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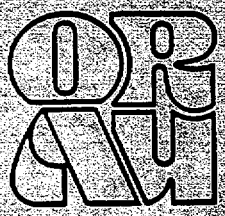
ORAU 88/F-130



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 II)

G. L. MURPHY AND J. D. BERGER

Radiological Site Assessment Program
Manpower Education, Research, and Training Division

FINAL REPORT
JUNE 1988

PDR

Oak Ridge Associated Universities
Post Office Box 117
Oak Ridge, Tennessee 37831-0117

Manpower Education, Research, and Training Division

July 13, 1988

30-20934

Mr. Leland Rouse
Division of Industrial and Medical
Nuclear Safety
Mail Stop 6H3
Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Rouse:

Enclosed are twenty copies of the report on the Radiological Impact of Effluent Releases to the Sanitary Sewer from Interstate Nuclear Services Corporation (Phase II), Royersford, Pennsylvania. Thirty copies of this report have been forwarded to Mr. John Kinneman.

If you have any questions or comments, please give me a call at FTS 636-3305.

Sincerely,

James D. Berger, Manager
Radiological Site Assessment Program

JDB:jle

Enclosures

cc: J. Kinneman, NRC/Region I
R. Provencher, NRC/6H3
E. Davis, NRC/6A4
R. Cloutier, MERT
W. Boyle, MERT

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Oak Ridge, Tennessee 37831-0117

Project Staff

R.D. Condra
E.J. Deming*
M.R. Dunsmore*
M.A. Edwards*
G.R. Foltz
J.L. Payne
R.R. Rookard
T.J. Sowell
C.F. Weaver

Prepared for

Division of Industrial and Medical Nuclear Safety
Nuclear Materials Safety and Safeguards
U.S. Nuclear Regulatory Commission

FINAL REPORT

June 1988

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*Currently at the University of Tennessee

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

INTRODUCTION

Interstate Nuclear Service Corporation (INS) of Royersford, Pennsylvania operates a laundry facility under Nuclear Regulatory Commission (NRC) license No. 37-23341-01, 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 plutonium.

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 was withdrawn and spread on land, as fertilizer, throughout a number of farms comprising a large area west of Philadelphia. During 1987 a total of approximately 9.4×10^5 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 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 continued through 1987 (Phase II). It is expected to continue into 1988 (Phase III). Activities during 1987 included: reviewing liquid effluent discharges from the INS laundry; measuring radiological conditions within the sewage treatment facility; determining concentrations in sewage sludge; measuring concentrations of radionuclides in two treated fields; and conducting preliminary estimates of potential dose commitments from such sludge application. Additional measurements during 1988 will enable evaluation of effects of repeated long-term sludge applications and uptake of various radionuclides by vegetation, grown on treated areas.

SITE DESCRIPTION

The Interstate Nuclear Services Corporation operates a 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 2) 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 (Figure 3). 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 throughout the winter, from October to May. Approximately 9.5×10^3 liters of the sludge, with a solids content of 5 - 8%, is transferred to the secondary digestor each week. Beginning early each spring the sludge has been withdrawn in 2.3×10^4 liter truckloads by a commercial sludge spreader. The sludge was spread on agricultural land, as fertilizer, throughout a number of farms, west of Philadelphia. The majority of the sludge was spread early in the growing season; spreading was 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 May (Site 1) and July (Site 2), 1987. 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. Winter wheat was planted on Site 2 in late October 1986. Corn was planted on Site 1 in the spring of 1987.

SURVEY PROCEDURES

INS Effluent Releases

ORAU reviewed and summarized INS effluent release data from October 1986 through September 1987.

Wastewater Treatment Facilities

In 1987, samples were collected from two additional waste water treatment facilities (Spring City and Doylestown, PA) similar to Royersford in capacity and facility design, for baseline comparison purposes (Figure 4).

1. Direct measurements at the surface and at 1 meter above the surface were made at trickling and bio-filters, digestors, and influent and effluent areas at the Royersford, Spring City and Doylestown wastewater treatment facilities.

2. ORAU personnel collected influent and effluent water samples from the Royersford, Spring City and Doylestown facilities.

3. Samples of sludge were collected in November, 1987 from the primary and secondary digestor tanks (Royersford) and from the secondary digestor tanks only (Spring City and Doylestown).

4. Royersford Wastewater Treatment Facility workers obtained samples of each batch of sludge as it was being withdrawn from the secondary digestor by the commercial spreader, during the 1987 sludge spreading season.

Sludge Application Sites

Site 1 (Limerick Township)

1. On May 13, 1987, before initial sludge application of the 1987 season, soil samples were collected at nine randomly selected locations within the same 10 x 10 m gridded area established in 1986. Soil samples were obtained using a shelby tube driven to a depth of 30 cm. Samples were composited to represent depths of 0-2.5, 2.5-7.5, 7.5-15, and 15-30 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. Forage crops had been harvested, and no crops were available for sampling.

2. On May 13, 1987, following the initial sludge application and tilling, soil was resampled from the 100 m^2 plot, following the same procedure described in step 1 above. Direct measurements were obtained at individual sampling locations.

3. On June 25, 1987, 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.

4. Soil sampling and direct measurements were repeated on the study plot on July 23, 1987. Soil sample composites were prepared for depths of 0-2.5, 2.5-7.5, 7.5-15, and 15-30 cm.

5. On November 10, 1987 soil sampling and direct measurements from the study plot were repeated as in #4, above. Vegetation (corn) had been harvested and mixed with corn from other areas; therefore, no vegetation was collected from Site 1 in 1987.

Site 2 (Providence Township)

1. The 1986 10 m x 10 m grid was re-established on the site on May 13 and June 24, 1987 and 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 30 cm. Samples were composited to represent depths of 0-2.5, 2.5-7.5, 7.5-15, and 15-30 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. Winter wheat samples were collected during May and June.

2. On July 23, 1987, prior to and immediately following the initial 1987 sludge application and tilling, soil was resampled from the 100 m^2 plot, following the same procedure described in step 1 above. Direct measurements were obtained at individual sampling locations. Winter wheat had been harvested.

3. On November 10, 1987, 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.

Background Samples and Measurements

In 1986, 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).[1] 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 radiochemistry procedures. Water was 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, and beta-gamma dose rates ranged from 22 to 30 μrad/h. Beta-gamma dose rates are measured at contact with the soil. The slight elevation in dose rate compared to exposure rates reflects the beta component which is not detected at 1 m.

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.

Interstate Nuclear Services Releases

Sampling records maintained by INS from October 1986 through September 1987 are complete and indicate compliance with 10 CFR 20.303.[2] Monthly discharges are summarized in Table 4. During this 12 month period, INS released a total volume of 1.70×10^7 l to the sanitary sewer; this discharge contained a total gross alpha activity of 0.754 mCi and a total gross beta activity of 203.52 mCi.

Wastewater Treatment Facilities

Exposure Rate Measurements

Gamma exposure rates (Table 5) measured in 1986 over most of the Royersford wastewater facility, generally ranged from 7 to 17 μR/h; these are slightly higher than typical background exposure rates for the Royersford area.[1] The elevated rates are associated with treatment processes which act as accumulators (Bio-filters, primary and secondary digestors). The exposure rates are not attributed to surface soil contamination. In comparison, gamma exposure rates measured at the Spring City and Doylestown facilities ranged from 8-11 μR/h and 9-11 μR/h, respectively. Measurements made in 1987 at the surface of the liquid in the secondary digestor at Royersford ranged from 240 to 470 μR/h, compared with a range of 360 to 470 μR/h in 1986.

Wastewater Influent and Effluent

Radionuclide concentrations measured in grab samples of influent and effluent streams from Royersford, Spring City and Doylestown wastewater treatment facilities are presented in Table 6. The Royersford influent and effluent data cannot be directly compared because the samples do not reflect the same volume of media. The Spring City and Doylestown samples were collected to establish a background concentration for comparison purposes. Royersford influent contained gross alpha and gross beta concentrations of 2.8 pCi/l and 12.4 pCi/l, respectively. Spring City and Doylestown influent water contained measured gross

alpha concentrations of 1.1 and 2.2 pCi/l, and gross beta concentrations of 7.9 and 9.3 pCi/l. Effluent water from the Royersford facility had a measured gross alpha concentration of 5.3 pCi/l and gross beta concentration of 22.5 pCi/l. In contrast, Spring City and Doylestown effluents contained gross alpha levels of 0.3 pCi/l and 1.0 pCi/l and gross beta concentrations of 8.8 pCi/l and 5.6 pCi/l, respectively. Cesium 137 and 134 were the principal radionuclides identified in the Royersford effluent. The Cs-137 concentration measured in the Royersford effluent sample was 230 pCi/l, and the Cs-134 concentration was 71.8 pCi/l. The highest cesium concentration measured in effluents from the other two facilities was 6.4 pCi/l of Cs-137 from the Doylestown Plant.

Digestor Sludge Concentrations

A comparison of radionuclide concentrations measured in sludge samples collected from the Royersford, Spring City and Doylestown facilities is presented in Table 7. The Royersford sludge contains radionuclide concentrations which range up to four orders of magnitude higher than similar radionuclide concentrations measured in sludge from Spring City and Doylestown.

Table 8 contains radionuclide concentration information on sludge samples collected from March through September, 1987, as the sludge spreading truck was being filled. The maximum average radionuclide concentration was for Co-60 (55,000 pCi/l), the same as in 1986. A comparison of average radionuclide concentrations measured in 1986 and 1987 is presented in Table 9. Although the data suggests a trend towards higher concentration in 1987, there is no statistically significant increase or decrease, with the exception of the plutonium concentrations.

Sludge Application Sites

Direct Radiation Levels

Tables 10 and 11 summarize the direct radiation levels measured on Sites 1 and 2, respectively, before 1987 sludge applications and at successive dates following the applications. Radiation levels measured before sludge application averaged 3 to 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. (Note: Phosphate fertilizers contain natural uranium at low concentrations.) 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 14.6 to 16.7 μR/h. At surface contact the changes in exposure and dose rates were 14.8 to 17.8 μR/h and 29.7 to 38.9 μrad/h, respectively. By November, the radiation levels had decreased to levels similar to those measured before the sludge application in May.

Direct radiation levels on Site 2 after sludge applications also increased. The average exposure rate at one meter above the surface increased from 15.0 to 16.8 μR/h. Exposure rate and dose rate averages at surface contact increased from 14.6 to 17.6 μR/h and 27.2 to 37.9 μrad/h, respectively. Direct radiation levels increased in November. The reason for this increase is not known; however, an increased concentration of Co-60 was noted in the soil samples collected at that time (see below), suggesting two possibilities. The sites were selected to encompass 100 m^2, within the area nine random spots are selected for soil sampling. Since the site is non-homogeneous in nature, the sampling process may have been randomly chosen in an area which had elevated concentrations. An additional possibility would include additional sludge applications, although this is not considered likely.

Radionuclide Concentrations in Soil

Radionuclide concentrations, measured in the upper 15 cm of the soil, at the study sites are presented in Tables 12 and 13. In 1986, 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.[1] 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.

In May 1987, prior to sludge application, the Co-60 concentration was 0.5 pCi/g and the Cs-137 concentration was 0.4 pCi/g, in the upper 15 cm of soil. Strontium 89 and Sr-90 concentrations were 1.7 pCi/g and 0.3 pCi/g, respectively. Other radionuclides were below measurement sensitivities, or at typical naturally occurring levels. Following sludge application Mn-54, Co-60, Sr-89, Sr-90, Cs-134 and Cs-137 concentrations were elevated. Table 14 presents the radionuclide distribution throughout the upper 15 cm of soil at Site 1 after sludge application. The highest levels of concentration are in the top 2.5 cm of soil and drop rapidly to baseline levels within the 7.5-15 cm fraction. By November the Co-60 concentration in the upper 15 cm of soil at Site 1 had diminished to 0.7 pCi/g, Mn-54 had decreased to 0.1 pCi/g and Cs-137 and Cs-134 had returned to pre-application levels. This situation with time and depth was typical of both sites.

In 1986, 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.[1] 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 2.5-7.5 cm depth.

Radionuclide concentrations measured on Site 2 in 1987 indicated that Co-60 levels continued to drop to 0.7 pCi/g, in July, prior to sludge application. All other radionuclide concentrations were comparable with typical soil concentrations measured in area soils. Following sludge application in July 1987, Co-60 and Cs-137 concentrations were slightly elevated. By November Co-60 concentrations had increased to 2.3 pCi/g and the Cs-137 concentration was 1.0 pCi/g. In addition, Mn-54 increased from <0.1 pCi/g in July to 0.4 pCi/g in November. The additional increase in radionuclide concentration between July and November is unexplained but suggests non-homogeneity of the soil concentrations or possible subsequent sludge applications.

Radionuclide Concentrations in Vegetation

Radionuclide concentrations, measured in two forage samples collected from Site 2 in May and June, 1987, are presented in Table 15. For all but one of the principal radionuclides of concern, the measured concentrations are comparble to or less than the concentrations, calculated on the basis of soil levels and literature uptake factors. The concentrations of Sr-90, measured in the two samples, were 65 and 39 pCi/kg; for comparison, the calculated concentrations (Appendix C) was 6.8 pCi/kg. Although the calculated and measured samples were in relatively good agreement, the measured concentrations were based on only two samples of forage. It was therefore decided that the calculated values would be used for dosimetry purposes.

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 general 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.[3-8] 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 1987 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	5.8 mrem
Kidneys	4.2 mrem
Lung	3.8 mrem
Red Marrow	3.8 mrem
Effective	3.6 mrem

Over half of the dose equivalents were due to external, direct radiation.

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	4.9 mrem
Kidneys	2.3 mrem
LLI Wall	0.3 mrem
Effective	0.3 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	1.3 mrem
Kidneys	0.6 mrem
Effective	0.14 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 0.54 person-rem.

DISCUSSION

Interstate Nuclear Services

A review of the discharge records from INS indicates compliance with 10 CFR 20.303. The total activity reported by INS as discharged to the sanitary sewer, October 1986 through September 1987, was approximately 204 mCi. Based on the 1986 comparison of ORAU isotopic analyses with INS gross analyses, the INS values may be overestimating discharged activity by a factor of approximately 2.9^{8}; the recalculated discharge would be 70.3 mCi for this time period. The

total volume of sludge withdrawn from the Treatment Facility during the same time period was 9.3 x 10^5 liters; the average total concentration in the sludge, determined by ORAU, was about 1.02 E5 pCi/l. This results in a total activity of 94.9 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 reasonable 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 all three wastewater facilities were comparable to background levels, with the exception of the openings (2) to the Imhoff tanks (secondary digestors) at the Royersford Facility. 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 of exposure per day which would result in approximately 0.2 mrem per year. Direct exposure resulting from radionuclide concentrations in the Royersford wastewater treatment facility is negligible.

Concentrations of gross alpha and gross beta measured in the influent to the wastewater treatment facilities do not differ markedly. Effluent water from the Royersford Facility was slightly elevated in gross alpha and gross beta concentrations.

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.

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	3.6 mrem
Child (Soil)	0.3 mrem
Child (Milk)	0.14 mrem
Population Dose	0.54 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 3.6% of the recommended dose equivalent commitment, under the assumptions used in the analyses. This does not differ significantly from the 4% value, determined from the 1986 Phase I assessment.[1] Doses commitments for the other scenarios are approximately one-half, or less, of the 1986 calculated levels.

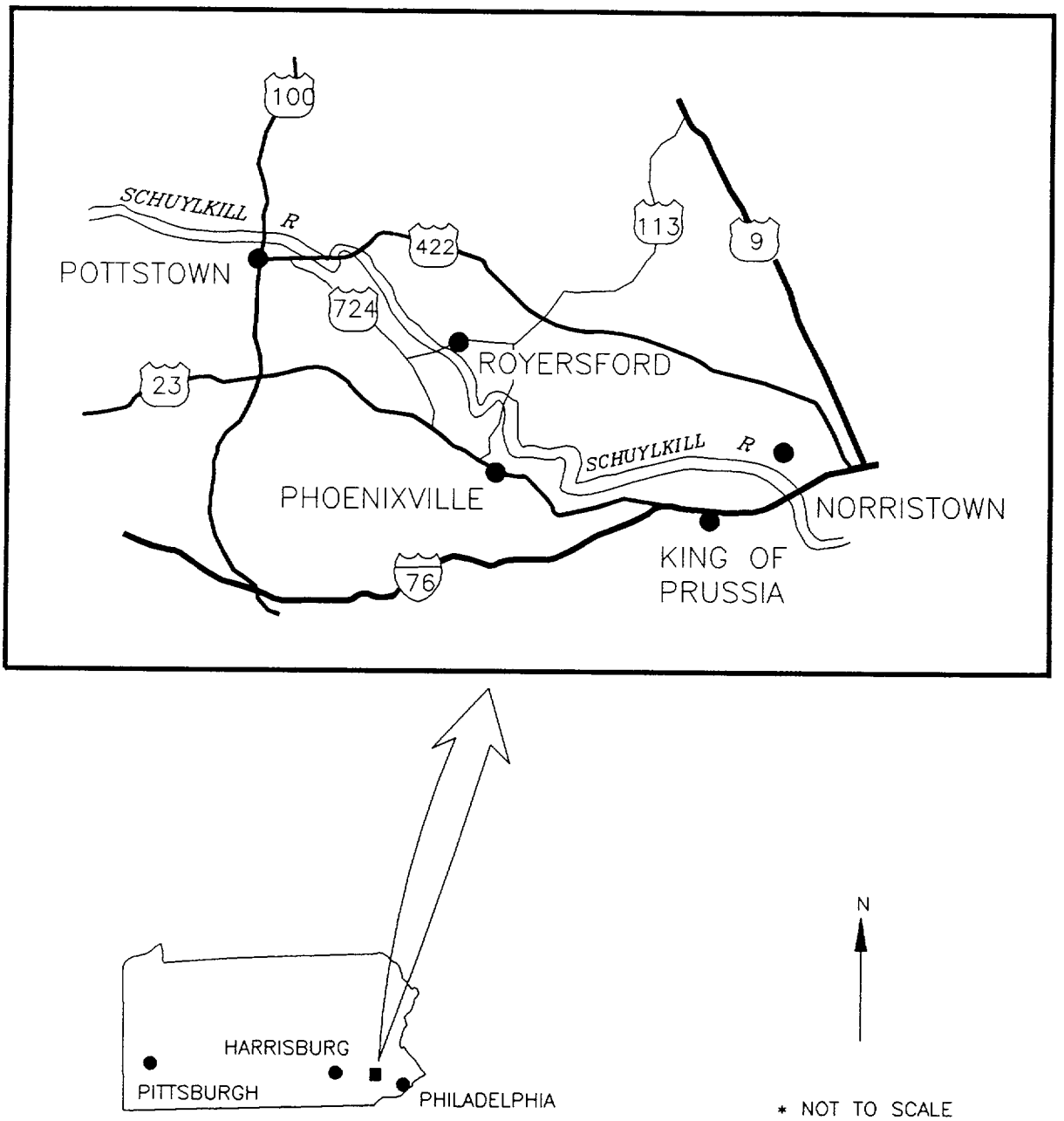

FIGURE 1: Map of Pennsylvania Indicating Location of the Borough of Royersford

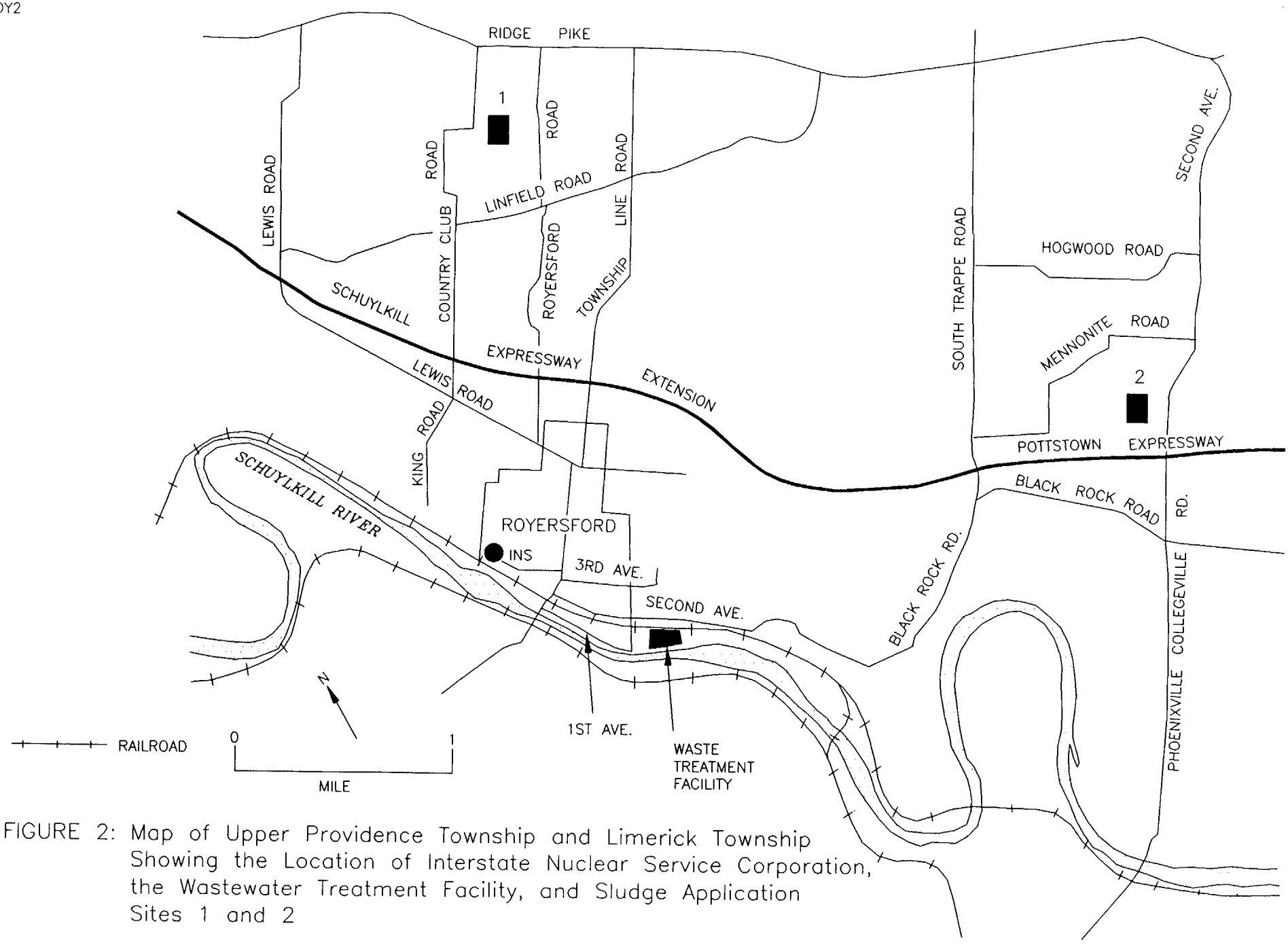

FIGURE 2: Map of Upper Providence Township and Limerick Township Showing the Location of Interstate Nuclear Service Corporation, the Wastewater Treatment Facility, and Sludge Application Sites 1 and 2

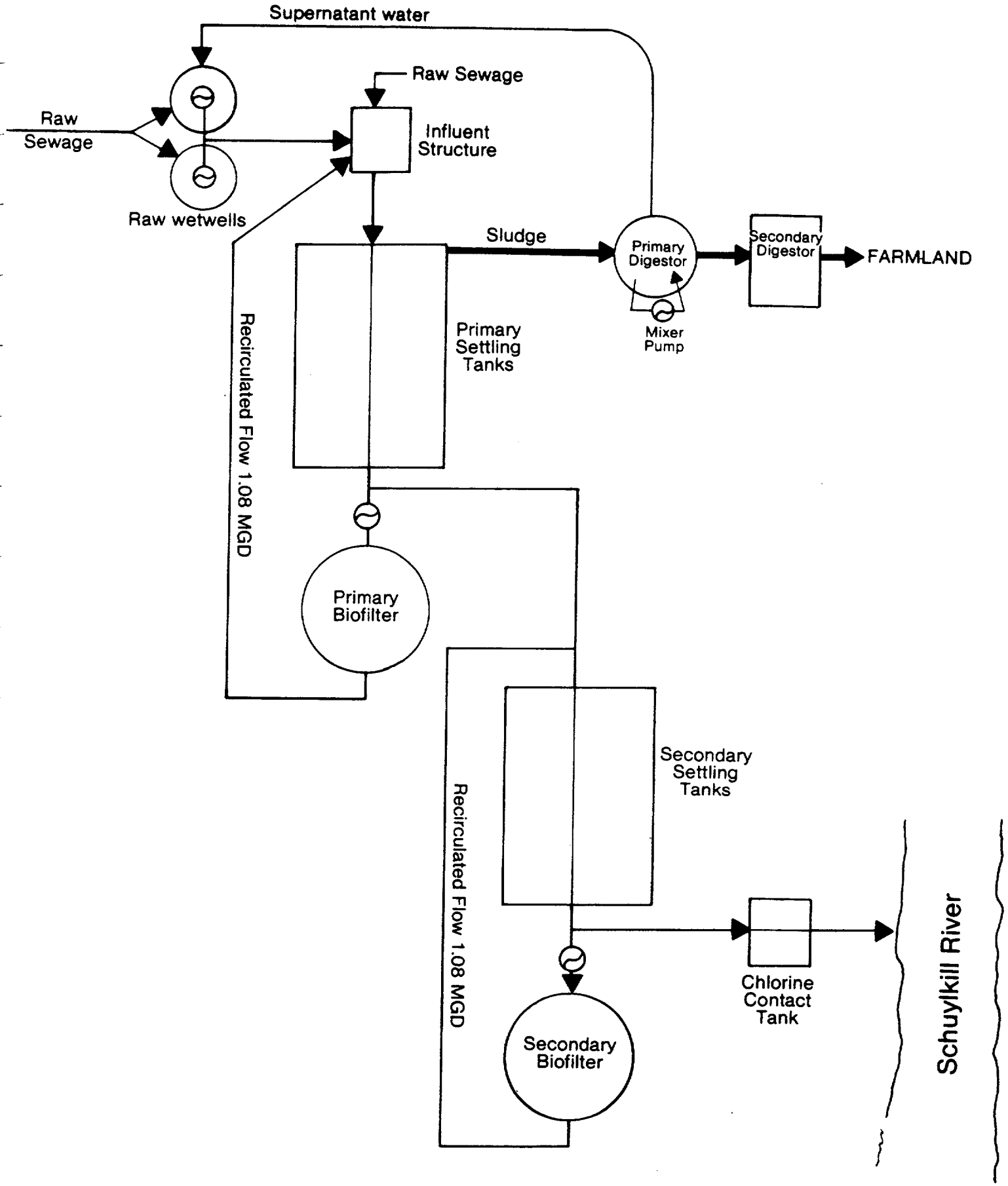

FIGURE 3: Flow Diagram of the Royersford Wastewater Treatment Facility

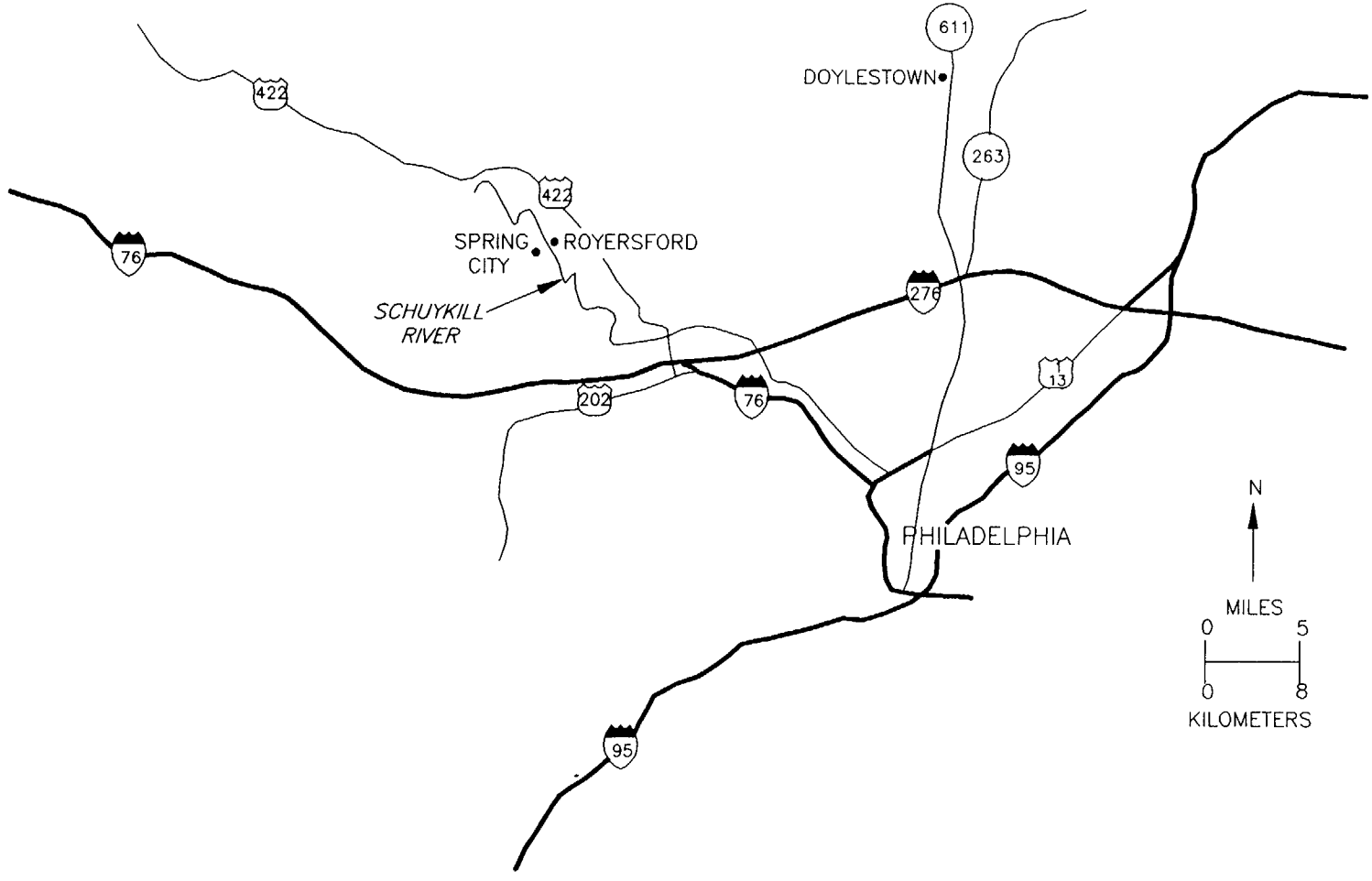

FIGURE 4: Location of Royersford Baseline Sewage Treatment Plants

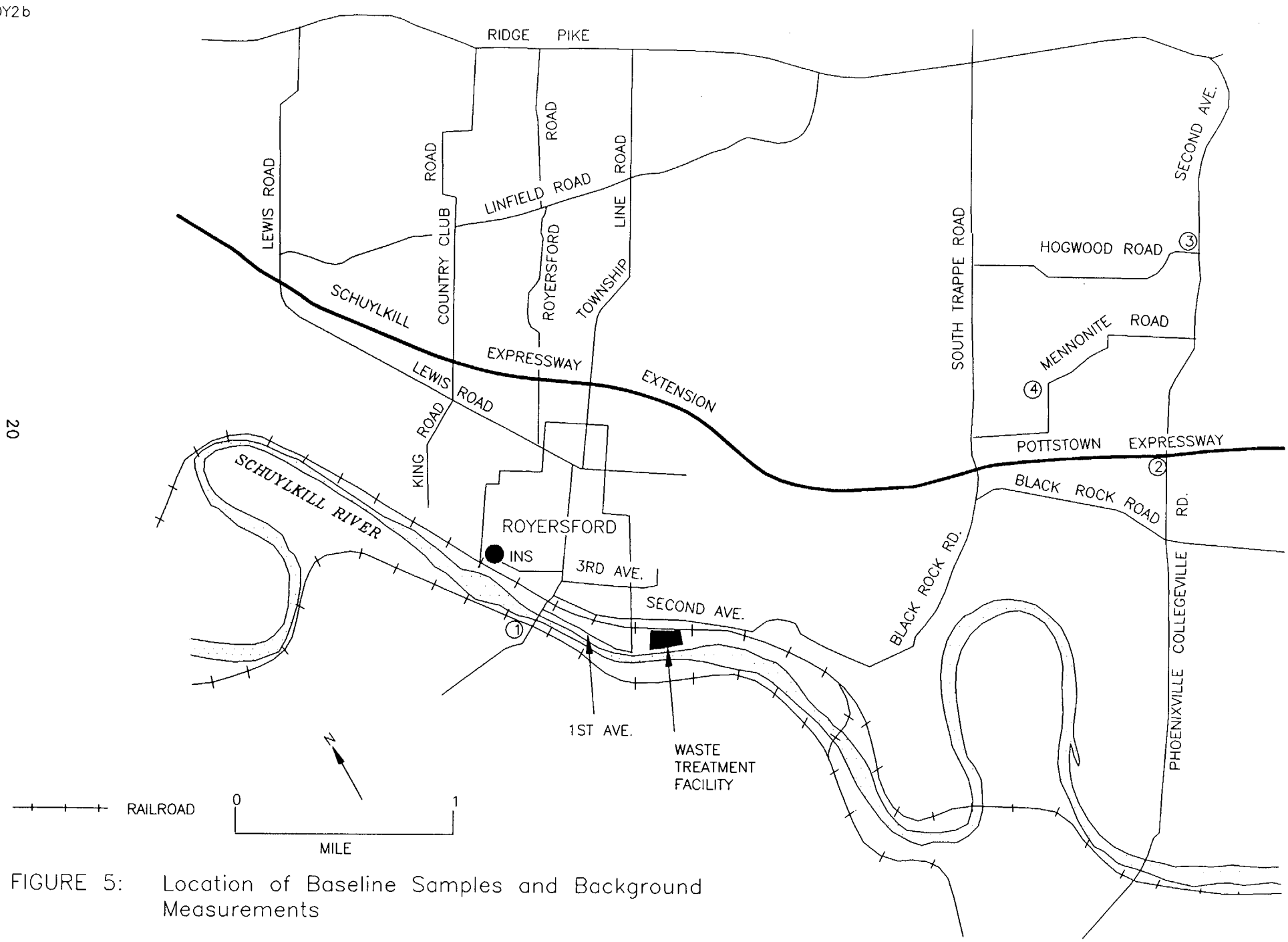

FIGURE 5: Location of Baseline Samples and Background Measurements

TABLE 1

DIRECT RADIATION LEVELS MEASURED AT BASELINE SAMPLE LOCATIONS
ROYERSFORD, PENNSYLVANIA[a]

Location[b]	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	c	c	c

[a]1986 data; see reference 8.
[b]Refer to Figure 5.
[c]No data collected.

TABLE 2

RADIONUCLIDE CONCENTRATIONS (pCi/g) IN BACKGROUND SOIL, SEDIMENT AND VEGETATION
ROYERSFORD, PENNSYLVANIA[a]

Radionuclide	Location 1[b]		Location 2[b]	Location 3[b]		Location 4[b]	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	c	c	c	c	c	c	<0.1
Sr-90	<0.5	<0.3	0.5 ± 0.6[d]	<0.4	<0.4	<0.4	0.2 ± 0.1
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	0.1 ± 0.1
U-234	2.3 ± 0.2	2.4 ± 0.2	1.7 ± 0.2	2.0 ± 0.2	1.8 ± 0.2	2.1 ± 0.2	c
U-235	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	c
U-238	1.9 ± 0.9	2.2 ± 0.2	1.7 ± 0.2	1.6 ± 0.2	1.5 ± 0.2	1.9 ± 0.2	c
Pu-238	<0.1	0.1 ± 0.1	<0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	c
Pu-239/240	<0.1	0.1 ± 0.1	<0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	c

[a]1986 Data; reference 8.
[b]Refer to Figure 5.
[c]Analysis not performed.
[d]Uncertainties represent the 95% confidence level, based only on counting statistics; additional laboratory uncertainties of ± 6 to 10% have not been propagated into these data.

TABLE 3

RADIONUCLIDE CONCENTRATIONS MEASURED IN BASELINE WATER SAMPLES ROYERSFORD, PENNSYLVANIA[a]

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

[a]1986 Data; reference 8.
[b]Refer to Figure 5.
[c]Water not available for sampling.
[d]Uncertainties represent the 95% confidence level, based only on counting statistics; additional laboratory uncertainties of ± 6 to 10% have not been propagated into these data.

TABLE 4

LIQUID EFFLUENT DISCHARGES FROM
INTERSTATE NUCLEAR SERVICES DURING
OCTOBER 1986 THROUGH SEPTEMBER 1987
ROYERSFORD, PENNSYLVANIA

Month	Volume ($\times 10^6$ l)	Activity discharged (mCi)	
		Gross Alpha	Gross Beta
10/86	1.26	0.050	14.17
11/86	1.27	0.052	25.86
12/86	1.33	0.053	22.19
1/87	1.30	0.062	22.58
2/87	1.47	0.073	19.11
3/87	1.36	0.065	20.64
4/87	1.56	0.079	25.45
5/87	1.57	0.069	16.68
6/87	1.53	0.067	6.23
7/87	1.21	0.051	6.94
8/87	1.51	0.061	11.64
9/87	1.65	0.072	12.03
TOTAL	1.70×10^7	0.754	203.52

Data summarized from records provided by INS.

TABLE 5

DIRECT RADIATION LEVELS MEASURED AT
WASTEWATER TREATMENT FACILITIES
IN THE ROYERSFORD AREA

Treatment Plant	Measurement Locations	Gamma Exposure Rates at 1 m Above the Surface (μR/h)	Gamma Exposure Rates at the Surface (μR/h)
Spring City	Basement Pump Room	8	9
	Influent Area	11	12
	Effluent Area	10	9
	Trickling Filter	---[a]	10
	Drying Bed	---	11
Doylestown	Effluent Area	9	8
	Influent Area	11	11
	Filters	9	---
	Digestor	10	9
	Settling Ponds	10	8
Royersford	East Imhoff Tank	300	470
	West Imhoff Tank	240	---
	General Facility	7-17[b]	9-18[b]

[a]Dash indicates measurement not performed.
[b]1986 data; reference 8.

TABLE 6

COMPARISON OF RADIONUCLIDE CONCENTRATIONS IN WATER SAMPLES
COLLECTED FROM THREE AREA WASTE TREATMENT PLANTS
PENNSYLVANIA[a]

RADIONUCLIDE	CONCENTRATION (pCi/l)					
	INFLUENT			EFFLUENT		
	SPRING CITY	DOYLESTOWN	ROYERSFORD	SPRING CITY	DOYLESTOWN	ROYERSFORD
gross alpha	2.2 ± 2.2[b]	1.1 ± 1.2	2.8 ± 1.2	0.3 ± 1.2	1.0 ± 1.1	5.3 ± 1.7
gross beta	7.9 ± 3.4	9.3 ± 2.0	12.4 ± 2.0	8.8 ± 2.3	5.6 ± 1.8	22.5 ± 6
H-3	<320	<320	<320	<320	<320	<320
Cr-51	<220[c]	<220[c]	<270[c]	<280[c]	<270[c]	<300[c]
Mn-54	<2.5	3.4 ± 4.3	<3.0	<2.9	<2.9	7.6 ± 6.4
Co-58	<5.2	<5.7	<6.3	<6.6	<5.9	33 ± 13
Fe-59	<19	<17	<19	<20	<22	<21
Co-60	6.5 ± 5.0	<2.2	<2.9	<2.7	5.3 ± 5.8	39.5 ± 6.7
Zn-65	<5.7	<5.6	<6.2	<6.4	<6.1	<7.4
Sr-89	<0.5	<0.5	<0.5	<0.7	<0.6	4.0 ± 1.5
Sr-90	<0.6	<0.6	<0.6	<0.8	<0.7	3.4 ± 0.2
Zr-95	<10	<10	<12	<12	<12	<13
Nb-95	<15	<15	<18	<20	<19	<18
Ag-110m	<2.4	<2.5	<2.9	<2.8	<27	<3.2
Sb-125	<6.0	<6.0	<7.0	<6.9	<7.1	<8.5
Cs-134	<2.0	<2.1	<2.2	<2.2	<2.3	71.8 ± 5.4
Cs-137	<2.1	<2.3	5.2 ± 5.2	3.5 ± 4.3	6.4 ± 4.9	230 ± 10
U-234	7.0 ± 2.5	4.0 ± 1.0	12.4 ± 2.0	3.9 ± 0.9	2.2 ± 1.1	2.0 ± 0.9
U-235	0.4 ± 0.4	0.1 ± 0.2	0.6 ± 0.5	0.1 ± 0.1	0.2 ± 0.6	0.4 ± 0.5
U-238	0.9 ± 0.6	1.9 ± 0.7	11.5 ± 2.0	1.3 ± 0.5	0.8 ± 0.8	1.7 ± 0.8
Pu-238	0.1 ± 0.1	0.1 ± 0.2	<0.1	<0.1	0.1 ± 0.3	0.1 ± 0.2
Pu-239	<0.1	0.1 ± 0.2	0.1 ± 0.2	0.1 ± 0.2	0.3 ± 0.5	0.1 ± 0.1

[a]Figure 4.

[b]Uncertainties represent 95% confidence level based only on counting statistics; additional analytical uncertainties of ± 6 to 10% have not been propagated into these data.

[c]Poor sensitivity is the result of greater than 3 half-lives decay time between sample collection and analysis. All data have been decay-corrected to the collection time.

TABLE 7

COMPARISON OF RADIONUCLIDE CONCENTRATIONS IN SLUDGE
FROM THREE AREA WASTE TREATMENT PLANTS
PENNSYLVANIA[a]

Radionuclide	Concentration (pCi/l)				
	SPRING CITY	DOYLESTOWN	ROYERSFORD (Primary Digestor)	ROYERSFORD (East Imhoff Tank)	ROYERSFORD (West Imhoff Tank)
H-3	<900	<900	<900	<900	<900
Cr-51	<310[b]	<250[b]	<380[b]	<2200[b]	<2200[b]
Mn-54	<3.0	6.0 ± 4.5[c]	367 ± 16	5640 ± 90	10720 ± 100
Co-58	<6.5	<5.8	59 ± 22	250 ± 130	600 ± 130
Fe-59	<22	<22	<44	<360	<310
Co-60	8.7 ± 6.4	6.5 ± 4.9	1049 ± 24	88220 ± 220	60480 ± 190
Zn-65	<6.4	<5.8	297 ± 35	5540 ± 220	8200 ± 200
Sr-89	<14	<15	21.2 ± 16.4	768 ± 83	58 ± 54
Sr-90	8.2 ± 1.1	7.4 ± 1.0	181.4 ± 6.3	2939 ± 36	3724 ± 26
Zr-95	<14	<12	<19	<150	<130
Nb-95	<22	<18	<31	508 ± 46	670 ± 45
Ag-110m	<2.8	<2.6	<5.6	640 ± 370	760 ± 310
Sb-125	<7.5	<6.2	<12	650 ± 110	980 ± 120
Cs-134	<2.4	<2.2	92 ± 10	1091 ± 31	1514 ± 36
Cs-137	9.8 ± 5.2	2.8 ± 4.0	692 ± 15	14250 ± 70	17790 ± 80
U-234	50 ± 13	129 ± 8	24.4 ± 4.3	448 ± 27	388 ± 18
U-235	5.3 ± 4.7	3.9 ± 1.5	1.5 ± 1.2	19.2 ± 6.4	8.6 ± 3.1
U-238	43 ± 12	62.0 ± 5.5	11.2 ± 2.9	212 ± 20	192 ± 13
Pu-238	0.1 ± 0.4	0.2 ± 0.4	0.4 ± 0.4	25.7 ± 3.1	1.2 ± 1.0
Pu-239	0.1 ± 0.4	0.1 ± 0.5	0.9 ± 0.6	48.7 ± 4.2	50.0 ± 6.8

[a]Refer to Figure 4.

[b]Poor sensitivity is the result of greater than 3 half-lives decay time between sample collection and analysis. All data have been decay-corrected to the collection time.

[c]Uncertainties represent 95% confidence interval based only on counting statistics; additional analytical uncertainties of ± 6 to 10% have not been propagated into these data.

TABLE 8

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

Radionuclide	DATES (1987) 3/30	3/30	5/13	5/14	6/15	6/15
	Radionuclide Concentrations (pCi/l)					
H-3	1600 ± 1200[a]	1600 ± 1200	800 ± 1200	800 ± 1200	800 ± 1200	<870
Cr-51	<45000[b]	<51000[b]	<18000[b]	<12000[b]	<8900	<7600
Mn-54	16700 ± 990	23800 ± 1100	23900 ± 1000	12430 ± 720	24500 ± 1000	21380 ± 920
Co-58	<1000	<1600	2800 ± 1200	<540	3100 ± 1000	2970 ± 860
Fe-59	<4550	<5040	<3020	<2030	<1910	<1800
Co-60	53100 ± 1400	69200 ± 1600	93100 ± 1900	46000 ± 1200	99500 ± 1900	90100 ± 1700
Zn-65	10200 ± 1800	12400 ± 1900	13400 ± 1800	7900 ± 1400	12000 ± 1900	12000 ± 1700
Sr-89	256 ± 25	317 ± 29	1593 ± 71	162 ± 45	493 ± 39	2090 ± 110
Sr-90	2164 ± 17	2223 ± 20	6727 ± 34	804.7 ± 1.3	3529 ± 22	4595.2 ± 2.4
Zr-95	<1700	<2000	<1400	<930	<1000	<910
Nb-95	<3500	<4100	<2000	<1300	<1100	<910
Ag-110m	<450	<520	<520	<370	<490	<460
Sb-125	<580	<690	<710	<500	<770	<680
Cs-134	1390 ± 410	2610 ± 570	2590 ± 470	1450 ± 370	2950 ± 570	2780 ± 530
Cs-137	13870 ± 710	20390 ± 850	26180 ± 890	13770 ± 690	27480 ± 990	24100 ± 850
U-234	171.0 ± 8.8	403 ± 14	415 ± 16	278 ± 11	329 ± 14	354 ± 11
U-235	83.1 ± 6.3	12.8 ± 3.6	14.4 ± 3.4	11.5 ± 2.4	13.5 ± 3.2	13.6 ± 2.5
U-238	4.7 ± 1.6	106.9 ± 7.4	185 ± 11	128.3 ± 7.1	157.5 ± 9.6	169.3 ± 7.6
Pu-238	12.9 ± 3.1	14.2 ± 2.3	17.2 ± 2.5	17.9 ± 2.3	15.1 ± 2.1	16.8 ± 2.1
Pu-239/240	51.5 ± 6.1	75.2 ± 5.2	76.2 ± 5.2	69.3 ± 4.6	60.3 ± 4.2	98.6 ± 5.1
Total	9.96 E4	1.33 E5	1.72 E5	8.38 E4	1.75 E5	1.61 E5

TABLE 8 (Continued)

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

Radionuclide	DATES (1987) 6/19	6/26	6/26	6/29	7/13	7/20
	Radionuclide Concentrations (pCi/l)					
H-3	800 ± 1200	<870	<870	<870	<870	1600 ± 1200
Cr-51	<5100	<5100	<4800	<5100	<3700	<2700
Mn-54	14880 ± 780	15780 ± 780	14060 ± 740	16260 ± 840	17630 ± 830	14710 ± 730
Co-58	<460	<470	<430	1700 ± 730	1760 ± 730	1140 ± 590
Fe-59	<1300	<1300	<1200	<1200	<980	<870
Co-60	65800 ± 1500	64600 ± 1400	55900 ± 1400	62200 ± 1500	64800 ± 1600	61800 ± 1400
Zn-65	7900 ± 1500	9600 ± 1400	8000 ± 1200	9600 ± 1600	9100 ± 1400	9400 ± 1400
Sr-89	474 ± 42	220 ± 25	808 ± 44	508 ± 45	246 ± 28	615 ± 61
Sr-90	4762 ± 25	1933 ± 16	5505 ± 28	2599 ± 29	1899 ± 15	2208 ± 31
Zr-95	<670	<690	<660	<690	<650	<520
Nb-95	<660	<680	<630	<670	<520	<400
Ag-110m	<380	<390	<360	<370	<380	<360
Sb-125	<580	<600	<540	<630	<630	<560
Cs-134	1650 ± 390	1650 ± 420	1530 ± 360	1600 ± 420	2370 ± 480	2060 ± 400
Cs-137	16940 ± 730	16860 ± 760	13960 ± 680	17380 ± 770	17200 ± 770	16610 ± 740
U-234	261 ± 10	216 ± 13	221 ± 10	246 ± 11	249 ± 19	275.2 ± 8.2
U-235	7.7 ± 2.0	3.0 ± 1.8	3.7 ± 1.4	6.6 ± 2.0	22.9 ± 6.2	7.9 ± 1.6
U-238	124.4 ± 7.1	110.2 ± 9.6	108.6 ± 7.0	116.5 ± 7.5	148 ± 14	131.2 ± 5.7
Pu-238	14.2 ± 3.9	10.5 ± 4.8	16.1 ± 3.8	23.2 ± 2.3	16.6 ± 3.6	15.1 ± 1.7
Pu-239/240	66.6 ± 8.5	69.7 ± 12	59.1 ± 7.2	96.1 ± 4.6	112.1 ± 9.4	90.9 ± 4.2
Total	1.21 E4	1.11 E5	1.00 E5	1.12 E4	1.16 E5	1.11 E5

TABLE 8 (Continued)

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

Radionuclide	DATES (1987) 7/21	7/21	7/21	7/22	7/22	7/22
	Radionuclide Concentrations (pCi/l)					
H-3	800 ± 1200	800 ± 1200	800 ± 1200	800 ± 1200	<870	2500 ± 1300
Cr-51	<2300	<2800	<3100	<1100	<4000	<2300
Mn-54	12150 ± 640	16110 ± 880	17810 ± 900	2120 ± 330	20760 ± 970	12180 ± 660
Co-58	1240 ± 530	1330 ± 530	<410	<150	<480	<310
Fe-59	<730	<860	<940	<310	<1100	<730
Co-60	47200 ± 1200	60600 ± 1500	79300 ± 1700	8330 ± 550	80200 ± 1700	48500 ± 1400
Zn-65	7200 ± 1200	9400 ± 1400	9100 ± 1500	1490 ± 540	10000 ± 1600	8000 ± 1200
Sr-89	84 ± 16	961 ± 67	877 ± 79	46 ± 13	94 ± 14	677 ± 44
Sr-90	664.2 ± 9.2	2034.9 ± 1.6	1372.9 ± 0.4	345.0 ± 7.4	498.3 ± 7.7	4091 ± 25
Zr-95	<460	<520	<620	<220	<700	<450
Nb-95	<350	<420	<450	<160	<540	<350
Ag-110m	<310	<360	<400	<130	<430	<320
Sb-125	<500	<610	<690	<250	<700	<490
Cs-134	1340 ± 420	2420 ± 460	2100 ± 470	440 ± 160	2580 ± 480	1530 ± 370
Cs-137	13600 ± 650	18370 ± 780	21910 ± 870	2600 ± 310	24470 ± 910	13560 ± 640
U-234	194 ± 15	262 ± 13	404.3 ± 9.3	36.0 ± 3.3	263 ± 11	203.1 ± 9.8
U-235	1.9 ± 1.7	6.2 ± 2.3	12.5 ± 1.8	1.7 ± 0.8	10.7 ± 2.4	4.3 ± 1.6
U-238	89 ± 10	126.6 ± 9.2	123.5 ± 5.1	16.5 ± 2.1	132.4 ± 7.5	101.3 ± 7.0
Pu-238	11.0 ± 1.9	21.2 ± 2.3	14.9 ± 1.6	1.1 ± 0.6	16.5 ± 3.2	13.4 ± 3.1
Pu-239/240	68.3 ± 4.8	136.1 ± 5.8	70.7 ± 3.6	7.0 ± 1.5	81.3 ± 7.0	68.6 ± 7.0
Total	8.46 E4	1.13 E5	1.34 E5	1.62 E4	1.39 E5	2.01 E5

TABLE 8 (Continued)

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

Radionuclide	DATES (1987)					
	7/24	7/28	7/30	7/30	8/7	8/7
	Radionuclide Concentrations (pCi/l)					
H-3	800 ± 1200	1600 ± 1200	800 ± 1200	1600 ± 1200	<900	<900
Cr-51	<2700	<3000	<2000	<1400	<8100[b]	<3100[b]
Mn-54	16790 ± 780	18700 ± 860	9830 ± 670	5160 ± 500	6720 ± 770	1070 ± 260
Co-58	1530 ± 530	<390	2300 ± 730	<210	1040 ± 670	<160
Fe-59	<870	<900	<650	<450	<1400	<530
Co-60	72400 ± 1600	81400 ± 1700	42200 ± 1200	22300 ± 890	27300 ± 1000	4780 ± 420
Zn-65	9900 ± 1600	11900 ± 1500	6900 ± 1300	3290 ± 770	3700 ± 1000	620 ± 420
Sr-89	1025 ± 53	230 ± 43	44 ± 14	55 ± 18	500 ± 70	<61
Sr-90	7014 ± 32	4893 ± 35	460.9 ± 8.9	501.5 ± 8.0	1180 ± 12	1875 ± 21
Zr-95	<550	<610	<430	<280	<590	<260
Nb-95	<410	<430	<300	<220	<870	<370
Ag-110m	<390	<420	<300	<220	450 ± 210	<80
Sb-125	<610	<710	<500	<370	930 ± 640	<150
Cs-134	2640 ± 450	2530 ± 500	1240 ± 340	590 ± 230	680 ± 300	180 ± 150
Cs-137	19900 ± 820	23640 ± 910	11000 ± 630	6820 ± 490	8550 ± 460	1610 ± 210
U-234	224.4 ± 9.0	390 ± 14	188.6 ± 8.1	76.7 ± 5.9	115.7 ± 7.6	40.9 ± 4.0
U-235	7.8 ± 1.9	14.0 ± 3.0	5.8 ± 1.6	3.6 ± 1.4	13.7 ± 3.2	1.0 ± 0.7
U-238	110.6 ± 6.3	143.6 ± 8.5	86.4 ± 5.5	32.3 ± 3.8	57.6 ± 5.3	21.8 ± 2.9
Pu-238	14.2 ± 2.9	13.6 ± 2.9	8.8 ± 2.3	4.8 ± 1.8	3.2 ± 1.0	2.5 ± 0.9
Pu-239/240	82.6 ± 7.0	85.3 ± 7.2	56.1 ± 5.8	14.1 ± 3.1	21.3 ± 2.7	3.5 ± 1.1
Total	1.32 E5	1.34 E5	7.51 E4	4.04 E4	5.13 E4	1.02 E4

TABLE 8 (Continued)

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

Radionuclide	DATES (1987) 8/7	8/12	8/12	8/12	8/14	8/14
	Radionuclide Concentrations (pCi/l)					
H-3	<900	<900	<900	<900	<900	<900
Cr-51	<13000[b]	<7700[b]	<10000[b]	<210[b]	<11000[b]	<7000[b]
Mn-54	17370 ± 740	14890 ± 790	13970 ± 670	340 ± 150	18730 ± 920	5390 ± 520
Co-58	2900 ± 1100	14840 ± 920	1400 ± 940	<84	1600 ± 1100	<350
Fe-59	<2000	<1500	<1900	<340	<2100	<1200
Co-60	75300 ± 1600	65900 ± 1500	72300 ± 1500	1740 ± 250	78900 ± 1700	2800 ± 1000
Zn-65	11900 ± 1700	9200 ± 1600	9900 ± 1500	<160	12000 ± 1800	4000 ± 1100
Sr-89	2820 ± 140	<38	340 ± 120	143 ± 29	1770 ± 190	955 ± 64
Sr-90	4244 ± 24	5288 ± 32	4087 ± 26	136.5 ± 4.0	570 ± 36	566.0 ± 8.8
Zr-95	<940	<740	<900	<180	<990	1600 ± 1300
Nb-95	<1300	<900	<1100	<200	<1200	<730
Ag-110m	1110 ± 390	1150 ± 290	690 ± 290	<44	840 ± 320	410 ± 210
Sb-125	2300 ± 1300	<500	600 ± 860	<110	1500 ± 1000	<350
Cs-134	2400 ± 280	1620 ± 370	1830 ± 370	100 ± 170	1840 ± 490	590 ± 270
Cs-137	19810 ± 660	18250 ± 630	17170 ± 620	640 ± 150	19890 ± 710	6530 ± 410
U-234	253.8 ± 7.5	296.5 ± 9.5	264.0 ± 9.8	29.9 ± 3.5	310 ± 24	72.6 ± 5.2
U-235	7.8 ± 1.5	16.1 ± 2.5	6.7 ± 1.7	1.0 ± 0.8	8.4 ± 4.2	3.0 ± 1.2
U-238	120.6 ± 5.1	147.0 ± 6.8	125.7 ± 6.7	6.9 ± 1.7	161 ± 16	36.4 ± 3.7
Pu-238	14.4 ± 2.1	9.1 ± 2.4	1.9 ± 0.8	<0.2	9.6 ± 2.0	20.6 ± 2.6
Pu-239/240	82.0 ± 5.0	46.8 ± 5.5	17.6 ± 2.3	<0.2	46.7 ± 4.4	64.7 ± 4.6
Total	1.41 E5	1.32 E5	1.23 E5	3.14 E3	1.38 E5	2.30 E4

TABLE 8 (Continued)

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

Radionuclide	DATES (1987) 8/14	8/18	8/18	8/20	8/20	8/20
	Radionuclide Concentrations (pCi/l)					
H-3	<900	<900	<900	<900	<900	<900
Cr-51	<1000[b]	<9800[b]	<10000[b]	<9000[b]	<6000[b]	<11000[b]
Mn-54	15480 ± 730	16550 ± 730	18650 ± 940	18510 ± 930	6560 ± 550	19000 ± 1000
Co-58	2070 ± 900	1600 ± 1000	1500 ± 1000	1560 ± 840	<340	1200 ± 1100
Fe-59	<1700	<1800	<1900	<1800	<1200	<2100
Co-60	66900 ± 1500	79900 ± 1700	75100 ± 1700	81800 ± 1600	33400 ± 1100	103200 ± 1900
Zn-65	10300 ± 1700	10400 ± 1600	11500 ± 1700	10800 ± 1700	4400 ± 1200	11900 ± 2100
Sr-89	<38	<34	1030 ± 110	2040 ± 120	300 ± 140	<34
Sr-90	4079 ± 26	9474 ± 38	4492 ± 26	4539 ± 24	3855 ± 32	6162 ± 32
Zr-95	<890	<890	<900	<880	<530	<1000
Nb-95	<1100	<1100	<1200	<1000	<710	<1200
Ag-110m	940 ± 330	800 ± 340	600 ± 350	1370 ± 330	390 ± 190	480 ± 440
Sb-125	800 ± 840	930 ± 870	1700 ± 1100	<550	<350	1900 ± 1100
Cs-134	1510 ± 380	1790 ± 450	2050 ± 440	2180 ± 430	720 ± 260	2560 ± 370
Cs-137	17360 ± 620	20620 ± 670	20830 ± 730	20200 ± 660	8860 ± 440	22850 ± 780
U-234	270 ± 10	329 ± 16	284 ± 29	283.6 ± 7.9	194.8 ± 9.7	409 ± 18
U-235	8.4 ± 2.0	28.6 ± 6.0	5.9 ± 4.8	9.2 ± 1.6	6.8 ± 2.0	27.3 ± 5.8
U-238	137.7 ± 7.2	180 ± 12	152 ± 21	132.7 ± 5.4	86.7 ± 6.4	208 ± 13
Pu-238	9.4 ± 1.8	17.6 ± 3.1	19.7 ± 3.1	10.4 ± 2.9	5.2 ± 1.7	16.6 ± 2.7
Pu-239/240	46.7 ± 4.1	107.3 ± 7.6	71.0 ± 5.8	56.6 ± 6.7	47.4 ± 5.1	114.8 ± 7.2
Total	1.20 E5	1.43 E5	1.38 E5	1.43 E5	5.88 E4	1.70 E5

TABLE 8 (Continued)

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

Radionuclide	DATES (1987) 8/24	8/26	9/3	9/3	9/4	Batch Average
	Radionuclide Concentrations (pCi/l)					
H-3	<900	<900	<900	<900	<900	c
Cr-51	<6500	<6900	<2200	<3000	<1200	c
Mn-54	7490 ± 610	14270 ± 810	1170 ± 250	1020 ± 360	310 ± 140	c
Co-58	<360	1120 ± 780	240 ± 180	<220	<69	c
Fe-59	<1200	<1500	<490	<710	<240	c
Co-60	38100 ± 1200	67500 ± 1500	5750 ± 450	17370 ± 780	1520 ± 250	55000
Zn-65	4600 ± 1400	7600 ± 1500	990 ± 460	1500 ± 1100	850 ± 370	c
Sr-89	757 ± 72	2550 ± 130	79 ± 28	28 ± 47	<24	c
Sr-90	1955 ± 16	6048 ± 30	344.1 ± 6.8	524 ± 11	79.7 ± 3.1	3400
Zr-95	<610	<730	<230	<390	<110	c
Nb-95	<700	<880	<250	<390	<110	c
Ag-110m	<200	720 ± 300	<87	<120	<39	c
Sb-125	1600 ± 540	1710 ± 950	<160	<260	<77	c
Cs-134	890 ± 320	1460 ± 390	210 ± 160	240 ± 220	115 ± 61	c
Cs-137	10290 ± 660	18580 ± 630	1680 ± 280	3320 ± 340	560 ± 140	18000
U-234	118.0 ± 5.8	7.6 ± 4.2	28.7 ± 5.5	95.0 ± 6.7	8.1 ± 5.0	26.0
U-235	2.3 ± 0.9	0.8 ± 1.5	2.1 ± 1.7	4.2 ± 1.5	1.0 ± 2.0	9.9
U-238	54.9 ± 4.0	0.6 ± 1.2	9.4 ± 3.2	42.7 ± 4.4	0.9 ± 1.6	120
Pu-238	0.5 ± 0.6	12.9 ± 3.4	0.8 ± 0.5	4.1 ± 1.2	<0.2	13
Pu-239/240	12.5 ± 2.8	69.1 ± 7.8	5.3 ± 1.4	3.6 ± 1.2	0.3 ± 0.3	69
Total	5.84 E4	1.22 E5	1.05 E4	2.41 E4	3.45 E3	1.02 E5

[a]Uncertainties represent 95% confidence interval based only on counting statistics; additional analytical uncertainties of ± 6 to 10% have not been propagated into these data.

[b]Poor sensitivity is the result of greater than 3 half-lives decay time between sample collection and analysis. All data have been decay-corrected to the collection time.

[c]Average not determined.

TABLE 9

COMPARISON OF AVERAGE RADIONUCLIDE CONCENTRATIONS IN SLUDGE SAMPLES COLLECTED DURING 1986 AND 1987 ROYERSFORD, PENNSYLVANIA

	1986 (pCi/l)	1987 (pCi/l)
Co-60	55000 ± 200	55000 ± 200
Sr-90	2300 ± 40	2900 ± 4
Cs-137	15000 ± 100	18000 ± 100
U-234	260 ± 2	260 ± 2
U-235	10 ± 0.5	9.9 ± 0.4
U-238	100 ± 1	120 ± 1
Pu-238	6.6 ± 0.3	12 ± 0.4
Pu-239/240	12.7 ± 0.4	60 ± 0.9

TABLE 10

DIRECT RADIATION LEVELS AT SITE 1
ROYERSFORD, PENNSYLVANIA

Measurement	Dates (1987)				
	May 13 before application	May 13 after application	June 25	July 23	November 10
Exposure Rate at 1 m above surface					
Range (μR/h)	13-15	15-19	10-17	12-15	13-15
Average (μR/h)	14.6	16.7	12.8	13.4	14.2
Exposure Rate at surface contact					
Range (μR/h)	13-19	15-21	10-18	12-17	13-15
Average (μR/h)	14.8	17.8	13.4	13.2	14.2
Beta-Gamma Dose Rate at Surface					
Range (μrad/h)	15-41	31-47	21-41	16-35	---[a]
Average (μrad/h)	29.7	38.9	29.7	26.1	---

[a]Dash indicates measurement not performed.

TABLE 11

DIRECT RADIATION LEVELS AT SITE 2
ROYERSFORD, PENNSYLVANIA

Measurement	Dates (1987)				
	May 13	June 24	July 23 before application	July 23 after application	November 10
Exposure Rate at 1 m above surface					
Range (μR/h)	13-19	13-17	12-17	14-19	15-23
Average (μR/h)	15.4	14.9	15.0	16.8	19.7
Exposure Rate at surface contact					
Range (μR/h)	13-19	12-17	12-18	15-22	15-23
Average (μR/h)	16.1	14.8	14.6	17.6	20.4
Beta-Gamma Dose Rate at Surface					
Range (μrad/h)	16-44	22-37	15-42	25-52	---[a]
Average (μrad/h)	28.4	26.2	27.2	37.9	---

[a]Dash indicates measurement not performed.

TABLE 12

RADIONUCLIDE CONCENTRATIONS IN THE UPPER 15 CM OF SOIL
SITE 1
ROYERSFORD, PENNSYLVANIA

Radionuclide	Concentration (pCi/g)				
	5/13/87 (before application)	5/13/87 (after application)	6/25/87	7/23/87	11/10/87
Cr-51	<0.3	<0.3	<0.4	<0.2	<0.4
Mn-54	<0.1	0.3 ± 0.1[a]	0.2 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Co-58	<0.1	<0.1	<0.1	<0.1	<0.1
Fe-59	<0.1	<0.1	<0.1	<0.1	<0.1
Co-60	0.5 ± 0.1	1.0 ± 0.2	0.9 ± 0.2	1.1 ± 0.2	0.7 ± 0.2
Zn-65	<0.1	<0.1	<0.1	<0.1	<0.1
Sr-89	1.7 ± 0.3	2.5 ± 0.3	<0.1	---[b]	<0.1
Sr-90	0.3 ± 0.1	1.5 ± 0.1	<0.1	---	<0.1
Zr-95	<0.1	<0.1	<0.1	<0.1	<0.1
Nb-95	<0.1	<0.1	<0.1	<0.1	<0.1
Ag-110m	<0.1	<0.1	<0.1	<0.1	<0.1
Sb-125	<0.1	<0.1	<0.1	<0.1	<0.1
Cs-134	<0.1	0.2 ± 0.2	<0.1	<0.1	<0.1
Cs-137	0.4 ± 0.1	0.6 ± 0.1	0.5 ± 0.3	0.5 ± 0.1	0.5 ± 0.2
U-234	2.3 ± 0.3	1.8 ± 0.2	0.5 ± 0.2	---	1.8 ± 0.3
U-235	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	---	0.1 ± 0.1
U-238	1.9 ± 0.2	1.8 ± 0.2	0.5 ± 0.2	---	1.7 ± 0.3
Pu-238	<0.1	<0.1	<0.1	<0.1	<0.1
Pu-239	<0.1	<0.1	<0.1	<0.1	<0.1

[a]Uncertainties represent 95% confidence lebel based only on counting statistics; additional analytical uncertainties of ± 6 to 10% have not been propagated into these data.
[b]Dash indicates analysis not performed.

TABLE 13

RADIONUCLIDE CONCENTRATIONS IN THE UPPER 15 CM OF SOIL
SITE 2
ROYERSFORD, PENNSYLVANIA

Radionuclide	Concentration (pCi/g)				
	5/13/87	6/24/87	7/23/87 (before application)	7/23/87 (after application)	11/10/87
Cr-51	<0.4	<0.3	<0.3	<0.3	<0.4
Mn-54	0.3 ± 0.2[a]	0.1 ± 0.1	<0.1	0.1 ± 0.1	0.4 ± 0.2
Co-58	<0.1	0.2 ± 0.1	0.1 ± 0.1	<0.1	<0.1
Fe-59	<0.1	<0.1	<0.1	<0.1	<0.1
Co-60	1.5 ± 0.2	1.7 ± 0.3	0.7 ± 0.1	1.4 ± 0.3	2.3 ± 0.3
Zn-65	<0.1	0.2 ± 0.2	<0.1	<0.1	<0.2
Sr-89	2.0 ± 0.3	<0.1	<0.1	<0.1	<0.1
Sr-90	<0.1	<0.1	<0.1	<0.1	<0.1
Zr-95	<0.1	<0.1	<0.1	<0.1	<0.1
Nb-95	<0.1	<0.1	<0.1	<0.1	<0.1
Ag-110m	<0.1	<0.1	<0.1	<0.1	<0.1
Sb-125	0.2 ± 0.3	<0.1	<0.1	<0.1	<0.1
Cs-134	0.2 ± 0.1	<0.1	<0.1	<0.1	0.1 ± 0.1
Cs-137	0.8 ± 0.1	1.0 ± 0.2	0.1 ± 0.1	0.9 ± 0.2	1.0 ± 0.2
U-234	2.6 ± 0.3	1.9 ± 0.4	2.0 ± 0.4	1.8 ± 0.3	1.7 ± 0.3
U-235	0.2 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
U-238	2.0 ± 0.3	1.7 ± 0.4	2.0 ± 0.4	2.3 ± 0.4	1.6 ± 0.3
Pu-238	<0.1	<0.1	<0.1	<0.1	<0.1
Pu-239	<0.1	<0.1	<0.1	<0.1	<0.1

[a]Uncertainties represent 95% confidence level based only on counting statistics; additional analytical uncertainties of ± 6 to 10% have not been propagated into these data.

TABLE 14

TYPICAL RADIONUCLIDE DISTRIBUTION IN UPPER SOIL
SITE 1
ROYERSFORD, PENNSYLVANIA

Radionuclide	CONCENTRATION (pCi/g)							
	IMMEDIATELY AFTER APPLICATION				SIX MONTHS AFTER APPLICATION			
	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	<1.5	<0.8	<0.9	<0.3	<0.8	<0.7	<0.5	<0.5
Mn-54	0.8 ± 0.5[a]	0.4 ± 0.2	<0.1	<0.1	0.2 ± 0.1	0.1 ± 0.2	<0.1	<0.1
Co-58	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Fe-59	<0.5	<0.2	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1
Co-60	3.5 ± 1.0	1.7 ± 0.4	0.5 ± 0.3	<0.1	0.9 ± 0.2	1.3 ± 0.3	0.2 ± 0.2	<0.1
Zn-65	<0.6	<0.2	<0.2	<0.1	<0.2	<0.2	<0.1	<0.1
Sr-89	----	2.5 ± 0.3[b]	----	1.4 ± 0.2	----	<0.1[b]	----	<0.1
Sr-90	----	1.5 ± 0.1[b]	----	<0.1	----	<0.1[b]	----	<0.1
Zr-95	0.4 ± 0.7	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Nb-95	<0.2	<0.1	1.2 ± 0.3	<0.1	0.2 ± 0.1	<0.1	<0.1	<0.1
Ag-110m	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sb-125	<0.6	<0.3	<0.2	<0.1	<0.2	<0.2	<0.1	<0.1
Cs-134	0.3 ± 0.2	0.3 ± 0.2	<0.1	0.1 ± 0.1	<0.1	<0.1	<0.1	<0.1
Cs-137	2.0 ± 0.5	1.5 ± 0.3	0.5 ± 0.3	0.2 ± 0.1	0.5 ± 0.2	1.0 ± 0.2	0.3 ± 0.1	<0.1
U-234	----	1.8 ± 0.2[b]	----	1.9 ± 0.3	----	1.8 ± 0.3[b]	----	1.9 ± 0.3
U-235	----	0.1 ± 0.1[b]	----	0.1 ± 0.1	----	0.1 ± 0.1[b]	----	0.1 ± 0.1
U-238	----	1.8 ± 0.2[b]	----	2.0 ± 0.3	----	1.7 ± 0.3[b]	----	1.6 ± 0.3
Pu-238	----	<0.1[b]	----	<0.1	----	<0.1[b]	----	<0.1
Pu-239	----	<0.1[b]	----	<0.1	----	<0.1[b]	----	<0.1

[a]Uncertainties represent 95% confidence levels based only on counting statistics; additional analytical uncertainties of ± 6 to 10% have not been propagated into these data.

[b]Value represents average concentration in top 15 cm of soil.

TABLE 15

RADIONUCLIDE CONCENTRATIONS IN WINTER WHEAT
SITE 2
ROYERSFORD, PENNSYLVANIA

Radionuclide[a]	pCi/kg		
	May 1987		June 1987[b]
	Vegetation (Uptake)	Vegetation (Wash Fraction)	Vegetation Uptake
Co-60	2.1 ± 7.9[c]	<3.8	<5.2
Sr-90	65 ± 15	25.0 ± 9.1	39 ± 17
Cs-137	7.3 ± 4.8	<3.1	5.1 ± 4.3
U-234	<1	<1	<1
U-235	<1	<1	<1
U-238	<3	<3	<1

[a]Other radionuclides were less than the instrument sensitivities.
[b]Wash fraction not analyzed.
[c]Uncertainties represent 95% confidence levels based only on counting statistics; additional analytical uncertainties of ± 6 to 10% have not been propagated into these data.

REFERENCES

1. Murphy, G.L. and Deming, E.J., Radiological Impacts of Effluent Releases to the Sanitary Sewer from Interstate Nuclear Services Corporation, Royersford, Pennsylvania, (Phase I), Oak Ridge Associated Universities, September 1987.

2. Title 10 Code of Federal Regulations Part 20, Standards for Protection Against Radiation, 1985.

3. International Commission on Radiological Protection (ICRP), ICRP Publication 26, Recommendations of the International Commission on Radiological Protection, Pergamon Press, 1977.

4. D.E. Dunning, Jr., et al, Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel Cycle Facilities, Vol III, NUREG/CR-150 Vol 3, Oak Ridge National Laboratory, October 1981.

5. 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 10 CFR Part 50, Appendix I, October 1977.

6. 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.

7. 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.

8. 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)

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 Sample Analysis

Gamma Spectrometry

Soil 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 600 to 900 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).

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.

Sludge Sample Analysis

Sludge samples were homogenized by mixing in an electric high-speed blender. A 0.5-liter Marinelli beaker was filled with the blended sludge, sealed, and analyzed by gamma spectroscopy in the same manner as described above for soil sample analysis. Aliquots of the sludge were withdrawn, evaporated to dryness, and analyzed for isotopic uranium, plutonium, and strontium using the same procedures as employed for soil. Additional aliquots of sludge were refluxed with low-background water to extract tritium (H-3). The resulting water was distilled and counted in a Packard liquid scintillation counter. An additional aliquot of each sample - spiked with a known tritium standard - was prepared and analyzed to determine quenching factors.

Water Sample Analysis

Water samples were rough filtered, according to solids contents; remaining suspended solids were removed by subsequent filtration through 0.45 μm membrane filters. The filtrate was acidified by addition of concentrated nitric acid.

Gross Alpha and Gross Beta

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.

Isotopic Uranium and Plutonium

Aliquots of filtered water were evaporated to dryness. Residues were then dissolved by pyrosulfate fusion and precipitated with barium sulfate; separation of and analysis of specific radionuclides were performed as described above for soil samples.

Strontium 89/90

Aliquots of filtered water were evaporated to dryness. Residues were then analyzed for Sr-89 and Sr-90 as described above for soil samples.

Tritium

Aliquots of filtered water were distilled; a known volume of the distillate was then counted as described above for sludge.

Vegetation Analysis

Vegetation samples were washed with distilled water to remove ground splash. The water was drained and a weight determined for the sample. Wash water was analyzed for gross alpha and gross beta concentration as described above. Vegetation was refluxed with low-background water to extract tritium. The distillate was analyzed for tritium as described for sludge samples. The sample was then ashed at approximately 400°C and the ratios of ash-to-wet or ash-to-dry weights (depending upon vegetation type) were determined. Ash was then analyzed by gamma spectroscopy and wet chemistry procedures for uranium, plutonium, and strontium 89/90, following the methods described above for soil and samples.

Uncertainties and Detection Limits

The uncertainties associated with the analytical data presented in the tables of this report, represent the 95% 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 95% statistical deviation of the background count, the sample concentration was reported as less than the detection capability of the measurement procedure. Because of variations in background levels, sample volumes or weights, measurement efficiencies, and Compton contributions from other radionuclides in samples, the detection limits differ from sample to sample and instrument to instrument. Additional uncertainties of ± 6 to 10%, associated with sampling and laboratory procedures, have not been propagated into the data presented in this report.

Calibration and Quality Assurance

Laboratory and field survey procedures are documented in the following manuals, developed specifically for the Oak Ridge Associated Universities' Radiological Site Assessment Program: "Survey Procedures Manual", Revision 3, May 1987; "Laboratory Procedures Manual", Revision 3, May 1987 and "Quality Assurance Manual", Revision 1, June 1987.

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 20 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, similar to the 1986 data. 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 3.7 mR, which would result in an annual dose equivalent of 3.3 mrem.

2. Inhalation

Resuspension of surface soil from treated areas creates a 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. Typical concentrations of the six radionuclides of concern, measured in the upper 2.5 cm of soil of the tilled fields six months after application in 1987 were:

Co-60	0.9 pCi/g
Sr-90	<0.1 pCi/g
Cs-137	0.5 pCi/g
U-234	1.8 pCi/g
U-235	0.1 pCi/g
U-238	1.7 pCi/g

Assuming an inhalation rate of 20 1/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	0.2 pCi
Sr-90	<0.1 pCi
Cs-137	0.1 pCi
U-234	0.4 pCi
U-235	0.02 pCi
U-238	0.4 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	1.2 pCi/g
Sr-90	0.4 pCi/g*
Cs-137	0.7 pCi/g
U-234	1.5 pCi/g
U-235	0.1 pCi/g
U-238	1.6 pCi/g

*Instrument sensitivities used to determine average soil concentration: represents conservative estimate.

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	11	pCi/kg
Sr-90	6.8	pCi/kg
Cs-137	7.0	pCi/kg
U-234	3.8	pCi/kg
U-235	0.3	pCi/kg
U-238	4.0	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	570	pCi
Sr-90	350	pCi
Cs-137	360	pCi
U-234	200	pCi
U-235	16	pCi
U-238	210	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	7	pCi/kg
Sr-90	0.2	pCi/kg
Cs-137	1.4	pCi/kg
U-234	0.06	pCi/kg
U-235	0.01	pCi/kg
U-238	0.07	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	385	pCi
Sr-90	11	pCi
Cs-137	77	pCi
U-234	3.3	pCi
U-235	.55	pCi
U-238	3.6	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 Section 2 above, and the uptake factors from Table C-3. Resulting concentrations are:

Co-60	0.6	pCi/l
Sr-90	0.3	pCi/l
Cs-137	4.2	pCi/l
U-234	0.12	pCi/l
U-235	0.009	pCi/l
U-238	0.12	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	190	pCi
Sr-90	93	pCi
Cs-137	1300	pCi
U-234	37.2	pCi
U-235	2.8	pCi
U-238	37.2	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	90 pCi
Sr-90	10 pCi

Cs-137	50 pCi
U-234	180 pCi
U-235	10 pCi
U-238	170 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	200	pCi
Sr-90	99	pCi
Cs-137	1400	pCi
U-234	40	pCi
U-235	3	pCi
U-238	40	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 1987, 41 truckloads (9.4×10^5 l) of sludge from the Royersford Wastewater Treatment Plant were applied to fields. Based on a standard application 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 3.3 mrem x 20 areas x 2 persons/area = 132 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 16 person-mrem; the effective dose equivalent commitment is 2 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 for 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 380 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 (f_1) 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	1.9 E+04 pCi
Sr-90	4.8 E+04 pCi
Cs-137	2.3 E+05 pCi
U-234	2.7 E+02 pCi
U-235	2.1 E+01 pCi
U-238	2.8 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 18 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	4.2E+03 pCi
Sr-90	2.1E+03 pCi
Cs-137	2.9E+04 pCi
U-234	8.4E+02 pCi
U-235	6.3E+01 pCi
U-238	8.4E+02 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 4 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 536 person-mrem or 0.54 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+04	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[a]	Cs-137	U-234	U-235	U-238	
Lung	2.4E-04	1.4E-06	1.6E-06	2.1E-01	9.7E-03	1.9E-01	4.1E-01
LLI Wall	5.8E-06	2.2E-06	1.6E-06	4.4E-05	5.0E-06	1.1E-04	1.7E-04
Kidneys	1.2E-05	9.8E-07	5.1E-06	6.8E-04	3.0E-05	6.0E-04	1.3E-3
Liver	2.4E-05	9.8E-07	5.2E-06	6.5E-6	6.3E-07	7.0E-06	4.4E-05
Gonads	3.4E-06	9.8E-07	5.0E-06	6.4E-6	3.2E-07	5.9E-06	2.2E-05
Red Marrow	1.2E-05	1.6E-04	4.9E-06	9.6E-05	3.8E-06	8.0E-05	3.6E-04
Endostial Bone	1.0E-05	3.5E-04	5.3E-06	1.4E-03	5.8E-05	1.2E-03	3.0E-03
Thyroid	1.2E-05	9.8E-07	4.5E-06	6.4E-06	4.1E-07	6.4E-06	3.1E-05
Effective	3.6E-05	3.0E-05	3.1E-06	2.6E-02	1.2E-03	2.3E-02	5.0E-02

[a]Based on lower limit of detection for analytical procedure.

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/l)
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	4.9E-03	1.4E-03	1.7E-02	3.4E-03	2.6E-04	3.2E-03	3.0E-02
LLI Wall	2.3E-02	2.8E-02	2.0E-02	3.4E-02	2.9E-03	3.4E-02	1.4E-01
Kidneys	3.2E-03	1.4E-03	1.9E-02	3.4E-01	2.4E-02	3.2E-01	7.1E-01
Liver	3.9E-03	1.4E-03	1.9E-02	3.2E-03	2.2E-04	2.8E-03	3.1E-02
Gonads	7.1E-03	1.4E-03	1.8E-02	3.2E-03	2.3E-04	2.8E-03	3.3E-02
Red Marrow	3.1E-03	2.3E-01	1.5E-02	4.6E-02	2.9E-03	4.0E-02	3.4E-01
Endostial Bone	2.3E-03	5.3E-01	7.6E-02	7.0E-01	4.6E-02	5.9E-01	1.9E+00
Thyroid	1.8E-03	1.4E-03	1.7E-02	3.2E-03	2.3E-04	3.0E-03	2.7E-02
Effective	4.9E-03	4.6E-02	1.7E-02	4.8E-02	3.2E-03	4.2E-02	1.6E-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	3.3E-03	4.5E-05	3.7E-03	5.7E-05	8.9E-06	5.5E-05	7.2E-03
LLI Wall	1.5E-07	8.9E-04	4.2E-03	5.6E-04	9.9E-05	5.8E-04	6.3E-03
Kidneys	2.2E-03	4.5E-05	4.1E-03	5.6E-03	8.3E-04	5.4E-03	1.8E-02
Liver	2.6E-03	4.5E-05	4.1E-03	5.2E-05	7.6E-06	4.8E-05	6.9E-03
Gonads	4.8E-03	4.5E-05	3.8E-03	5.2E-05	8.0E-06	4.8E-05	8.8E-03
Red Marrow	2.1E-03	7.2E-03	3.3E-03	7.6E-04	9.9E-05	6.8E-04	1.4E-02
Endostial Bone	1.5E-03	1.7E-02	1.6E-02	1.2E-02	1.6E-03	1.0E-02	5.8E-02
Thyroid	1.2E-03	4.5E-05	3.7E-03	5.2E-05	8.0E-06	5.1E-05	5.1E-03
Effective	3.3E-03	1.4E-03	3.6E-03	7.9E-04	1.1E-04	7.2E-04	9.9E-03

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	1.6E-03	3.8E-04	6.3E-02	6.4E-04	4.5E-05	1.1E-04	6.6E-02
LLI Wall	7.6E-03	7.5E-04	7.2E-02	6.3E-03	5.0E-04	1.2E-03	8.8E-02
Kidneys	1.1E-03	3.8E-04	6.8E-02	6.3E-02	4.2E-03	1.1E-02	1.5E-01
Liver	1.3E-03	3.8E-04	6.9E-02	5.9E-04	3.9E-05	9.6E-05	7.1E-02
Gonads	2.4E-03	3.8E-04	6.3E-02	5.9E-04	4.1E-05	9.6E-05	6.7E-02
Red Marrow	1.0E-03	6.0E-02	5.5E-02	8.6E-03	5.0E-04	1.4E-03	1.3E-01
Endostial Bone	7.6E-04	1.4E-01	2.7E-01	1.3E-01	8.1E-03	2.0E-02	5.7E-01
Thyroid	5.9E-04	3.8E-04	6.3E-02	5.9E-04	4.1E-05	1.0E-04	6.5E-02
Effective	1.6E-03	1.2E-02	6.1E-02	8.9E-03	5.6E-04	1.4E-03	8.5E-02

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	3.3E+00	4.1E-01	3.0E-02	7.2E-03	6.6E-02	3.8E+00
LLI Wall	3.3E+00	1.7E-04	1.4E-01	6.3E-03	8.8E-02	3.5E+00
Kidneys	3.3E+00	1.3E-03	7.1E-01	1.8E-02	1.5E-01	4.2E+00
Liver	3.3E+00	4.4E-05	3.1E-02	6.9E-03	7.1E-02	3.4E+00
Gonads	3.3E+00	2.2E-05	3.3E-02	8.8E-03	6.7E-02	3.4E+00
Red Marrow	3.3E+00	3.6E-04	3.4E-01	1.4E-02	1.3E-01	3.8E+00
Endostial Bone	3.3E+00	3.0E-03	1.9E+00	5.8E-02	5.7E-01	5.8E+00
Thyroid	3.3E+00	3.1E-05	2.7E-02	5.1E-03	6.5E-02	3.4E+00
Effective	3.3E+00	5.0E-02	1.6E-01	9.9E-03	8.5E-02	3.6E+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	8.4E-04	1.5E-04	1.6E-03	1.5E-02	7.8E-04	1.2E-02	3.0E-02
LLI Wall	1.2E-02	2.7E-03	1.8E-03	1.2E-01	6.8E-03	1.1E-01	2.5E-01
Kidneys	---[a]	1.5E-04	1.7E-03	1.2E+00	5.9E-02	9.9E-01	2.3E+00
Liver	2.0E-03	1.5E-04	1.7E-03	1.3E-02	6.1E-04	1.0E-02	2.7E-02
Gonads	3.1E-03	1.5E-04	1.8E-03	1.4E-02	7.0E-04	1.1E-02	3.1E-02
Red Marrow	9.9E-04	6.0E-03	1.7E-03	9.9E-02	4.3E-03	7.8E-02	1.9E-01
Endostial Bone	---	1.5E-02	7.5E-03	2.7E-02	1.3E-01	2.0E+00	4.9E+00
Thyroid	---	1.5E-04	1.8E-03	1.4E-02	7.0E-04	1.2E-02	2.9E-02
Effective	2.2E-03	1.5E-03	1.7E-03	1.7E-01	7.6E-03	1.3E-01	3.1E-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	1.9E-03	1.5E-03	4.5E-02	3.3E-03	2.3E-04	2.9E-03	5.5E-02
LLI Wall	2.6E-02	2.7E-02	4.9E-02	2.7E-02	2.1E-03	2.5E-02	1.6E-01
Kidneys	---[a]	1.5E-03	4.8E-02	2.7E-01	1.8E-02	2.3E-01	5.7E-01
Liver	4.4E-03	1.5E-03	4.9E-02	2.8E-03	1.8E-04	2.4E-03	6.0E-02
Gonads	6.8E-03	1.5E-03	5.1E-02	3.0E-03	2.1E-04	2.6E-03	6.5E-02
Red Marrow	2.2E-03	5.9E-02	4.8E-02	2.2E-02	1.3E-03	1.8E-02	1.5E-01
Endostial Bone	---	1.5E-01	2.1E-01	6.0E-01	3.8E-02	4.8E-01	1.3E+00
Thyroid	---	1.5E-03	4.9E-02	3.0E-03	2.1E-04	2.7E-02	8.1E-02
Effective	4.8E-03	1.53-02	4.6E-02	3.8E-02	2.3E-03	3.1E-02	1.4E-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	1.6E+05	2.4E+05	1.8E+05
Sr-90	0	9.6E+04	1.5E+05	1.1E+05
Cs-137	0	9.9E+04	1.5E+05	1.1E+05
U-234	0	5.4E+04	8.2E+04	6.2E+04
U-235	0	4.3E+03	6.5E+03	4.3E+03
U-238	0	5.7E+04	8.7E+04	2.6E+05

TABLE C-15

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

Radionuclide	Age Group			
	Infants	Children	Teenagers	Adults
Co-60	5.0 E-03	1.9 E-02	1.2 E-02	1.9 E-02
Sr-90	2.7 E-02	5.9 E-01	1.4 E-01	1.4 E-01
Cs-137	8.3 E-02	1.8 E-01	3.9 E-01	7.1 E-01
U-234	2.3 E-01	1.5 E-01	1.7 E-01	1.1 E-01
U-235	1.4 E-02	9.1 E-03	6.8 E-03	6.6 E-03
U-238	2.0 E-01	1.2 E-01	1.4 E-01	8.8 E-02
TOTAL	5.6 E-01	1.1 E+00	8.6 E-01	1.1 E+00