exposure rates (μR/h) by cross-calibrating with a Reuter-Stokes Model RSS-111 pressurized ionization chamber.

Soil and Sediment Sample Analysis

Gamma Spectrometry

Soil and sediment samples were dried, mixed, and a portion sealed in a 0.5-liter Marinelli beaker. The quantity placed in each beaker was chosen to reproduce the calibrated counting geometry and ranged from 400 to 800 g of soil. Net soil weights were determined and the samples counted using Ge(Li) and intrinsic germanium detectors coupled to a Nuclear Data Model ND-680 pulse height analyzer system. Background and Compton stripping, peak search, peak identification, and concentration calculations were performed using the computer capabilities inherent in the analyzer system.

Isotopic Uranium and Plutonium

Aliquots of soil were dissolved by pyrosulfate fusion and precipitated by barium sulfate. The barium sulfate precipitate was redissolved and the specific radionuclides of interest were individually separated by liquid-liquid extraction. The radionuclide was then precipitated with a cerium fluoride carrier and counted using surface barrier detectors (ORTEC), alpha spectrometers (Tennelec), and an ND-66 Multichannel Analyzer (Nuclear Data).

Technetium 99

Aliquots of sample media were leached with sodium hypochlorite and hydrogen peroxide. Leachates were extracted with methyl ethyl ketone, dissolved in water, scavenged by hydroxide precipitation, and recycled through the methyl ethyl ketone extraction. The final water strip was dried on stainless steel planchets and counted on a low-background proportional counter.

Strontium 89/90

Aliquots of soil were dissolved using pyrosulfate fusion and precipitated as strontium sulfate. The sulfate precipitate was treated with EDTA to preferentially dissolve lead and excess calcium. Further EDTA treatment dissolved the strontium sulfate which was then reprecipitated by pH adjustment. Barium and chromate were removed using DTPA; the strontium sulfate was metathesized to the carbonate prior to removal of chromate to avoid interference by the sulfate ion. The final strontium carbonate precipitate was counted using a low-background proportional counter. After seven days the sample was recounted. Comparison of the two count rates allow determination of Sr-89 and Sr-90. Chemical yield was determined gravimetrically, based on recovery of the strontium carrier.

Tritium

Aliquots of sample media were refluxed with background water to extract H-3 from the media. The resulting water was distilled and counted in a low background liquid scintillation counter.

Water Sample Analysis

Water samples were rough-filtered through Whatman No. 2 filter paper. Remaining suspended solids were removed by subsequent filtration through 0.45 μm membrane filters. The filtrate was acidified by addition of 10 ml of concentrated nitric acid. A known volume of each sample was evaporated to dryness and counted for gross alpha and gross beta using a Tennelec Model LB-5110 low-background proportional counter.

Uncertainties and Detection Limits

The uncertainties associated with the analytical data presented in the tables of this report, represent the 95% (2σ) confidence levels for that data. These uncertainties were calculated based on both the gross sample count levels and the associated background count levels. When the net sample count was less than the 2σ statistical deviation of the background count, the sample concentration was reported as less than the minimum detectable concentration (MDC).

Because of variation in background levels and the effects of the Compton continuum caused by other constituents in the samples, the MDC's for specific radionuclides differ from sample to sample. Other sources of uncertainties associated with the sampling and analyses introduce an additional uncertainty of ± 6 to 10% in the final results.

Calibration and Quality Assurance

Laboratory and field survey procedures are documented in manuals developed specifically for the Oak Ridge Associated Universities' Radiological Site Assessment Program.

With the exception of the measurements conducted with portable gamma scintillation survey meters, instruments were calibrated with NBS-traceable standards. The calibration procedures for the portable gamma instruments are performed by comparison with an NBS calibrated pressurized ionization chamber.

Quality control procedures on all instruments included daily background and check-source measurements to confirm equipment operation within acceptable statistical fluctuations. The ORAU laboratory participates in the EPA and EML Quality Assurance Programs.

APPENDIX C

DOSE ESTIMATION PROCEDURES

APPENDIX C

Dose Estimation Procedures

Maximally Exposed Individual

1. Direct Radiation

Although the highest average exposure rate at 1 m above the surface was 21 μR/h on Site 2, immediately following sludge appplication and tilling, the ORAU measurements throughout the year indicated a more likely average exposure rate of 15 μR/h. This is 4 μR/h above the average background level measured in the area. Exposure is assumed to be 4 hr/d, 240/d; the total annual increase in gamma exposure due to the sludge-treated field would be 3.8 mR, which would result in an annual dose equivalent of 3.4 mrem.

2. Inhalation

Radionuclide air concentrations measured during sludge application and tilling procedures (assumed to be the time of maximum potential air concentrations) were well below the NRC guidelines for unrestricted areas. Because the concentrations were very low, and the fraction of time during the year when such activities are being performed is quite small, the potential dose commitment from the inhalation pathway during sludge applications is considered negligible.

Resuspension of surface soil from treated area is another potential inhalation pathway. The airborne concentrations were estimated based on the concentrations of radionuclides in the surface soil and a mass loading factor of 200 $\mu g/m^3$. Airborne dust particles were assumed to be entirely from the contaminated soil and to contain the same concentrations of radionuclides as measured in the surface layer of soil. Average concentrations of the six radionuclides of concern, measured in the upper 2.5 cm of soil of the tilled fields during 1986 were:

Co-60	6.9 pCi/g
Sr-90	<0.43 pCi/g

Cs-137	1.6	pCi/g
U-234	6.4	pCi/g
U-235	0.28	pCi/g
U-238	2.6	pCi/g

Assuming an inhalation rate of 20 l/m and an occupancy of 4 h/d, 240/d, the annual dust inhalation would be 0.23 g. For soil containing the above radionuclide concentrations the annual intake by inhalation would be:

Co-60	1.6	pCi
Sr-90	<0.10	pCi
Cs-137	0.37	pCi
U-234	1.5	pCi
U-235	0.064	pCi
U-238	0.60	pCi

Conversion to dose, using the inhalation dose-conversion factors in Table C-1, provides the committed dose equivalent estimates, presented in Table C-2.

3. Ingestion of Vegetation

It is assumed that vegetables for direct human consumption are grown on a sludge-treated field. Planting is performed after sludge application and tilling; therefore, contamination by deposition is not applicable. Foliar deposition as a result of resuspension and rain splash are assumed insignificant compared to other vegetation contamination mechanisms. Radionuclides in vegetation would therefore be limited to those incorporated by uptake from the soil. The upper 15 cm of soil is considered the region from which radionuclide uptake accumulates vegetation.[4] The average concentrations of the six radionuclides of interest, measured in the upper 15 cm of soil on the two study sites were:

Co-60	2.8	pCi/g
Sr-90	<0.43	pCi/g
Cs-137	0.79	pCi/g
U-234	4.3	pCi/g

U-235	0.23 pCi/g
U-238	2.8 pCi/g

Uptake factors for vegetation are presented in Table C-3. Resulting radionuclide concentrations in vegetation grown in soil containing the above levels would be:

Co-60	26 pCi/kg
Sr-90	7.3 pCi/kg
Cs-137	7.9 pCi/kg
U-234	11 pCi/kg
U-235	0.58 pCi/kg
U-238	7.0 pCi/kg

Sludge-treated lands are used for growing grain and forage crops, rather than as family vegetable garden plots. It is therefore assumed that an individual would obtain only a small fraction of the total annual vegetation intake from such areas. For the purpose of these calculations, the maximally exposed individual is assumed to obtain 10% of the total adult intake (520 kg of vegetation) from sludge application sites.[4] The total activities ingested annually were calculated to be:

Co-60	1350 pCi
Sr-90	380 pCi
Cs-137	410 pCi
U-234	570 pCi
U-235	30 pCi
U-238	360 pCi

Conversion to dose-commitment values was performed using the ingestion dose-conversion factors in Table C-1. Committed dose equivalent estimates for the various organs are presented in Table C-4.

4. Ingestion of Meat

It is assumed that grain and forage crops are used to feed livestock that are then consumed by the maximally exposed individual. For the purpose of

calculating dose from this pathway the same vegetation concentrations, as used in the vegetation pathway calculation were used. Cattle are the livestock for this calculation and are assumed to consume 50 kg of feed per day; it is also assumed that all of the vegetation is grown on sludge-treated sites. Transfer coefficients from forage to meat for the radionuclides of interest are presented in Table C-3. Resulting radionuclide concentrations in meat are:

Co-60	17	pCi/kg
Sr-90	0.22	pCi/kg
Cs-137	1.6	pCi/kg
U-234	0.19	pCi/kg
U-235	0.01	pCi/kg
U-238	0.12	pCi/kg

Annual consumption of meat for the maximally exposed individual is 110 kg[4]. It is assumed that 50% of the individuals meat diet is from this source. Total radionuclide intake by this pathway is therefore:

Co-60	940	pCi
Sr-90	12	pCi
Cs-137	88	pCi
U-234	10	pCi
U-235	0.6	pCi
U-238	6.6	pCi

Dose-conversion factors from Table C-1 were used to calculate resulting organ dose commitments from these annual intakes. Values are presented in Table C-5.

5. Ingestion of Milk

Radionuclide uptake by milk was calculated, using the concentrations in feed (vegetation) determined in the Section 2 above, and the uptake factors from Table C-3. Resulting concentrations are:

Co-60	1.3	pCi/l
Sr-90	0.29	pCi/l
Cs-137	4.7	pCi/l
U-234	0.34	pCi/l
U-235	0.02	pCi/l
U-238	0.21	pCi/l

It is assumed that 100% of the maximally exposed individual's annual milk intake of 310 l is from cattle fed with vegetation grown on the sludge-treated land.[4] The annual radionuclide ingestion via this pathway is:

Co-60	400	pCi
Sr-90	90	pCi
Cs-137	1500	pCi
U-234	110	pCi
U-235	6.2	pCi
U-238	65	pCi

Using the dose-conversion factors from Table C-1 the organ dose commitments were calculated; these are presented in Table C-6.

6. Total of all Exposure Pathways

Dose commitments for the maximally exposed individual from all pathways were summed and the total for each organ determined. Table C-7 presents the results of these calculations.

Ingestion of Soil by Child (pica)

It is assumed that a child ingests 100 g of soil per year from a field fertilized by the contaminated sludge. Based on the concentration levels, determined for the upper 2.5 cm of soil (Section 2 above, of the maximally exposed individual calculations), the total radionuclide intake would be:

Co-60	690	pCi
Sr-90	44	pCi

Cs-137	160 pCi
U-234	630 pCi
U-235	27 pCi
U-238	260 pCi

Using ingestion dose-conversion factors for a child, (see Table C-1), organ dose commitments from this pathway were calculated; results are presented in Table C-8. It is assumed, for the purpose of this calculation, that the occupancy time for a child in a treated field will be much less than that of the maximally exposed individual and that during the time in the treated field, activities, which would generate higher levels of airborne dust, would not be in progress. The inhalation and direct exposure pathways would therefore result in much smaller doses to the child than those received by the maximally exposed individual. Such doses would be insignificant compared to those from the ingested soil.

Ingestion of Milk by Child

It is assumed that a child annually ingests 330 liters of milk, containing the same radionuclide concentrations determined in section 5 above for the maximally exposed individual.[4] Total annual intake would be:

Co-60	430	pCi
Sr-90	96	pCi
Cs-137	1600	pCi
U-234	110	pCi
U-235	6.6	pCi
U-238	69	pCi

Using the dose-conversion factors from Table C-1, the organ dose commitments were calculated. Results are presented in Table C-9.

Population Dose

During 1986, 31 truckloads (1.2×10^6 l) of sludge from the Royersford Wastewater Treatment Plant were applied to fields. Based on a standard applicaton concentration of 11.5 l/m^2, the total area treated would have been

approximately 10^5 m^2, or 10 ha. Limited observation of spreading operations indicated that individual areas of treatment average 0.5 ha or larger. Dates of tanktruck filling at the Wastewater Treatment Plant suggest that between 15 and 20 separate areas may have been treated. For the purpose of estimating population dose, it is assumed that 20 different areas were treated, and that each of these areas comprise a separate farm. Direct radiation levels and soil concentrations on each treated area are assumed to be the same as the study plots.

1. Direct Radiation

Two individuals are assumed to work each treated area for 4 hours per day, 240 days per year. The total population dose equivalent would be 3.4 mrem x 20 areas x 2 persons/area = 136 person-mrem.

Monitoring in the vicinity of treated areas indicated that direct radiation levels decreased to background levels a short distance from these areas; exposure of additional individuals by the direct exposure pathway is therefore considered negligible.

2. Inhalation

As with the direct radiation pathway, exposure to airborne dust, contaminated by the treated areas, would be essentially limited to those workers on the areas. The population dose is thus estimated to be 40 (2 persons/area x 20 areas) times the inhalation doses determined for the maximally exposed individual (See Table C-2).

The calculated population lung dose equivalent is 44 person-mrem; the effective dose equivalent commitment is 5.6 person-mrem. All other organ doses are at least a factor of 10 less than the lung dose.

3. Ingestion of Vegetation

Regulatory Guide 1.109 recommends a crop yield value of 2 kg/m^2, for leafy vegetables or produce ingested by man. Assuming 50% of the treated areas

are used to grow crops for direct human consumption, the total quantity of vegetation or produce would be 50% x 10^5 m^2 x 2 kg/m^2 = 10^5 kg.

All vegetables are assumed to contain the same radionuclide concentrations as determined above the maximally exposed individual. Fractions of the production, ingested by each age group are (from Regulatory Guide 3.51)[5]:

Infants	0
Children	0.1418
Teenagers	0.2167
Adults	0.16415

The total radionuclide ingestion by each age group is given in Table C-10. Based on the dose conversion factors in Table C-1, the effective (weighted total body) dose equivalent commitments for the various population groups were calculated and are presented in Table C-11. The population dose commitment via this pathway is 960 person-mrem.

4. Ingestion of Meat

It is assumed that 50% of the sludge-treated land is planted in forage crops. Regulatory Guide 1.109 recommends a forage crop yield value of 0.7 kg/m^2; a total yield of 3.5 x 10^4 kg of forage would therefore be obtained from the sludge treated land. Forage crops are assumed to contain the same radionuclide concentrations as determined above, for the maximally exposed individual, and, in the absence of specific absorption factors (Fl) for beef, the following human absorption factors were used:

Co	5.00E-02
Sr	2.00E-01
Cs	9.50E-01
U	2.00E-03

Resulting total radionuclide levels transferred to meat from forage crops would be:

Co-60	4.6 E+04 pCi
Sr-90	5.1 E+04 pCi
Cs-137	2.6 E+05 pCi
U-234	7.7 E+02 pCi
U-235	4.1 E+01 pCi
U-238	4.9 E+02 pCi

Fractions of meat production, ingested by each age group are:[5]

Infants	0
Children	0.0780
Teenagers	0.1485
Adults	0.7735

Total radionuclide ingestion by age group is given in Table C-12. Calculated effective dose equivalents are presented in Table C-13. The effective total body dose equivalent to the population from ingestion of meat is 19 person-mrem.

5. Ingestion of Milk

For calculation of population dose from ingestion of milk, it was assumed that 3.5×10^4 kg of forage is consumed at the rate of 50 kg/day for 700 days. This is equivalent to approximately 2 cattle - years of feed. (For population dose estimation purposes, it makes no difference whether this forage is distributed to many cattle or limited to 2 cattle.) Using the radionuclide concentrations determined above for milk (Section 5 of the maximally exposed individual) and a total available milk output of 23 l/day per cow for 305 days/year, the following total annual milk radionuclide activities are calculated as available via the milk pathway:

Co-60	1.8E+04 pCi
Sr-90	4.1E+03 pCi
Cs-137	6.6E+04 pCi
U-234	4.8E+03 pCi
U-235	2.8E+02 pCi
U-238	2.9E+03 pCi

Fractional milk consumption by age groups[5] is:

Infants	0.0178
Children	0.1850
Teenagers	0.2728
Adults	0.5244

Using these consumption factors, total ingestion by the milk pathway was calculated and is presented in Table C-14. Dose conversion factors from Table C-1 were then used to convert the milk ingestion levels to effective dose equivalent for the four population groups; results, summarized in Table C-15, indicate an effective population dose equivalent of 10 person-mrem via this pathway.

6. Total Population Dose

The sum of the effective dose-equivalents from all pathways yields a total population dose of 1169 person-mrem or 1.2 person-rem.

TABLE C-1

DOSE CONVERSION FACTORS (mrem/μCi)

A. Co-60; Inhalation (Class Y)[a]

Organ	Age Group Adult	Teenager	Child	Infant
Lung	1.20E+03	1.80E+03	3.60E+03	1.15E+04
LLI Wall	2.90E+01	4.10E+01	1.10E+02	3.60E+02
Kidneys	5.85E+01	---[b]	---	---
Liver	1.20E+02	1.70E+02	3.40E+02	8.60E+02
Gonads	1.70E+01	2.30E+01	6.70E+01	2.10E+02
Red Marrow	6.20E+01	8.80E+01	1.60E+02	3.80E+02
Endostial Bone	5.08E+01	---	---	---
Thyroid	6.01E+01	---	---	---
Effective[c]	1.8 E+02[d]	2.6 E+02[d]	5.3 E+02[d]	1.7 E+03[d]

[a]Conversion factors based on adult metabolism, using pediatric phantoms of Christy and Eckerman (ORNL/TM-8381).
[b]Dash indicates data not available.
[c]Weighted committed effective dose equivalent.
[d]Estimated based on limited organ dose data.

B. Co-60; Ingestion (F= 0.05)[a]

Organ	Age Group Adult	Teenager	Child	Infant
Lung	8.62E+00	4.20E+00	9.30E+00	2.60E+01
LLI Wall	4.02E+01	5.00E+01	1.30E+02	4.00E+02
Kidneys	5.67E+00	---	---	---
Liver	6.83E+00	1.10E+01	2.20E+01	6.00E+01
Gonads	1.24E+01	1.60E+01	3.40E+01	8.80E+01
Red Marrow	5.42E+00	5.60E+00	1.10E+01	2.60E+01
Endostial Bone	3.99E+00	---	---	---
Thyroid	3.10E+00	---	---	---
Effective	8.6 E+00[b]	1.1 E+01[b]	2.4 E+01[b]	6.7 E+01[b]

[a]Conversion factors based on adult metabolism, using pediatric phantoms of Christy and Eckerman (ORNL/TM-8381).
[b]Estimated based on limited organ dose data.

TABLE C-1 (Continued)

DOSE CONVERSION FACTORS (mrem/μCi)

C. Sr-90; Inhalation (Class D)[a]

Organ	Age Group			
	Adult	Teenager	Child	Infant
Lung	1.40E+01	1.60E+01	4.30E+01	1.10E+02
LLI Wall	2.20E+01	2.20E+01	7.00E+01	1.40E+02
Kidneys	9.80E+00	9.60E+00	2.90E+01	5.30E+01
Liver	9.80E+00	9.60E+00	2.90E+01	5.30E+01
Gonads	9.80E+00	9.60E+00	2.90E+01	5.30E+01
Red Marrow	1.60E+03	1.20E+03	1.10E+03	3.00E+03
Endostial Bone	3.50E+03	6.20E+03	2.80E+03	9.20E+03
Thyroid	9.80E+00	9.60E+00	2.90E+01	5.30E+01
Effective	3.00E+02	3.40E+02	2.50E+02	7.00E+02

[a]Source of data - NUREG/CR-3535.[6]

D. Sr-90; Ingestion[a]

Organ	Age Group			
	Adult	Teenager	Child	Infant
Lung	4.10E+00	6.70E+00	1.50E+01	5.20E+01
LLI Wall	8.10E+01	8.10E+01	2.70E+02	5.60E+02
Kidneys	4.10E+00	6.70E+00	1.50E+01	5.20E+01
Liver	4.10E+00	6.70E+00	1.50E+01	5.20E+01
Gonads	4.10E+00	6.70E+00	1.50E+01	5.20E+01
Red Marrow	6.50E+02	8.60E+02	6.00E+02	3.10E+03
Endostial Bone	1.50E+03	4.40E+03	1.50E+03	9.50E+03
Thyroid	4.10E+00	6.70E+00	1.50E+01	5.20E+01
Effective	1.30E+02	2.50E+02	1.50E+02	7.40E+02

[a]Source of data - NUREG/CR-3535.[6]

TABLE C-1 (Continued)

DOSE CONVERSION FACTORS (mrem/μCi)

E. Cs-137; Inhalation (Class D)[a]

Organ	Age Group Adult	Teenager	Child	Infant
Lung	1.62E+01	3.59E+01	3.08E+01	1.46E+01
LLI Wall	1.60E+01	3.24E+01	2.20E+01	9.42E+01
Kidneys	5.13E+01	3.28E+01	2.17E+01	9.21E+01
Liver	5.23E+01	3.34E+01	2.21E+01	9.36E+01
Gonads	5.00E+01	3.54E+01	2.31E+01	9.63E+01
Red Marrow	4.91E+01	3.04E+01	2.15E+01	1.10E+02
Endostial Bone	5.31E+01	1.34E+02	9.46E+01	6.68E+02
Thyroid	4.47E+01	3.91E+01	2.23E+01	9.43E+01
Effective	3.9 E+01[b]	3.2 E+01[b]	2.2 E+01[b]	9.1 E+01[b]

[a]Source of data - Personal communication from K. Eckerman, ORNL.
[b]Estimated based on limited organ data.

F. Cs-137; Ingestion[a]

Organ	Age Group Adult	Teenager	Child	Infant
Lung	4.86E+01	4.95E+01	3.24E+01	1.41E+02
LLI Wall	5.50E+01	5.15E+01	3.50E+01	1.50E+02
Kidneys	5.22E+01	5.20E+01	3.43E+01	1.46E+02
Liver	5.28E+01	5.28E+01	3.49E+01	1.48E+02
Gonads	4.88E+01	5.56E+01	3.67E+01	1.53E+02
Red Marrow	4.23E+01	4.82E+01	3.41E+01	1.74E+02
Endostial Bone	2.10E+02	2.12E+02	1.50E+02	1.06E+03
Thyroid	4.84E+01	5.06E+01	3.53E+01	1.49E+02
Effective	4.7 E+01[b]	4.9 E+01[b]	3.3E +01[b]	1.6 E+02[b]

[a]Source of data - Personal communcation from K. Eckerman, ORNL.
[b]Estimated based on limited organ data.

TABLE C-1 (Continued)

DOSE CONVERSION FACTORS (mrem/μCi)

G. U-234; Inhalation (Class Y)

Organ	Age Group[a]			
	Adult	Teenager	Child	Infant
Lung	5.36E+05	6.43E+05	1.23E+06	2.57E+06
LLI Wall	1.10E+02	1.32E+02	3.52E+02	1.10E+03
Kidneys	1.70E+03	2.04E+03	3.57E+03	8.16E+03
Liver	1.62E+01	1.80E+01	3.89E+01	8.59E+01
Gonads	1.61E+01	1.77E+01	3.86E+01	9.02E+01
Red Marrow	2.40E+02	2.64E+02	3.60E+02	1.13E+03
Endostial Bone	3.50E+03	5.60E+03	9.10E+03	3.85E+04
Thyroid	1.61E+01	1.77E+01	3.86E+01	9.02E+01
Effective	6.5 E+04	7.8 E+04	1.5 E+05	3.1 E+05

[a]Sources of data - NUREG/CR-0150 and NUREG/CR-4628.[3,7]

H. U-234; Ingestion (F= 0.05)[a]

Organ	Age Group			
	Adult	Teenager	Child	Infant
Lung	1.72E+01	4.13E+01	8.26E+01	6.02E+02
LLI Wall	1.70E+02	2.55E+02	6.63E+02	2.89E+03
Kidneys	1.70E+03	4.25E+03	6.63E+03	5.61E+04
Liver	1.58E+01	3.95E+01	6.95E+01	5.21E+02
Gonads	1.58E+01	3.79E+01	7.58E+01	5.53E+02
Red Marrow	2.30E+02	4.83E+02	5.52E+02	9.89E+03
Endostial Bone	3.50E+03	1.51E+04	1.51E+04	3.85E+05
Thyroid	1.58E+01	3.79E+01	7.58E+01	5.53E+02
Effective	2.4 E+02	7.4 E+02	9.6 E+02	1.5 E+04

[a]Sources of data - NUREG/CR-0150 and NUREG/CR-4628.[3,7]

TABLE C-1 (Continued)

DOSE CONVERSION FACTORS (mrem/µCi)

I. U-235; Inhalation (Class Y)[a]

Organ	Age Group			
	Adult	Teenager	Child	Infant
Lung	4.84E+05	5.81E+05	1.11E+06	2.32E+07
LLI Wall	2.50E+02	3.00E+02	8.00E+02	2.50E+03
Kidneys	1.50E+03	1.80E+03	3.15E+03	7.20E+03
Liver	3.16E+01	3.79E+01	6.95E+01	1.42E+02
Gonads	1.62E+01	1.78E+01	3.89E+01	9.07E+01
Red Marrow	1.90E+02	2.09E+02	2.85E+02	8.74E+02
Endostial Bone	2.90E+03	4.64E+03	7.54E+03	3.19E+04
Thyroid	2.07E+01	2.48E+01	5.18E+01	1.16E+02
Effective	5.9 E+94	7.1 E+04	1.4 E+05	2.8 E+05

[a]Sources of data - NUREG/CR-0150 and NUREG/CR-4628.[3,7]

J. U-235; Ingestion (F= 0.05)[a]

Organ	Age Group			
	Adult	Teenager	Child	Infant
Lung	1.62E+01	3.89E+01	7.78E+01	5.67E+02
LLI Wall	1.80E+02	2.52E+02	6.84E+02	3.06E+03
Kidneys	1.50E+03	3.75E+03	5.85E+03	4.95E+04
Liver	1.38E+01	3.45E+01	6.07E+01	4.55E+02
Gonads	1.45E+01	3.34E+01	6.96E+01	5.08E+02
Red Marrow	1.80E+02	3.78E+02	4.32E+02	7.74E+03
Endostial Bone	2.90E+03	1.25E+04	1.25E+04	3.19E+05
Thyroid	1.45E+01	3.34E+01	6.96E+01	5.08E+02
Effective	2.0 E+02	4.0 E+02	7.6 E+02	1.3 E+04

[a]Sources of data - NUREG/CR-0150 and NUREG/CR-4628.[3,7]

TABLE C-1 (Continued)

DOSE CONVERSION FACTORS (mrem/μCi)

K. U-238; Inhalation (Class Y)[a]

Organ	Age Group Adult	Teenager	Child	Infant
Lung	4.80E+05	5.76E+05	1.10E+06	2.26E+06
LLI Wall	2.80E+02	3.36E+02	8.96E+02	2.74E+03
Kidneys	1.50E+03	1.80E+03	3.15E+03	7.20E+03
Liver	1.76E+01	2.11E+01	4.05E+01	8.80E+01
Gonads	1.47E+01	1.62E+01	3.53E+01	8.23E+01
Red Marrow	2.00E+02	2.20E+02	3.00E+02	9.20E+02
Endostial Bone	2.90E+03	4.64E+03	7.54E+03	3.19E+04
Thyroid	1.59E+01	1.75E+01	3.82E+01	8.75E+01
Effective	5.8 E+04	7.0 E+04	1.3 E+05	2.8 E+05

[a]Sources of data - NUREG/CR-0150 and NUREG/CR-4628.[3,7]

L. U-238; Ingestion (F= 0.05)[a]

Organ	Age Group Adult	Teenager	Child	Infant
Lung	1.53E+01	3.67E+01	7.34E+01	5.20E+02
LLI Wall	1.60E+02	2.24E+02	6.24E+02	2.72E+03
Kidneys	1.50E+03	3.75E+03	5.85E+03	4.80E+04
Liver	1.34E+01	3.35E+01	5.90E+01	4.29E+02
Gonads	1.34E+01	3.08E+01	6.43E+01	4.56E+02
Red Marrow	1.90E+02	3.80E+02	4.56E+02	7.60E+03
Endostial Bone	2.80E+03	1.20E+04	1.20E+04	2.80E+05
Thyroid	1.41E+01	3.24E+01	6.77E+01	4.79E+02
Effective	2.0 E+02	6.20E+02	7.80E+02	1.3 E+04

[a]Sources of data - NUREG/CR-0150 and NUREG/CR-4628.[3,7]

TABLE C-2

INHALATION DOSE COMMITMENT TO ORGANS OF MAXIMALLY EXPOSED INDIVIDUAL

Organ	Dose Commitment (mrem/year of exposure)						Total
	Co-60	Sr-90	Cs-137	U-234	U-235	U-238	
Lung	1.9E-03	1.4E-06	4.9E-06	8.0E-01	3.1E-02	2.9E-01	1.1E+00
LLI Wall	4.6E-05	2.2E-06	4.8E-06	1.7E-04	1.6E-05	1.7E-04	4.1E-04
Kidneys	9.4E-05	9.8E-07	1.9E-05	2.6E-03	9.6E-05	9.0E-04	3.7E-03
Liver	1.9E-04	9.8E-07	1.9E-05	2.4E-05	2.0E-06	1.1E-05	2.5E-04
Gonads	2.7E-05	9.8E-07	1.9E-05	2.4E-05	1.0E-06	8.8E-06	8.0E-05
Red Marrow	9.9E-05	1.6E-04	1.8E-05	3.6E-04	1.2E-05	1.2E-04	7.7E-04
Endostial Bone	8.1E-05	3.5E-04	2.0E-05	5.3E-03	1.9E-04	1.7E-03	7.6E-03
Thyroid	9.6E-05	9.8E-07	1.7E-05	2.4E-05	1.3E-06	9.5E-06	1.5E-04
Effective	2.9E-04	3.0E-05	1.4E-05	9.8E-02	3.8E-03	3.5E-02	1.4E-01

TABLE C-3

RADIONUCLIDE UPTAKE OR BIOACCUMULATION FACTORS FOR SELECTED FOOD PATHWAYS

Radionuclide	Soil-to-Vegetation (pCi/kg plant-wet weight) / (pCi/kg soil-dry weight)	Forage-to-Meat (d/kg forage intake)	Forage-to-Milk (d/1)
Co-60	9.4E-03[a]	1.3E-02	1.0E-03
Sr-90	1.7E-02	6.0E-04	8.0E-04
Cs-137	1.0E-02	4.0E-03	1.2E-02
U-234	2.5E-03	3.4E-04	6.1E-04
U-235	2.5E-03	3.4E-04	6.1E-04
U-238	2.5E-03	3.4E-04	6.1E-04

[a]Uranium values from Regulatory Guide 3.51[5]; other values from Regulatory Guide 1.109[4].

TABLE C-4

DOSE COMMITMENT TO ORGANS OF MAXIMALLY EXPOSED INDIVIDUAL
VIA THE VEGETATION INGESTION PATHWAY

Organ	Dose Commitment (mrem/year of exposure)						Total
	Co-60	Sr-90	Cs-137	U-234	U-235	U-238	
Lung	1.2E-02	1.6E-03	2.0E-02	9.8E-03	4.9E-04	5.5E-03	4.9E-02
LLI Wall	5.4E-02	3.1E-02	2.3E-02	9.8E-02	5.4E-03	5.8E-02	2.7E-01
Kidneys	7.7E-03	1.6E-03	2.1E-02	9.8E-01	4.5E-02	5.4E-01	1.6E+00
Liver	9.2E-03	1.6E-03	2.2E-02	9.0E-03	4.1E-04	4.8E-03	4.7E-02
Gonads	1.7E-02	1.6E-03	2.0E-02	9.0E-03	4.4E-04	4.8E-03	5.2E-02
Red Marrow	7.3E-03	2.5E-01	1.7E-02	1.3E-01	5.4E-03	6.8E-02	4.7E-01
Endostial Bone	5.4E-03	5.7E-01	8.6E-02	2.0E+00	8.7E-02	1.0E+00	3.7E+00
Thyroid	4.2E-03	1.6E-03	2.0E-02	9.0E-03	4.4E-04	5.0E-03	4.0E-02
Effective	1.2E-02	4.9E-02	1.9E-02	1.4E-01	6.0E-03	7.2E-02	2.9E-01

TABLE C-5

DOSE COMMITMENT TO ORGANS OF MAXIMALLY EXPOSED INDIVIDUAL
VIA THE MEAT INGESTION PATHWAY

Organ	Dose Commitment (mrem/year of exposure)						Total
	Co-60	Sr-90	Cs-137	U-234	U-235	U-238	
Lung	8.1E-03	4.9E-05	4.3E-03	1.7E-04	9.7E-06	1.0E-04	1.3E-02
LLI Wall	3.8E-02	9.7E-04	4.8E-03	1.7E-03	1.1E-04	1.1E-03	4.7E-02
Kidneys	5.3E-03	4.9E-05	4.6E-03	1.7E-02	9.0E-04	9.9E-03	3.8E-02
Liver	6.4E-03	4.9E-05	4.6E-03	1.6E-04	8.3E-06	8.8E-05	1.2E-02
Gonads	1.2E-02	4.9E-05	4.3E-03	1.6E-04	8.7E-06	8.8E-05	1.6E-02
Red Marrow	5.1E-03	7.8E-03	3.7E-03	2.3E-03	1.1E-04	1.3E-03	2.0E-02
Endostial Bone	3.8E-03	1.8E-02	1.8E-02	3.5E-02	1.7E-03	1.8E-02	9.5E-02
Thyroid	2.9E-03	4.9E-05	4.3E-03	1.6E-04	8.7E-06	9.3E-05	7.5E-03
Effective	8.1E-03	1.6E-03	4.1E-03	2.4E-03	1.2E-04	1.3E-03	1.8E-02

TABLE C-6

DOSE COMMITMENT TO ORGANS OF MAXIMALLY EXPOSED INDIVIDUAL
VIA THE MILK INGESTION PATHWAY

Organ	Dose Commitment (mrem/year of exposure)						Total
	Co-60	Sr-90	Cs-137	U-234	U-235	U-238	
Lung	3.4E-03	3.7E-04	7.3E-02	1.9E-03	1.0E-04	9.9E-04	8.0E-03
LLI Wall	1.6E-02	7.3E-03	8.3E-02	1.9E-02	1.1E-03	1.0E-02	1.4E-01
Kidneys	2.3E-03	3.7E-04	7.8E-02	1.9E-01	9.3E-03	9.8E-02	4.0E-01
Liver	2.7E-03	3.7E-04	7.9E-02	1.7E-03	8.6E-05	8.7E-04	8.5E-02
Gonads	5.0E-03	3.7E-04	7.3E-02	1.7E-03	9.0E-05	8.7E-04	8.1E-02
Red Marrow	2.2E-03	5.9E-02	6.3E-02	2.5E-02	1.1E-03	1.2E-02	1.6E-01
Endostial Bone	1.6E-03	1.4E-01	3.2E-01	3.9E-01	1.8E-02	1.8E-01	1.0E+00
Thyroid	1.2E-03	3.7E-04	7.3E-02	1.7E-03	9.0E-05	9.2E-04	7.6E-02
Effective	3.4E-03	1.2E-02	7.1E-02	2.6E-02	1.43-03	1.3E-02	1.3E-01

TABLE C-7

SUMMARY DOSE COMMITMENT TO MAXIMALLY EXPOSED INDIVIDUAL
FROM ALL PATHWAYS

Organ	Dose Commitment (mrem/year of exposure)					Total
	Direct Radiation	Inhalation	Ingestion (Vegetation)	Ingestion (Meat)	Ingestion (Milk)	
Lung	3.4E+00	1.1E+00	4.9E-02	1.3E-02	8.0E-03	4.6E+00
LLI Wall	3.4E+00	4.1E-04	2.7E-01	4.7E-02	1.4E-01	3.9E+00
Kidneys	3.4E+00	3.7E-03	1.6E+00	3.8E-02	4.0E-01	5.4E+00
Liver	3.4E+00	2.5E-04	4.7E-02	1.2E-02	8.5E-02	3.6E+00
Gonads	3.4E+00	8.0E-05	5.2E-02	1.6E-02	8.1E-02	3.6E+00
Red Marrow	3.4E+00	7.7E-04	4.7E-01	2.0E-02	1.6E-01	4.1E+00
Endostial Bone	3.4E+00	7.6E-03	3.7E+00	9.5E-02	1.0E+00	8.2E+00
Thyroid	3.4E+00	1.5E-04	4.0E-02	7.5E-03	7.6E-02	3.5E+00
Effective	3.4E+00	1.4E-01	2.9E-01	1.8E-02	1.3E-01	4.0E+00

TABLE C-8

DOSE COMMITMENT TO CHILD FROM INGESTION OF SOIL

Organ	Dose Commitment (mrem/year exposure)						
	Co-60	Sr-90	Cs-137	U-234	U-235	U-238	Total
Lung	6.3E-03	6.6E-04	5.2E-03	5.2E-02	2.1E-03	1.9E-02	7.9E-02
LLI Wall	9.0E-02	1.2E-02	5.5E-03	4.1E-01	1.9E-02	1.6E-01	6.1E-01
Kidneys	---[a]	6.6E-04	5.5E-03	4.1E+00	1.6E-01	1.5E+00	5.8E+00
Liver	1.5E-02	6.6E-04	5.5E-03	4.4E-02	1.7E-03	1.5E-02	8.2E-02
Gonads	2.3E-02	6.6E-04	5.8E-03	4.7E-02	1.9E-03	1.7E-02	9.5E-02
Red Marrow	7.7E-03	2.6E-02	5.5E-03	3.6E-01	1.2E-02	1.2E-01	5.3E-01
Endostial Bone	---	6.6E-02	2.4E-02	9.6E+00	3.6E-01	3.0E+00	1.3E+01
Thyroid	---	6.6E-04	5.5E-03	4.7E-02	1.9E-03	1.8E-02	7.3E-02
Effective	1.6E-02	6.6E-03	5.2E-03	6.0E-01	2.1E-02	2.0E-01	8.4E-01

[a]Dash indicates dose conversion factor not available.

TABLE C-9

DOSE COMMITMENT TO CHILD FROM INGESTION OF MILK

Organ	Dose Commitment (mrem/year exposure)						
	Co-60	Sr-90	Cs-137	U-234	U-235	U-238	Total
Lung	4.0E-03	1.4E-03	5.2E-02	9.1E-03	5.1E-04	5.1E-03	7.2E-02
LLI Wall	5.6E-02	2.6E-02	5.6E-02	7.3E-02	4.5E-03	4.3E-02	2.6E-01
Kidneys	---[a]	1.4E-03	5.5E-02	7.3E-01	3.9E-02	4.0E-01	1.2E+00
Liver	9.5E-03	1.4E-03	5.6E-02	7.6E-03	4.0E-04	4.1E-03	7.9E-02
Gonads	1.5E-02	1.4E-03	5.9E-02	8.3E-03	4.6E-04	4.4E-03	8.8E-02
Red Marrow	4.7E-03	5.8E-02	5.5E-02	6.1E-02	2.9E-03	3.2E-02	2.1E-01
Endostial Bone	---	1.4E-01	2.4E-01	1.7E+00	8.3E-02	8.3E-01	3.0E+00
Thyroid	---	1.4E-03	5.6E-02	8.3E-03	4.6E-04	4.7E-03	7.1E-02
Effective	1.0E-02	1.43-02	5.3E-02	1.1E-01	5.0E-03	5.4E-02	2.5E-01

[a]Dash indicates dose conversion factor not available.

TABLE C-10

TOTAL ANNUAL POPULATION RADIONUCLIDE INGESTION (pCi) BY CONSUMPTION OF VEGETABLES GROWN ON SLUDGE-TREATED AREAS

Radionuclide	Age Group			
	Infants	Children	Teenagers	Adults
Co-60	0	3.7E+05	5.7E+05	1.7E+06
Sr-90	0	1.0E+05	1.6E+05	4.8E+05
Cs-137	0	1.1E+05	1.7E+05	5.1E+05
U-234	0	1.6E+05	2.4E+05	7.2E+05
U-235	0	8.7E+03	1.3E+04	2.9E+04
U-238	0	1.0E+05	1.6E+05	4.6E+05

TABLE C-11

DOSE COMMITMENT (person-mrem) TO POPULATION
VIA VEGETATION INGESTION PATHWAY

Radionuclide	Age Group Infants	 Children	 Teenagers	 Adults
Co-60	0	8.9 E+00	6.3 E+00	1.5 E+01
Sr-90	0	1.5 E+01	4.0 E+01	6.2 E+01
Cs-137	0	3.6 E+00	8.3 E+00	2.4 E+01
U-234	0	1.5 E+02	1.8 E+02	1.7 E+02
U-235	0	6.6 E+00	5.2 E+00	5.8 E+00
U-238	0	7.8 E+01	9.9 E+01	9.2 E+01
TOTAL	0	2.52E+02	3.39E+02	3.69E+02

TABLE C-12

TOTAL ANNUAL POPULATION RADIONUCLIDE INGESTION (pCi) BY CONSUMPTION OF MEAT FED FORAGE CROPS GROWN ON SLUDGE-TREATED AREAS

Radionuclide	Age Group			
	Infants	Children	Teenagers	Adults
Co-60	0	3.6E+03	6.8E+03	3.6E+04
Sr-90	0	4.0E+03	7.6E+03	3.9E+04
Cs-137	0	2.0E+04	3.9E+04	2.0E+05
U-234	0	6.0E+01	1.1E+02	6.0E+02
U-235	0	3.2E+00	6.1E+00	3.2E+01
U-238	0	3.8E+01	7.3E+01	3.8E+02

TABLE C-13

EFFECTIVE DOSE COMMITMENT (person-mrem) TO POPULATION
VIA MEAT INGESTION PATHWAY

Radionuclide	Age Group Infants	Children	Teenagers	Adults
Co-60	0	8.6 E-02	7.5 E-02	3.1 E-01
Sr-90	0	6.0 E-01	1.5 E-01	5.1 E+00
Cs-137	0	6.6 E-01	1.9E +00	9.4 E+00
U-234	0	5.8 E-02	8.1 E-02	1.4 E-01
U-235	0	2.4 E-03	2.4 E-03	6.4 E-03
U-238	0	3.0 E-02	4.5 E-02	7.6 E-02
TOTAL	0	1.43E+00	2.25E+00	1.50E+01

TABLE C-14

TOTAL ANNUAL POPULATION RADIONUCLIDE INGESTION (pCi) BY CONSUMPTION OF MILK FROM CATTLE FED CROPS GROWN ON SLUDGE-TREATED AREAS

Radionuclide	Age Group			
	Infants	Children	Teenagers	Adults
Co-60	3.2E+02	3.3E+03	4.9E+03	9.4E+03
Sr-90	7.3E+01	7.6E+02	1.1E+03	2.2E+03
Cs-137	1.2E+03	1.2E+04	1.8E+04	3.5E+04
U-234	8.5E+01	8.9E+02	1.3E+03	2.5E+03
U-235	5.0E+00	5.2E+01	7.6E+01	1.5E+02
U-238	5.2E+01	5.4E+02	7.9E+02	1.5E+03

TABLE C-15

EFFECTIVE DOSE COMMITMENT (person-mrem) TO POPULATION VIA MILK INGESTION PATHWAY

Radionuclide	Age Group			
	Infants	Children	Teenagers	Adults
Co-60	2.1 E-02	7.9 E-02	5.4 E-02	8.1 E-02
Sr-90	5.4 E-02	1.1 E-01	2.8 E-01	2.9 E-01
Cs-137	1.9 E-01	4.0 E-01	8.8 E-01	1.6 E+00
U-234	1.3 E+00	8.5 E-01	9.6 E-01	6.0 E-01
U-235	6.5 E-02	4.0 E-02	3.0 E-02	3.0 E-02
U-238	6.8 E-01	4.2 E-01	4.9 E-01	3.0 E-01
TOTAL	2.91E+00	1.90E+00	2.69E+00	2.90E+00