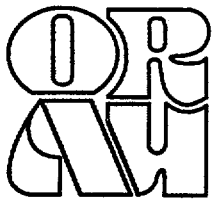

Prepared by
Oak Ridge Associated
Universities

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 III)

S. A. WICAL, G. L. MURPHY, and J. D. BERGER

Environmental Survey and Site Assessment Program
Energy/Environment Systems Division

FINAL REPORT
JUNE 1989

See "Sludge Disposal" letter dated 8/1/89

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

Prepared by

S.A. WICAL, G.L. MURPHY*, & J.D. BERGER

Environmental Survey and Site Assessment Program
Energy/Environment Systems Division
Oak Ridge Associated Universities
Oak Ridge, Tennessee 37831-0117

Project Staff

S.F. Barnett
R.D. Condra**
G.R. Foltz
F.A. Templon
J.F. Payne
R.R. Rookard
C.H. Searcy
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 1989

This report is based on work performed under Interagency Agreement DOE No. 40-770-80 NRC Fin No. A-9093 between the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy. Oak Ridge Associated Universities performs complementary work under contract number DE-AC05-76OR00033 with the U.S. Department of Energy.

*Currently with Martin Marietta Energy Systems
**Currently with IT Corporation

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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

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. Liquid wastes from laundering operations are filtered to remove suspended solids collected in holding tanks, and monitored. If the measured radionuclide concentrations are within the NRC limits for release, these liquids are discharged to the sanitary sewer. INS typically releases approximately 10^5 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 receives, as influent, about 2 million liters of wastewater per day, including the discharge from INS. Sludges from the treatment process accumulate in the secondary digester. Prior to 1988 sludge was withdrawn between May and October each year and spread on agricultural land as fertilizer, throughout a number of farms west of Philadelphia. In 1988 alternate methods of disposal were pursued. Approximately 2.1×10^5 liters of sludge were applied as fertilizer; however, no applications were performed at the previously selected study plots. About 3.2×10^5 liters of sludge were transferred to the waste treatment plant in nearby Pottstown for evaluation of other disposal options. Effluent from the plant is chlorinated and discharged to the Schuykill River.

Analyses of sludge from the secondary digester 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)[1] and continued through 1987 (Phase II)[2], and 1988 (Phase III). Activities during 1988 included: reviewing liquid effluent discharges from the INS laundry; determining concentrations in sewage sludge; measuring concentrations of radionuclides in two study plots; and conducting preliminary estimates of potential dose commitments from previous sludge application.

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 a 1.6×10^4 liter tank (A). A sump pump in the tank periodically transfers settlings into a holding tank (B); liquids are transferred through a filtration system to a batch tank (C). The holding tank (B) is used as a settling/dewatering tank. Sludge from the holding tank is removed and spread on drying beds. Liquids from the holding tank and the drying beds are filtered and transferred to tank C. The contents of tank C are sampled, analyzed, and discharged to the sanitary sewer system, if the concentration is less than the limits specified in 10 CFR 20.303.[3] Tank C (1.6×10^4 liters) is typically released to the sewer six to eight times per day, for a total daily discharge ranging from 9.6×10^4 to 1.3×10^5 liters.

The Borough of Royersford, Pennsylvania, Wastewater Treatment Facility consists of two pumping stations, approximately 20 km of sewer line, and a secondary treatment plant. The facility was originally constructed in 1937 and was upgraded to secondary treatment in 1952. The 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 digester, where the organic content of the sludge is stabilized. Excess water is decanted to the plant raw sewage wetwalls and thicker digested sludge is pumped to the secondary digester 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 digester each week. Prior to 1988, beginning early each spring, the sludge was 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. Beginning in 1988, alternate disposal methods were evaluated, resulting in a significant reduction in the quantities of sludge applied to agricultural lands.

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 not available. 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. Because no sludge was applied to either Site 1 or 2 in 1988, the objective of the study was to monitor changes in radionuclide concentrations at the study plots due to leaching, erosion, plant uptake, tilling, wind blown transport, decay, or other mechanisms.

SURVEY PROCEDURES

INS Effluent Releases

ORAU reviewed and summarized INS effluent release data from October 1987 through September 1988.

Wastewater Treatment Facilities

During 1988, samples of influent and effluent were collected at the Royersford plant and at two additional wastewater treatment facilities (Spring City and Pottstown, PA), similar to Royersford in capacity and facility design, for baseline comparison purposes (Figure 4). Royersford Wastewater Treatment Facility workers obtained samples of each batch of sludge as it was being withdrawn from the secondary digester during the 1988 season and provided these samples to ORAU for analyses.

Sludge Application Sites

On April 19, June 21, August 10, and October 10, 1988 soil samples were collected at nine randomly selected locations within the 10 x 10 m gridded study plots, originally established at the Limerick Township (Site 1) and Providence Township (Site 2) application areas during the 1986 survey. Samples were obtained using a shelby tube driven to a depth of 30 cm. Samples were composited to represent depths of 0-15, 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.

At the Limerick Township site, winter wheat was sampled in June; no crops were available for sampling in April, August, or October. Winter wheat was also collected from the Providence Township site in April and June. No vegetation was available at this location during the August and October visits, because crops were not replanted following the winter wheat harvest.

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). 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, 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 surface 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 at contact with the soil surface ranged from 20 to 30 μrad/h. The slight elevation in dose rates, compared to exposure rates, reflects the beta component.

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 1987 through September 1988, are complete and indicate compliance with 10 CFR 20.303.[3] Monthly discharges are summarized in Table 4. During this 12 month period, INS released a total volume of 2.1×10^7 liters to the sanitary sewer; INS data indicated that this discharge contained a total activity of 122.55 mCi.

Wastewater Treatment Facilities

Wastewater Influent and Effluent

Radionuclide concentrations, measured in grab samples of influent and effluent streams from Royersford, Spring City, and Pottstown wastewater treatment facilities, are presented in Table 5. Royersford influent contained gross alpha and gross beta concentrations of 3.9 pCi/l and 49.1 pCi/l, respectively. Spring City and Pottstown influent water contained measured gross alpha concentrations of 3.3 and 2.2 pCi/l; gross beta concentrations were 13.2 and 22.5 pCi/l. Effluent water from the Royersford facility had a measured gross alpha concentration of 5.4 pCi/l and gross beta concentration of 174.2 pCi/l. In contrast, Spring City and Pottstown effluents contained gross alpha levels of 1.9 pCi/l and 1.2 pCi/l and gross beta concentrations of 13.5 pCi/l and 28.0 pCi/l, respectively. Cesium 137 and Sr-90 were the principal radionuclides identified in the Royersford effluent. The highest Cs-137 concentration, measured in the Royersford effluent samples, was 94.6 pCi/l, and the highest Sr-90 concentration was 24.7 pCi/l. The highest Cs-137 concentration, measured in effluents from the other two facilities, was 2.9 pCi/l from the Spring City Plant; the maximum Sr-90 concentration was 2.6 pCi/l from Pottstown Plant. In some samples the concentrations of certain radionuclides were slightly higher in the effluent than they were in the influent. The reason for this is unknown; however, all did satisfy the NRC guidelines for release to unrestricted areas.

Digester Sludge Concentrations

Table 6 contains radionuclide concentration information on sludge samples, collected from April through September, 1988, as the sludge was removed from the secondary digester. The maximum average radionuclide concentration was 24,000 pCi/l (Co-60). A comparison of average radionuclide concentrations measured in 1986, 1987, and 1988 is presented in Table 7. These data indicate a significant decrease in the levels of Co-60 and Cs-137 during 1988.

Sludge Application Sites

Direct Radiation Levels

Tables 8 and 9 summarize direct radiation levels measured on application study Sites 1 and 2, respectively. Radiation levels remained relatively constant throughout the 1988 study season, averaging 3 to 4 μR/h higher than background levels for the Royersford area. This may be due, in part, to previous soil treatment with phosphate fertilizers, which contain natural uranium at low concentrations. Tables 10 and 11 present a comparison of average direct radiation levels, measured during the 1986, 1987, and 1988 studies. At Site 1 the levels have decreased very slightly, since 1987; at Site 2 levels have decreased by 3-4 μR/h since 1987.

Radionuclide Concentrations in Soil

Radionuclide concentrations, measured in the upper 15 cm of soil at the two sludge-application study sites, are presented in Tables 12 and 13. Most of the radionuclides were at concentrations typical of natural background levels or at levels below the detection limits of the procedures. Variations in concentrations of some specific radionuclides in samples collected on different sampling dates are considered to be due to non-homogeneous mixing of the applied sludge, throughout the upper soil layer. Cobalt 60, Cs-137, and uranium isotopes were the radionuclides for which concentrations above baseline levels were consistently noted; several samples also contained elevated levels of Sr-89. Average concentrations of Co-60, Cs-137, and uranium were determined for use in performing dose calculations. At Site 1 the average concentrations

for these radionuclides were: Co-60, 0.8 pCi/g; Cs-137, 0.4 pCi/g; and total uranium, 3.3 pCi/g. Average concentrations for Site 2 were: Co-60, 0.6 pCi/g; Cs-137, 0.4 pCi/g; and total uranium, 3.3 pCi/g. Because of its relatively short half-life of about 50 days, Sr-89 was not considered a significant source of potential radiation dose associated with these sludge application sites. Although Sr-90 was not present at measurable levels, it was decided that due to its long half-life (approximately 29 years) it would be included in the dose calculations. The concentrations of Sr-90 at both study sites were <0.1 pCi/g.

Tables 14 and 15 present the radionuclide concentrations in soil from the 15-30 cm depth. All radionuclide concentrations are typical of baseline levels for the Royersford Area. This indicates very little, if any, migration of the radionuclides from the surface soil layer.

A comparison of the average (both sites) surface soil concentrations for six radionuclides of interest during the 1986, 1987, and 1988 studies is presented in Table 16. As noted from this table, there has been a decrease in concentrations of all of these nuclides, since initiation of the study in 1986.

Radionuclide Concentrations in Vegetation

Radionuclide concentrations, measured in one winter wheat sample from Site 1 and two winter wheat samples from Site 2, are presented in Table 17. Uptake levels appear to be generally higher for the samples from Site 2. The highest radionuclide level measured was Sr-90 at 59 pCi/kg in the June 21 sample from Site 2. For all radionuclides other than Sr-90, measured concentrations are comparable to or less than the concentrations, calculated on the basis of soil levels and literature uptake factors (Appendix C). The calculated concentration for Sr-90 was 1.7 pCi/kg. Because the measured concentrations were based on only three samples of vegetation, it was decided that the calculated values would be used for dose estimation 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.[4-9] 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 1988 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. It should be noted that at the present time, the sludge is not being spread on agriculture lands where crops used for human consumption are grown.

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

Endostial cells on bone surfaces	5.1 mrem
Kidneys	4.0 mrem
Lung	3.6 mrem
Red Marrow	3.4 mrem
Effective	3.4 mrem

Over half of these dose equivalent levels were due to external, direct gamma 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	1.8 mrem
Kidneys	2.0 mrem
LLI Wall	0.2 mrem
Red Marrow	0.2 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	0.1 mrem

Population Dose

Records, indicating the total number of sludge application areas during 1988 were not available. Although there were fewer applications in 1988 than in 1987, the conservative assumption was made that 20 different farms had treated areas (the same as for 1987). Furthermore, it was assumed that 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 human consumption; and half of the areas are used to raise livestock forage crops. Calculations were based on direct radiation levels and average radionuclide concentrations, measured during 1988 on the two study sites, which received no sludge applications this year. The resulting estimated population dose equivalent commitment for the total body was 0.38 person-rem, as compared to 0.54 person-rem during 1987.[2] Because (1) there were no applications to these study plots during 1988; (2) the total quantity of sludge applied to all agricultural lands was less than in 1987; and (3) the average radionuclide concentrations in sludge during 1988 were less than in previous years, the actual population dose would be slightly greater than 0.38 person-rem, but less than the 1987 level of 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 1987 through September 1988, was approximately 123 mCi. Based on the previous comparison of ORAU isotopic analyses with INS gross analyses, the INS values may be overestimating discharged activity by a factor

of approximately 2.9[1]; the recalculated discharge would be 42 mCi for this time period. The total quantity of sludge withdrawn from the Royersford Treatment Facility during the same time period was 5.3 x 10^4 liters; the average total concentration in the sludge, determined by ORAU, was about 5.3 E4 pCi/l. This results in a total activity of 28 mCi. Considering the uncertainties in beginning and ending digester 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 digester.

Wastewater Treatment Facilities

Concentrations of radionuclides in the influents to the three wastewater treatment facilities do not differ markedly, except for higher levels of Co-60, Sr-90, and Cs-137 in several samples from the Royersford facility. Effluent from the Royersford facility also contained elevated levels of these radionuclides. The average concentrations of radionuclides in the sludge from the Royersford site were significantly lower than in the two previous years. This is likely due to modified treatment procedures, implemented by INS prior to release of the liquid to the sanitary sewer.

Sludge Application Sites

Direct radiation and soil concentrations of some radionuclides at the study sites are slightly elevated above background and baseline levels. Comparison of 1988 data with previous years indicates a reduction in both the direct radiation and radionuclide concentrations. 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	3.4 mrem
Child (Soil)	0.3 mrem
Child (Milk)	0.1 mrem
Population Dose	0.38 to 0.54 person-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 3.4% 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, or the 3.6% value, determined from the 1987 Phase II assessment. Dose commitments for the other scenarios are significantly less than the 1986 and 1987 calculated levels.

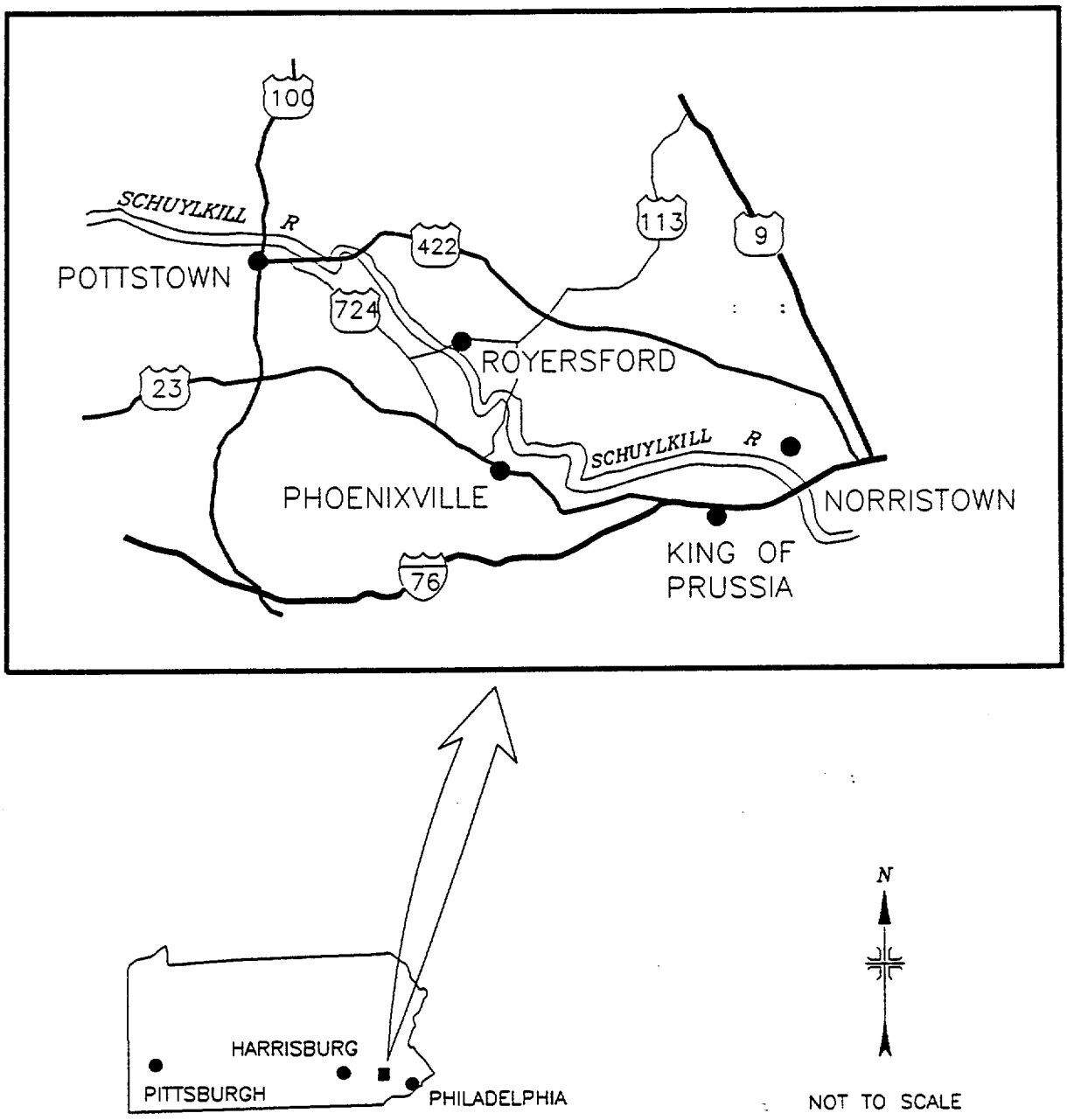

FIGURE 1: Map of Pennsylvania Indicating Location of the Borough of Royersford

ROY2

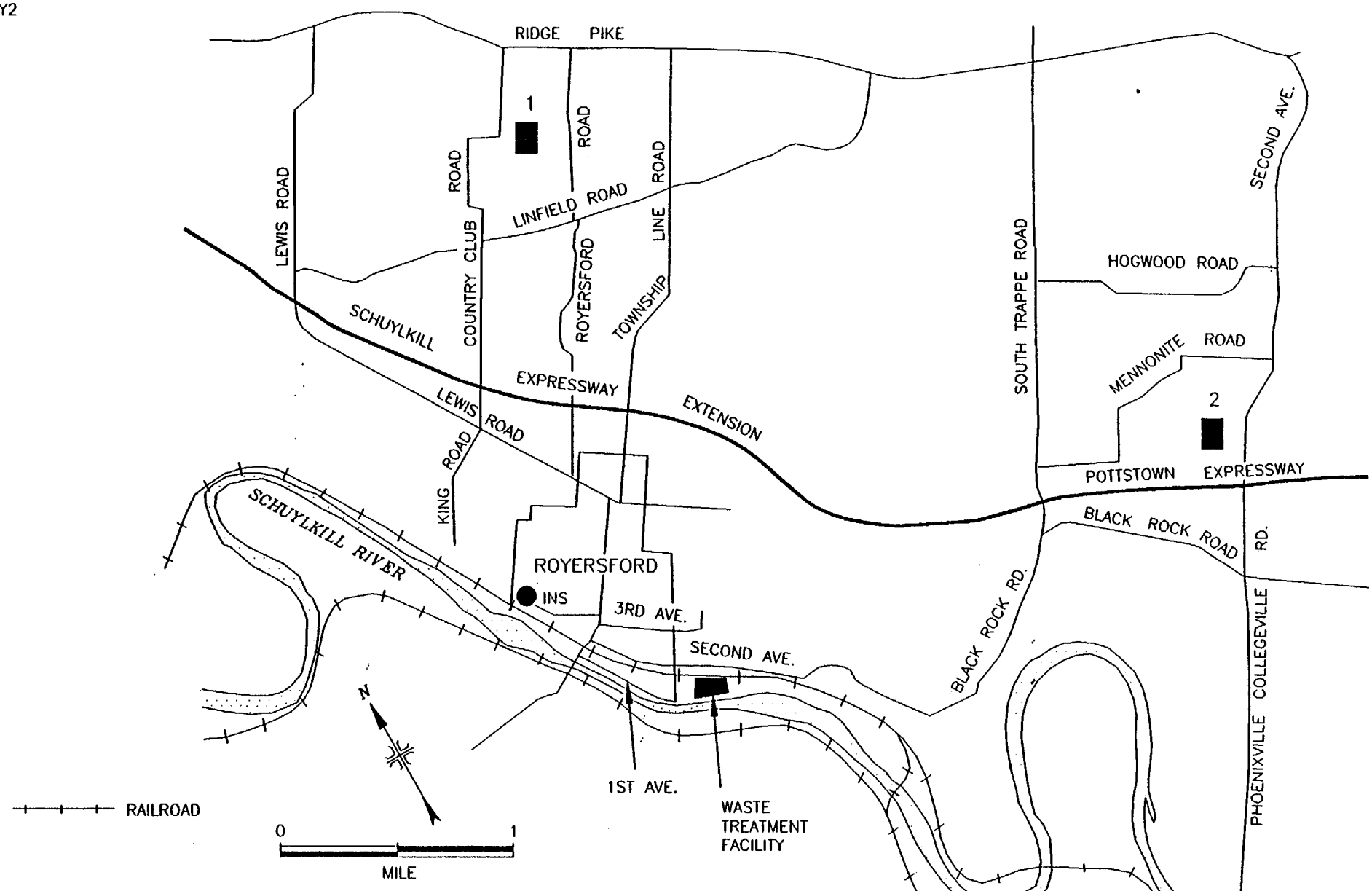

FIGURE 2: Map of Upper Providence Township and Limerick Township Showing the Location of Interstate Nuclear Service Corporation, the Wastewater Treatment Facility, and Sludge Application Sites 1 and 2

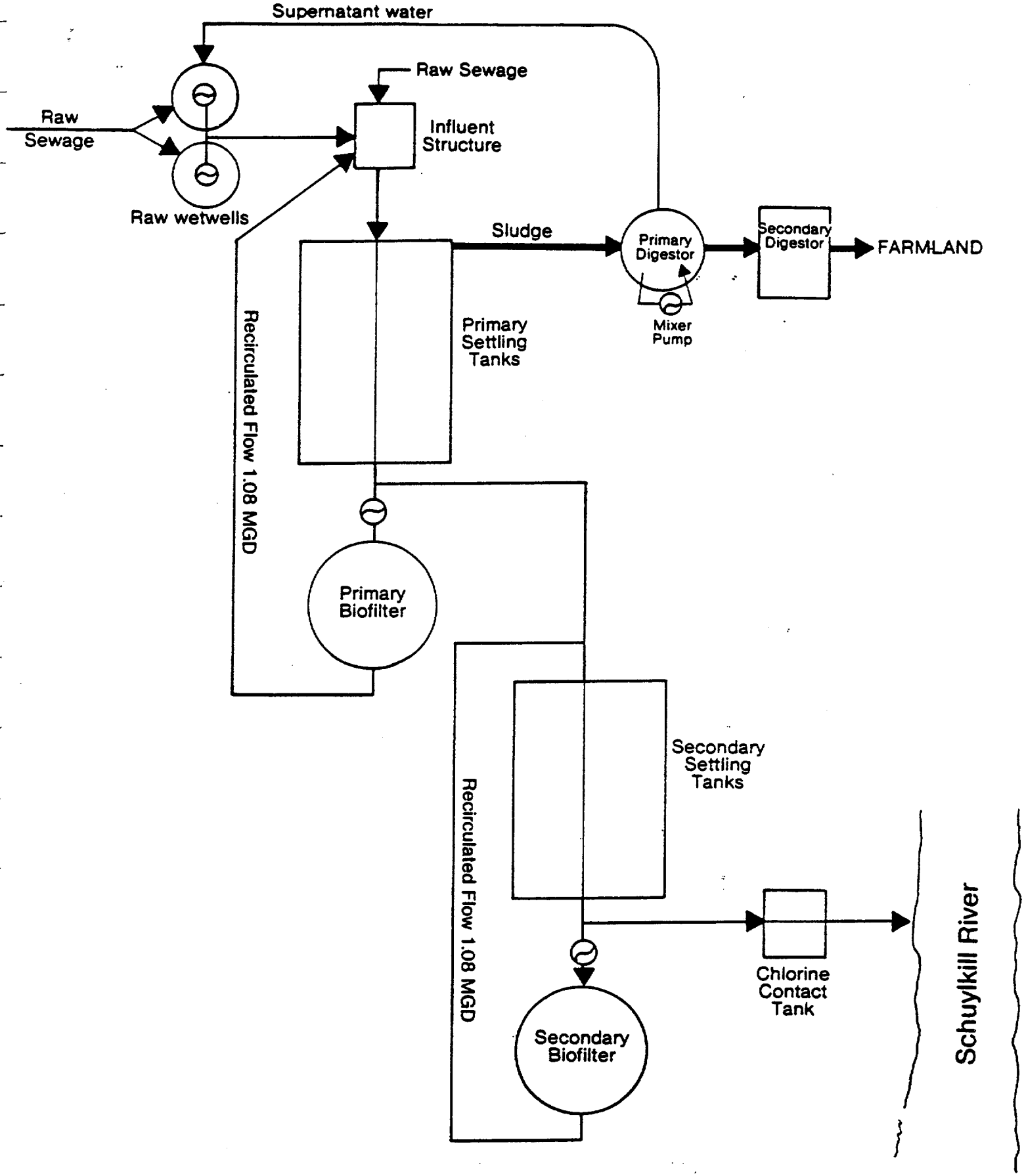

FIGURE 3: Flow Diagram of the Royersford Wastewater Treatment Facility

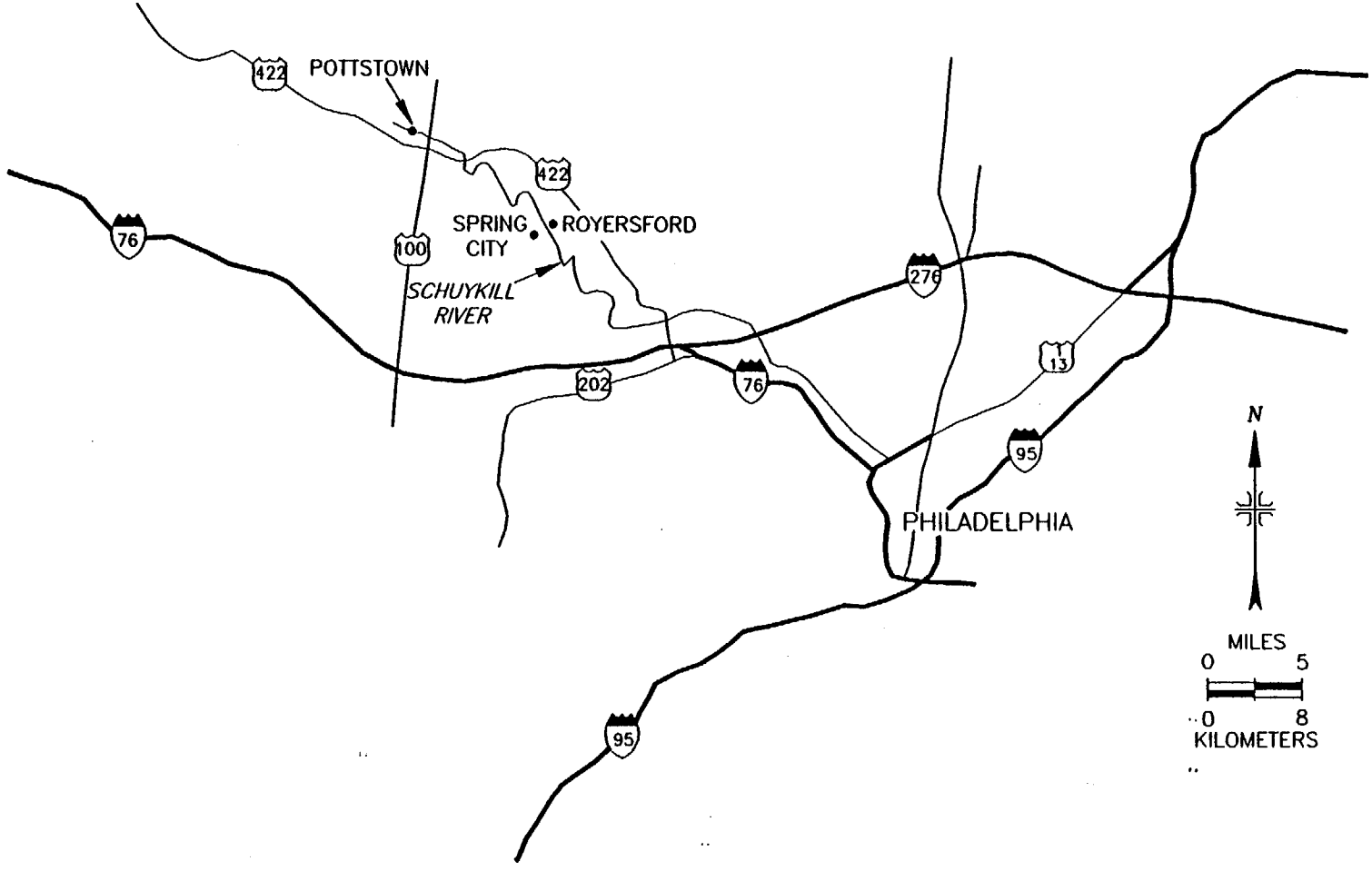

FIGURE 4: Location of Royersford Baseline Sewage Treatment Plants

ROY2b

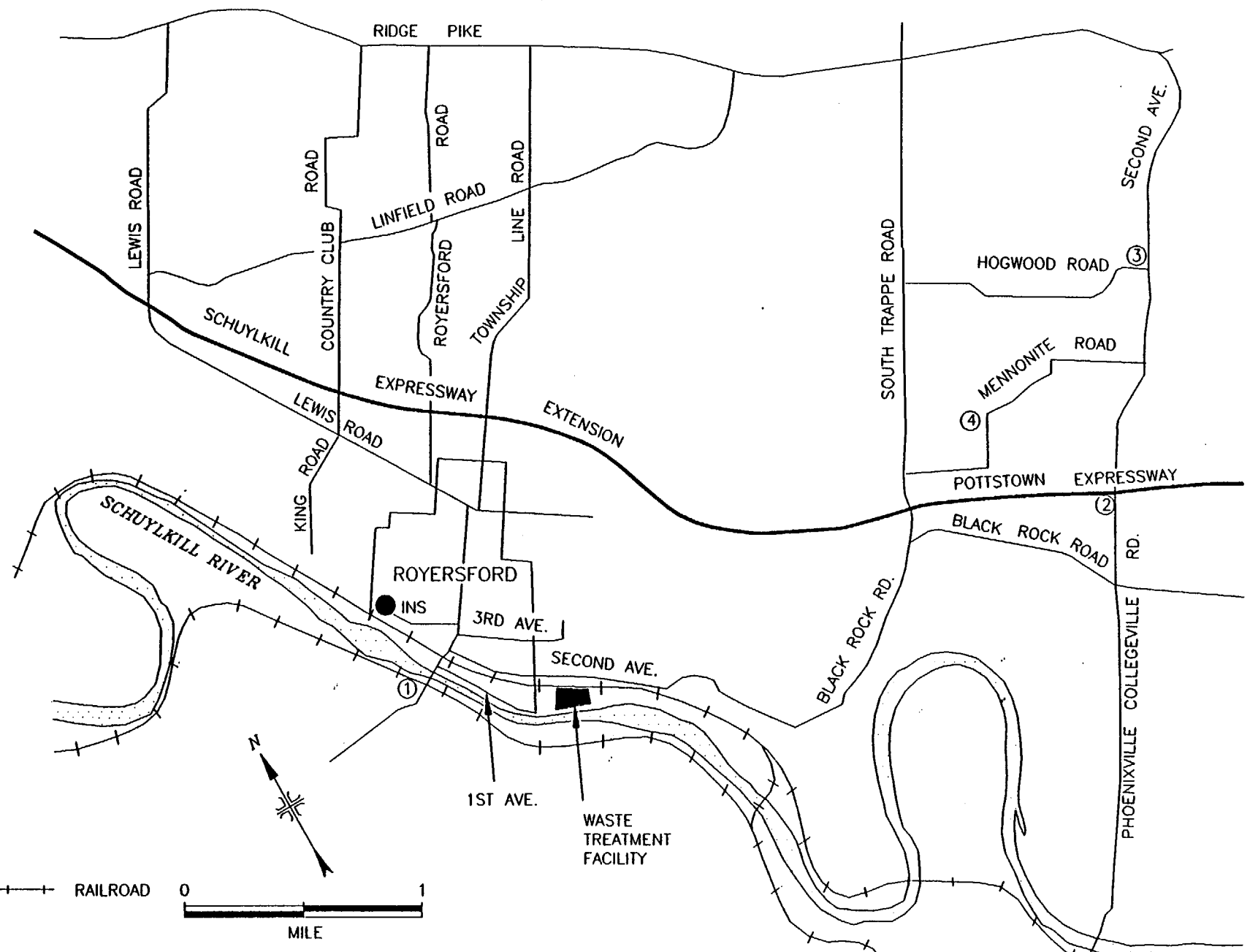

FIGURE 5: Location of Baseline Samples and Background Measurements

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.
[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.
[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.
[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 1987 THROUGH SEPTEMBER 1988
ROYERSFORD, PENNSYLVANIA

Month	Volume ($\times 10^6$ l)	Activity discharged (mCi)
10/87	2.05	9.68
11/87	1.75	13.93
12/87	1.40	9.36
1/88	0.19	8.17
2/88	2.20	10.17
3/88	2.53	25.45
4/88	2.15	9.80
5/88	1.78	6.93
6/88	1.87	5.41
7/88	1.79	7.41
8/88	1.70	8.56
9/88	1.67	7.68
TOTAL	21.08	122.55

Data summarized from records provided by INS.

TABLE 5

RADIONUCLIDE CONCENTRATIONS MEASURED IN
INFLUENT AND EFFLUENT WATER SAMPLES FROM
WASTEWATER TREATMENT PLANTS
ROYERSFORD, SPRING CITY, AND POTTSTOWN, PENNSYLVANIA[a]

	RADIONUCLIDE CONCENTRATIONS (pCi/l)					
	ROYERSFORD		SPRING CITY		POTTSTOWN	
	April 20, 1988		April 20, 1988		May 18, 1988	
RADIONUCLIDE	Influent	Effluent	Influent	Effluent	Influent	Effluent
gross alpha	<1.0	<0.9	<1.0	<0.9	3.2 ± 2.8[b]	2.8 ± 2.7
gross beta	<2.0	<1.7	<1.9	<1.8	5.3 ± 5.4	8.1 ± 5.5
H-3	<220	<220	<220	<220	<300	<300
Cr-51	<17	<21	<17	<21	<36	<33
Mn-54	<2.1	<3.9	<2.0	<2.2	<2.9	<2.5
Co-58	<2.0	<2.5	<1.8	<2.3	<3.2	<2.6
Fe-59	<3.9	<4.4	<3.9	<4.3	<6.5	<5.4
Co-60	8.0 ± 5.3	16.9 ± 5.5	<2.4	<4.2	<3.2	<2.8
Zn-65	<4.5	<5.3	<4.4	<4.6	<5.8	<5.0
Sr-89	<4.1	<5.7	<2.2	<2.2	<7.1	<5.6
Sr-90	<4.7	19.1 ± 1.2	<2.6	<2.5	<2.3	2.6 ± 0.4
Zr-95	<3.4	<4.3	<3.6	<4.0	<5.1	<5.1
Nb-95	<2.1	<2.5	<2.1	<2.2	<3.6	<3.5
Ag-110m	<2.0	<2.2	<1.8	<2.2	<2.6	<2.3
Sb-125	<5.5	<6.7	<5.7	<6.3	<7.7	<6.7
Cs-134	<2.0	6.3 ± 5.0	<1.9	<2.1	<2.6	<2.2
Cs-137	9.9 ± 5.4	62.2 ± 7.1	4.3 ± 4.2	<3.8	4.8 ± 3.3	<2.4
U-234	1.4 ± 0.4	1.1 ± 0.3	1.4 ± 0.4	1.3 ± 0.3	0.6 ± 0.4	0.5 ± 0.3
U-235	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
U-238	0.8 ± 0.3	0.5 ± 0.2	0.4 ± 0.2	0.3 ± 0.2	<0.1	<0.1
Pu-238	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pu-239	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

TABLE 5 (Continued)

RADIONUCLIDE CONCENTRATIONS MEASURED IN
INFLUENT AND EFFLUENT WATER SAMPLES FROM
WASTEWATER TREATMENT PLANTS
ROYERSFORD, SPRING CITY, AND POTTSTOWN, PENNSYLVANIA[a]

RADIONUCLIDE	RADIONUCLIDE CONCENTRATIONS (pCi/l) June 21, 1988					
	ROYERSFORD		SPRING CITY		POTTSTOWN	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
gross alpha	5.2 ± 2.0	5.6 ± 2.0	4.2 ± 1.8	1.6 ± 1.6	4.0 ± 1.1	1.8 ± 1.2
gross beta	53.9 ± 4.3	209 ± 7	15.6 ± 3.0	9.7 ± 2.8	24.9 ± 2.4	13.7 ± 3.0
H-3	<350	<350	650 ± 500	<350	540 ± 490	<350
Cr-51	<19	<24	<19	<2.4	<19	<25
Mn-54	<2.0	3.6 ± 2.5	<2.1	<2.5	<2.0	<2.3
Co-58	<2.0	<2.5	<1.8	<2.5	<2.0	<2.4
Fe-59	<4.4	<4.5	<3.8	<4.5	<4.2	<5.0
Co-60	<2.0	5.8 ± 1.6	<2.3	<2.7	<1.6	<2.4
Zn-65	<3.9	<4.8	<4.4	<4.4	<4.1	<4.9
Sr-89	<5.3	9.0 ± 4.5	<1.8	<2.9	<1.9	<2.9
Sr-90	5.5 ± 0.5	24.7 ± 1.3	<2.1	<3.4	<2.2	<3.4
Zr-95	<3.2	<4.2	<3.6	<4.2	<3.6	<4.4
Nb-95	<2.2	<2.5	<2.2	<2.7	<2.2	<2.7
Ag-110m	<2.0	<2.2	<1.9	<2.1	<1.9	<2.1
Sb-125	<5.6	<6.8	<5.5	<6.6	<5.5	<6.7
Cs-134	<2.0	<2.5	<1.8	<2.2	<1.8	<2.2
Cs-137	25.2 ± 1.8	94.6 ± 3.8	<2.2	2.9 ± 2.5	<2.2	<2.3
U-234	0.8 ± 0.4	0.6 ± 0.2	0.6 ± 0.2	1.1 ± 0.3	0.6 ± 0.3	0.4 ± 0.2
U-235	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
U-238	0.4 ± 0.3	<0.1	0.3 ± 0.2	0.7 ± 0.2	0.4 ± 0.2	0.3 ± 0.1
Pu-238	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Pu-239	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1

TABLE 5 (Continued)

RADIONUCLIDE CONCENTRATIONS MEASURED IN
INFLUENT AND EFFLUENT WATER SAMPLES FROM
WASTEWATER TREATMENT PLANTS
ROYERSFORD, SPRING CITY, AND POTTSTOWN, PENNSYLVANIA[a]

RADIONUCLIDE	RADIONUCLIDE CONCENTRATIONS (pCi/l) August 16, 1988					
	ROYERSFORD		SPRING CITY		POTTSTOWN	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
gross alpha	3.5 ± 2.0	3.5 ± 1.9	1.8 ± 1.3	1.0 ± 0.8	<1.8	<1.4
gross beta	18.5 ± 2.6	106 ± 5	9.5 ± 1.5	10.9 ± 1.6	15.2 ± 3.5	48.1 ± 3.6
H-3	<300	<200	<200	<300	<200	<200
Cr-51	<7.6	<9.0	<7.7	<7.8	<8.0	<8.0
Mn-54	<0.7	<0.8	<0.6	<0.7	<0.8	<0.7
Co-58	<0.8	9.1 ± 0.7	<0.7	<0.7	<0.8	<0.8
Fe-59	<1.5	<1.4	<1.5	<1.6	<1.6	<1.5
Co-60	<0.8	4.5 ± 1.0	<0.8	<0.8	<0.7	<0.8
Zn-65	<1.4	<1.4	<1.4	<1.4	<1.5	<1.4
Sr-89	<0.4	<0.9	<0.3	<0.9	<0.8	<1.7
Sr-90	<0.5	4.5 ± 0.7	<0.3	<1.0	<0.9	<1.9
Zr-95	<1.4	<1.4	<1.4	<1.3	<1.4	<1.5
Nb-95	<0.8	<0.9	<0.9	<0.9	<0.9	<0.9
Ag-110m	<0.7	<0.8	<0.7	<0.7	<0.7	<0.8
Sb-125	<2.2	<2.6	<2.0	<2.1	<2.1	<2.2
Cs-134	<0.8	18.0 ± 0.8	<0.7	<0.7	<0.7	<0.7
Cs-137	4.9 ± 0.8	89.4 ± 1.8	<0.8	<0.8	<0.8	<0.8
U-234	<0.1	0.4 ± 0.3	0.5 ± 0.4	0.6 ± 0.5	<0.2	<0.2
U-235	<0.1	<0.1	<0.2	<0.2	<0.2	<0.2
U-238	<0.1	<0.1	<0.2	0.6 ± 0.5	<0.2	<0.2
Pu-238	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1
Pu-239	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1

TABLE 5 (Continued)

RADIONUCLIDE CONCENTRATIONS MEASURED IN
INFLUENT AND EFFLUENT WATER SAMPLES FROM
WASTEWATER TREATMENT PLANTS
ROYERSFORD, SPRING CITY, AND POTTSTOWN, PENNSYLVANIA[a]

RADIONUCLIDE	RADIONUCLIDE CONCENTRATIONS (pCi/l) October 10, 1988					
	ROYERSFORD		SPRING CITY		POTTSTOWN	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
gross alpha	3.1 ± 1.3	7.1 ± 1.6	3.9 ± 1.3	2.1 ± 1.1	1.6 ± 1.1	1.2 ± 1.0
gross beta	74.9 ± 3.1	207 ± 5	14.0 ± 1.8	19.8 ± 1.9	27.4 ± 2.2	22.1 ± 2.1
H-3	<330	1400 ± 420	<330	<340	<360	<390
Cr-51	<15	<12	<13	<13	<12	<14
Mn-54	<0.9	<0.9	<1.0	<0.8	<0.9	<0.9
Co-58	4.6 ± 1.0	<1.1	<1.2	<1.1	<1.1	<1.1
Fe-59	<2.0	<2.2	<2.5	<2.2	<2.4	<2.6
Co-60	3.7 ± 1.1	3.3 ± 1.2	<1.0	<0.9	1.0 ± 0.8	<1.0
Zn-65	<1.7	<1.8	<2.2	<1.9	<1.9	<1.9
Sr-89	<2.0	<5.8	<0.4	<0.4	<0.3	<0.4
Sr-90	2.2 ± 0.2	13.5 ± 0.7	<0.5	<0.4	<0.4	<0.4
Zr-95	<1.9	<1.9	<2.3	<2.0	<2.0	<1.9
Nb-95	<1.3	<1.2	<1.5	<1.4	<1.4	<1.5
Ag-110m	<1.2	<0.9	<1.1	<0.9	<1.0	<0.9
Sb-125	<3.3	<2.3	<2.5	<2.7	<2.3	<2.7
Cs-134	34.3 ± 1.5	2.9 ± 1.1	<0.7	<0.9	<0.7	<0.9
Cs-137	128.7 ± 2.5	25.4 ± 1.1	<1.1	1.7 ± 0.9	<1.2	<1.0
U-234	<0.2	<0.2	<0.1	<0.6	<0.1	<0.2
U-235	<0.2	<0.2	<0.1	<0.6	<0.1	<0.2
U-238	<0.1	<0.2	<0.1	<0.7	<0.1	<0.2
Pu-238	<0.2	<0.1	<0.1	0.4 ± 0.3	<0.2	<0.4
Pu-239	<0.2	<0.1	<0.1	<0.1	<0.2	<0.4

[a]Refer to Figure 4.
[b]Uncertainties represent 95% confidence levels based only on counting statistics; additional analytical uncertainties of ± 6 to 10% have not been propagated into these data.

TABLE 6

RADIONUCLIDE CONCENTRATIONS MEASURED IN
SLUDGE SAMPLES COLLECTED DURING TRANSFER FOR DISPOSAL
ROYERSFORD, PENNSYLVANIA

Radionuclide	Dates (1988) 4/22	4/25	4/27	4/29
	Radionuclide Concentration (pCi/l)			
Cr-51	<77000[a]	<36000[a]	<26000[a]	<73000[a]
Mn-54	8760 ± 950[b]	9750 ± 320	6700 ± 410	11610 ± 770
Co-58	<1700	<740	1120 ± 610	<1600
Fe-59	<6500	<3300	<2400	<6200
Co-60	49700 ± 1300	57240 ± 640	3920 ± 610	57700 ± 1300
Zn-65	60800 ± 1100	10810 ± 740	7920 ± 710	12800 ± 2000
Sr-90	763 ± 19	1322 ± 34	1928 ± 36	135 ± 28
Zr-95	<3300	<1400	<1200	<3000
Nb-95	<5900	<2800	<2400	<4800
Ag-110m	<530	<320	<200	<550
Sb-125	<950	<530	<410	<1100
Cs-134	<420	1060 ± 210	910 ± 200	1640 ± 440
Cs-137	13190 ± 630	14310 ± 320	10450 ± 300	15330 ± 660
U-234	219.1 ± 8.2	272.5 ± 8.8	256.6 ± 9.9	210.3 ± 7.5
U-235	8.9 ± 2.2	9.9 ± 2.2	9.3 ± 2.5	5.3 ± 1.6
U-238	123.1 ± 6.2	144.0 ± 6.4	144.1 ± 7.4	113.4 ± 5.5
Pu-238	8.0 ± 1.4	6.7 ± 1.4	5.9 ± 1.5	4.2 ± 1.1
Pu-239/240	26.0 ± 2.5	36.2 ± 3.3	22.2 ± 2.8	21.6 ± 2.4
TOTAL	1.34 E05	9.50 E04	3.34 E04	9.96 E04

TABLE 6 (Continued)

RADIONUCLIDE CONCENTRATIONS MEASURED IN
SLUDGE SAMPLES COLLECTED DURING TRANSFER FOR DISPOSAL
ROYERSFORD, PENNSYLVANIA

Radionuclide	Dates (1988) 5/2	5/4	5/6	5/9
	Radionuclide Concentration (pCi/l)			
Cr-51	<28000[a]	<1700[a]	<2100[a]	<1200[a]
Mn-54	10000 ± 3100	42230 ± 230	7070 ± 280	6620 ± 290
Co-58	1220 ± 610	370 ± 210	1250 ± 240	1250 ± 220
Fe-59	<2700	630 ± 470	1620 ± 550	<590
Co-60	46510 ± 610	23000 ± 450	3080 ± 520	31780 ± 530
Zn-65	12140 ± 710	5370 ± 540	8370 ± 560	7330 ± 540
Sr-90	2187 ± 77	2600 ± 21	2400 ± 18	4100 ± 26
Zr-95	<1100	<300	<330	<350
Nb-95	<2100	<250	<280	<240
Ag-110m	<200	<140	<160	<160
Sb-125	<510	<330	<380	<390
Cs-134	1430 ± 100	610 ± 120	740 ± 160	1060 ± 150
Cs-137	13800 ± 3100	6000 ± 200	8040 ± 270	8760 ± 290
U-234	147.7 ± 6.6	282.5 ± 9.9	287 ± 11	322 ± 11
U-235	4.5 ± 1.3	7.0 ± 1.7	8.1 ± 2.6	8.2 ± 2.5
U-238	89.3 ± 5.2	152.8 ± 7.3	168.0 ± 8.0	163.5 ± 8.0
Pu-238	5.5 ± 1.4	5.2 ± 1.1	8.1 ± 1.3	9.4 ± 1.4
Pu-239/240	18.4 ± 2.5	37.0 ± 2.8	40.0 ± 3.0	74.5 ± 3.8
TOTAL	8.76 E04	8.13 E04	3.31 E04	6.15 E04

TABLE 6 (Continued)

RADIONUCLIDE CONCENTRATIONS MEASURED IN
SLUDGE SAMPLES COLLECTED DURING TRANSFER FOR DISPOSAL
ROYERSFORD, PENNSYLVANIA

Radionuclide	Dates (1988) 6/27	6/29	7/1	7/6
	Radionuclide Concentration (pCi/l)			
Cr-51	<2600[a]	<2500[a]	<620[a]	<640[a]
Mn-54	6100 ± 200	5350 ± 180	6030 ± 180	5670 ± 230
Co-58	370 ± 180	660 ± 200	650 ± 170	1040 ± 170
Fe-59	<720	<670	<650	<590
Co-60	28000 ± 350	25350 ± 340	27560 ± 330	27060 ± 330
Zn-65	7800 ± 440	7720 ± 420	7820 ± 400	8520 ± 410
Sr-90	2348 ± 50	553 ± 19	2551 ± 43	3858 ± 76
Zr-95	<350	<340	<310	<300
Nb-95	<420	<370	<320	<330
Ag-110m	<120	<110	<100	<100
Sb-125	<210	<210	<230	<230
Cs-134	733 ± 71	603 ± 66	682 ± 93	610 ± 100
Cs-137	7500 ± 160	6750 ± 150	6680 ± 130	6800 ± 140
U-234	274.6 ± 9.8	263.9 ± 8.5	258.6 ± 8.1	230.0 ± 8.1
U-235	11.3 ± 2.3	12.5 ± 2.3	8.6 ± 1.8	6.3 ± 1.6
U-238	166.5 ± 7.6	163.2 ± 6.8	158.7 ± 6.4	135.1 ± 6.2
Pu-238	7.9 ± 1.7	5.3 ± 1.3	6.5 ± 1.4	1.9 ± 0.7
Pu-239/240	21.6 ± 2.8	39.5 ± 3.4	52.5 ± 3.8	70.7 ± 1.5
TOTAL	7.45 E04	4.75 E04	5.25 E04	5.40 E04

TABLE 6 (Continued)

RADIONUCLIDE CONCENTRATIONS MEASURED IN
SLUDGE SAMPLES COLLECTED DURING TRANSFER FOR DISPOSAL
ROYERSFORD, PENNSYLVANIA

Radionuclide	Dates (1988) 7/8	7/11	9/23	9/27A[c]
	Radionuclide Concentration (pCi/l)			
Cr-51	<1100	<1900[a]	<820	<620
Mn-54	1484 ± 94	62600 ± 180	4720 ± 150	2900 ± 100
Co-58	220 ± 140	830 ± 180	640 ± 120	428 ± 58
Fe-59	<330	<570	<300	<210
Co-60	6800 ± 190	27170 ± 350	21900 ± 300	11860 ± 220
Zn-65	1900 ± 190	8560 ± 460	5660 ± 320	3770 ± 240
Sr-90	540 ± 20	1531 ± 29	1370 ± 30	1650 ± 40
Zr-95	<150	<310	<180	<130
Nb-95	<170	<280	<120	<90
Ag-110m	<56	<110	<88	<65
Sb-125	<120	<200	<200	<160
Cs-134	232 ± 53	539 ± 94	438 ± 75	255 ± 64
Cs-137	2300 ± 120	7580 ± 150	5460 ± 120	3160 ± 110
U-234	68.4 ± 7.1	248.7 ± 9.1	176 ± 8	60.9 ± 4.9
U-235	1.5 ± 1.3	10.0 ± 2.4	9.6 ± 2.5	3.3 ± 1.6
U-238	38.9 ± 5.5	154.3 ± 7.2	102 ± 7	28.9 ± 3.5
Pu-238	1.1 ± 0.8	16.4 ± 4.2	2.5 ± 1.0	1.0 ± 0.7
Pu-239/240	5.1 ± 1.7	21.9 ± 4.3	21.6 ± 2.5	4.4 ± 1.1
TOTAL	1.36 E04	1.09 E05	4.05 E04	2.41 E04

TABLE 6 (Continued)

RADIONUCLIDE CONCENTRATIONS MEASURED IN
SLUDGE SAMPLES COLLECTED DURING TRANSFER FOR DISPOSAL
ROYERSFORD, PENNSYLVANIA

Radionuclide	Dates (1988)			
	9/27B[C]	9/28A[C]	9/28B[C]	9/28C[C]
	Radionuclide Concentration (pCi/l)			
Cr-51	<450	<1100	<290	<920
Mn-54	1290 ± 85	6860 ± 190	183 ± 45	4900 ± 130
Co-58	213 ± 42	720 ± 140	630 ± 130	630 ± 130
Fe-59	<150	<370	<81	<330
Co-60	6100 ± 150	38100 ± 400	1400 ± 80	33400 ± 400
Zn-65	1790 ± 180	8780 ± 480	323 ± 58	4950 ± 360
Sr-90	390 ± 20	3610 ± 54	68 ± 9	3614 ± 72
Zr-95	<89	<220	<49	<210
Nb-95	<65	<160	<36	<150
Ag-110m	<49	<110	<20	<98
Sb-125	<120	<240	<65	<240
Cs-134	101 ± 54	820 ± 100	69 ± 25	560 ± 81
Cs-137	2114 ± 85	7890 ± 150	680 ± 50	7940 ± 170
U-234	101.9 ± 5.7	179 ± 9	6.0 ± 1.6	303 ± 10
U-235	3.4 ± 1.5	10.0 ± 2.7	0.3 ± 0 5	10.0 ± 2.3
U-238	57.4 ± 4.3	303 ± 12	3.5 ± 1.3	178 ± 8
Pu-238	1.3 ± 0.9	2.5 ± 1.5	<0.1	6.7 ± 1.4
Pu-239/240	18.1 ± 2.6	29.2 ± 3.5	0.5 ± 0.3	18.3 ± 2.2
TOTAL	1.22 E04	6.73 E04	3.36 E03	5.65 E04

TABLE 6 (Continued)

RADIONUCLIDE CONCENTRATIONS MEASURED IN
SLUDGE SAMPLES COLLECTED DURING TRANSFER FOR DISPOSAL
ROYERSFORD, PENNSYLVANIA

Radionuclide	Dates (1988) 9/28D[c]	9/29A[c]	9/29B[c]	BATCH AVERAGE
	Radionuclide Concentration (pCi/l)			
Cr-51	610 ± 380	<460	<260	d
Mn-54	1288 ± 75	1518 ± 83	160 ± 40	d
Co-58	148 ± 55	200 ± 64	60 ± 40	d
Fe-59	<130	<140	<82	d
Co-60	6160 ± 160	6000 ± 160	1900 ± 90	24000
Zn-65	11510 ± 160	1600 ± 170	530 ± 90	d
Sr-90	317 ± 16	361 ± 17	70 ± 10	2600
Zr-95	<95	<91	<55	d
Nb-95	<64	<65	<37	d
Ag-110m	<45	<46	<23	d
Sb-125	<120	<120	<52	d
Cs-134	95 ± 40	176 ± 48	40 ± 14	d
Cs-137	1611 ± 85	1820 ± 70	487 ± 45	6900
U-234	38.4 ± 3.4	67.1 ± 4.7	4.0 ± 1.9	190
U-235	1.2 ± 1.0	2.3 ± 1.3	<0.5	6.8
U-238	19.0 ± 2.5	21.1 ± 2.8	1.7 ± 1.3	120
Pu-238	1.2 ± 0.5	0.9 ± 0.5	<0.1	d
Pu-239/240	6.1 ± 1.1	4.8.± 1.0	0.6 ± 0.4	d
TOTAL	2.18 E04	1.18 E04	3.25 E03	3.38 E04

[a]Poor senisitivity is the result of greater than three half-lives decay time between sample collection and analysis. All data have been decay-corrected to the collection time.
[b]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of ± 6 to 10% have not been propagated into these data.
[c]Multiple samples taken on the same date.
[d]Average not determined.

TABLE 7

COMPARISON OF AVERAGE RADIONUCLIDE CONCENTRATIONS
IN SLUDGE SAMPLES COLLECTED DURING
1986, 1987, AND 1988
ROYERSFORD, PENNSYLVANIA

Radionuclide	Concentration (pCi/l)		
	1986	1987	1988
Co-60	55000 ± 200	55000 ± 200	24000 ± 170
Sr-90	2300 ± 40	2900 ± 4	2600 ± 10
Cs-137	15000 ± 100	18000 ± 100	6900 ± 200
U-234	260 ± 2	260 ± 2	190 ± 2
U-235	10.0 ± 0.5	9.9 ± 0.4	6.8 ± 0.6
U-238	100 ± 1	120 ± 1	120 ± 2
Pu-238	6.6 ± 0.3	12.0 ± 0.4	5.2 ± 0.3
Pu-239/240	12.7 ± 0.4	60.0 ± 0.9	25.7 ± 0.8

TABLE 8

DIRECT RADIATION LEVELS AT SITE 1[a]
ROYERSFORD, PENNSYLVANIA

Measurement	Dates 1988			
	April 20	June 21	August 16	October 10
Exposure Rate at 1m Above Surface				
Range (μR/h)	12-15	12-14	14	14-17
Average (μR/h)	13.7	13.4	14	15.4
Exposure Rate at Surface Contact				
Range (μR/h)	12-15	12-14	14-15	13-18
Average (μR/h)	13.7	13.4	14.1	15.7
Beta-Gamma Dose Rate At Surface				
Range (μRad/h)	18-46	15-40	15-47	19-39
Average (μRad/h)	28.4	28.6	24.0	30.0

[a]Refer to Figure 2.

TABLE 9

DIRECT RADIATION LEVELS AT SITE 2[a]
ROYERSFORD, PENNSYLVANIA

Measurement	Dates 1988			
	April 20	June 21	August 16	October 10
Exposure Rate at 1m Above Surface				
Range (μR/h)	12-14	12-16	12-14	12-14
Average (μR/h)	12.2	14.2	13.1	12.4
Exposure Rate at Surface Contact				
Range (μR/h)	12	12-17	10-14	12-14
Average (μR/h)	12	14.1	12.4	13.3
Beta-Gamma Dose Rate At Surface				
Range (μRad/h)	12-27	12-41	14-47	14-33
Average (μRad/h)	20.1	24.7	30.0	22.6

[a]Refer to Figure 2.

TABLE 10

COMPARSION OF AVERAGE DIRECT RADIATION LEVELS AT SITE 1[a]
DURING 1986, 1987, AND 1988
ROYERSFORD, PENNSYLVANIA

Measurement	Year		
	1986[b]	1987[c]	1988
Exposure Rate at 1m Above Surface			
Average (μR/h)	13.6	14.3	14.1
Exposure Rate at Surface Contact			
Average (μR/h)	14.3	14.7	14.2
Beta-Gamma Dose Rate At Surface			
Average (μRad/h)	28.4	31.1	27.8

[a]Refer to Figure 2.
[b]Reference 1.
[c]Reference 2.

TABLE 11

COMPARSION OF AVERAGE DIRECT RADIATION LEVELS AT SITE 2[a]
DURING 1986, 1987, AND 1988
ROYERSFORD, PENNSYLVANIA

Measurement	Year		
	1986[b]	1987[c]	1988
Exposure Rate at 1m Above Surface			
Average (μR/h)	16.3	16.3	13.0
Exposure Rate at Surface Contact			
Average (μR/h)	17.1	16.7	13.0
Beta-Gamma Dose Rate At Surface			
Average (μRad/h)	30.3	30.0	21.9

[a]Refer to Figure 2.
[b]Reference 1.
[c]Reference 2.

TABLE 12

RADIONUCLIDE CONCENTRATIONS MEASURED IN THE UPPER 15 CM SOIL
SITE 1[a]
ROYERSFORD, PENNSYLVANIA

Radionuclide	Concentration (pCi/g)				
	April 20	June 21	August 16	October 10	Average[b]
Cr-51	<0.3	<0.2	<0.2	<0.7	
Mn-54	<0.1	0.2 ± 0.1[c]	0.2 ± 0.1	<0.1	
Co-58	<0.1	<0.1	<0.1	<0.1	
Fe-59	<0.1	<0.1	<0.1	<0.2	
Co-60	0.3 ± 0.1	0.3 ± 0.1	1.7 ± 0.1	1.0 ± 0.1	0.8 ± 0.1
Zn-65	<0.1	<0.1	<0.1	<0.1	
Sr-89	<0.1	<0.2	<0.1	1.4 ± 0.2	
Sr-90	<0.1	<0.1	<0.1	<0.1	<0.1
Zr-95	<0.1	<0.1	<0.1	<0.1	
Nb-95	<0.1	<0.1	<0.1	<0.1	
Ag-110m	<0.1	<0.1	<0.1	<0.1	
Sb-125	<0.1	<0.1	<0.1	<0.1	
Cs-134	<0.1	<0.1	<0.1	<0.1	
Cs-137	0.3 ± 0.1	0.2 ± 0.1	0.7 ± 0.1	0.6 ± 0.1	0.5 ± 0.1
U-234	1.5 ± 0.2	0.8 ± 0.1	1.3 ± 0.2	1.6 ± 0.2	1.3 ± 0.1
U-235	<0.1	<0.1	<0.1	<0.1	<0.1
U-238	1.5 ± 0.2	0.5 ± 0.1	1.4 ± 0.2	1.5 ± 0.2	1.2 ± 0.1
Pu-238	<0.1	<0.1	<0.1	<0.1	
Pu-239/240	<0.1	<0.1	<0.1	<0.1	

[a]Refer to Figure 2.
[b]Average soil concentrations of six major radionuclides selected for pathway analyses.
[c]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of ± 6 to 10% have not been propagated into these data.

TABLE 13

RADIONUCLIDE CONCENTRATIONS MEASURED IN THE UPPER 15 CM SOIL
SITE 2[a]
ROYERSFORD, PENNSYLVANIA

Radionuclide	Concentration (pCi/g)				
	April 20	June 21	August 16	October 10	Average[b]
Cr-51	<0.3	<0.3	<0.2	<0.6	
Mn-54	<0.1	0.2 ± 0.1[c]	<0.1	<0.1	
Co-58	<0.1	<0.1	<0.1	<0.1	
Fe-59	<0.1	<0.1	<0.1	<0.2	
Co-60	<0.1	1.3 ± 1.0	0.4 ± 0.1	0.2 ± 0.1	0.6 ± 0.3
Zn-65	<0.1	<0.1	<0.1	<0.1	
Sr-89	<0.1	0.4 ± 0.1	<0.1	1.2 ± 0.2	
Sr-90	<0.1	<0.1	<0.1	<0.1	<0.1
Zr-95	<0.1	<0.1	<0.1	<0.1	
Nb-95	<0.1	<0.1	<0.1	<0.1	
Ag-110m	<0.1	<0.1	<0.1	<0.1	
Sb-125	<0.1	<0.1	<0.1	<0.1	
Cs-134	<0.1	<0.1	<0.1	<0.1	
Cs-137	0.3 ± 0.1	0.7 ± 0.1	0.4 ± 0.1	0.3 ± 0.1	0.4 ± 0.1
U-234	1.6 ± 0.2	2.3 ± 0.3	1.8 ± 0.2	1.6 ± 0.2	1.8 ± 0.1
U-235	<0.1	<0.1	<0.1	<0.1	<0.1
U-238	1.6 ± 0.1	1.4 ± 0.2	1.7 ± 0.2	1.4 ± 0.2	1.5 ± 0.1
Pu-238	<0.1	<0.1	<0.1	<0.1	
Pu-239/240	<0.1	<0.1	<0.1	<0.1	

[a]Refer to Figure 2.
[b]Average soil concentrations of six major radionuclides selected for pathway analyses.
[c]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of ± 6 to 10% have not been propagated into these data.

TABLE 14

RADIONUCLIDE CONCENTRATIONS IN SUB-SURFACE SOIL (15-30 CM SOIL)
SITE 1[a]
ROYERSFORD, PENNSYLVANIA

Radionuclide	Concentration (pCi/g)				
	April 20	June 21	August 16	October 10	Average[b]
Cr-51	<0.4	<0.2	<0.2	<0.7	
Mn-54	<0.1	<0.1	<0.1	0.2 ± 0.1[c]	
Co-58	<0.1	<0.1	<0.1	<0.1	
Fe-59	<0.1	<0.1	<0.1	<0.1	
Co-60	<0.1	<0.1	0.3 ± 0.1	0.6 ± 0.1	<0.3
Zn-65	<0.3	<0.1	<0.1	<0.1	
Sr-89	<0.1	<0.2	<0.1	1.0 ± 0.2	
Sr-90	<0.1	<0.1	<0.1	<0.1	<0.1
Zr-95	<0.1	<0.1	<0.1	<0.1	
Nb-95	<0.1	<0.1	<0.1	<0.1	
Ag-110m	<0.1	<0.1	<0.1	<0.1	
Sb-125	<0.1	<0.1	<0.1	<0.1	
Cs-134	<0.1	<0.1	<0.1	<0.1	
Cs-137	<0.1	0.2 ± 0.1	0.3 ± 0.1	0.7 ± 0.1	<0.3
U-234	2.5 ± 0.2	1.4 ± 0.2	1.2 ± 0.2	1.4 ± 0.2	1.6 ± 0.1
U-235	<0.1	<0.1	<0.1	<0.1	<0.1
U-238	1.3 ± 0.1	1.2 ± 0.2	1.3 ± 0.2	1.4 ± 0.2	1.3 ± 0.1
Pu-238	<0.1	<0.1	<0.1	<0.1	
Pu-239/240	<0.1	<0.1	<0.1	<0.1	

[a]Refer to Figure 2.
[b]Average soil concentrations of six major radionuclides selected for pathway analyses.
[c]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of ± 6 to 10% have not been propagated into these data.

TABLE 15

RADIONUCLIDE CONCENTRATIONS IN SUB-SURFACE SOIL (15-30 CM SOIL)
SITE 2[a]
ROYERSFORD, PENNSYLVANIA

Radionuclide	Concentration (pCi/g)				
	April 20	June 21	August 16	October 10	Average[b]
Cr-51	<0.3	<0.3	<0.2	<0.6	
Mn-54	<0.1	<0.1	<0.1	<0.1	
Co-58	<0.1	<0.1	<0.1	<0.1	
Fe-59	<0.1	<0.1	<0.1	<0.1	
Co-60	<0.1	0.3 ± 0.1[c]	0.2 ± 0.1	<0.1	<0.2
Zn-65	<0.1	<0.1	<0.1	<0.1	
Sr-89	<0.1	0.2 ± 0.1	<0.1	1.4 ± 0.2	
Sr-90	<0.1	<0.1	<0.1	<0.1	<0.1
Zr-95	<0.1	<0.1	<0.1	<0.1	
Nb-95	<0.1	<0.1	<0.1	<0.1	
Ag-110m	<0.1	<0.1	<0.1	<0.1	
Sb-125	<0.1	<0.1	<0.1	<0.1	
Cs-134	<0.1	<0.1	<0.1	<0.1	
Cs-137	<0.1	0.2 ± 0.1	0.4 ± 0.1	0.3 ± 0.1	<0.3
U-234	1.7 ± 0.2	1.6 ± 0.2	1.5 ± 0.2	1.5 ± 0.2	1.6 ± 0.1
U-235	<0.1	<0.1	<0.1	<0.1	<0.1
U-238	1.6 ± 0.1	1.4 ± 0.1	1.4 ± 0.2	1.6 ± 0.2	1.5 ± 0.1
Pu-238	<0.1	<0.1	<0.1	<0.1	
Pu-239/240	<0.1	<0.1	<0.1	<0.1	

[a]Refer to Figure 2.
[b]Average soil concentrations of six major radionuclides selected for pathway analyses.
[c]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory uncertainties of ± 6 to 10% have not been propagated into these data.

TABLE 16

COMPARSION OF AVERAGE RADIONUCLIDE CONCENTRATIONS IN SURFACE SOIL COLLECTED DURING THE 1986, 1987, AND 1988 ROYERSFORD, PENNSYLVANIA

Radionuclide	Average Concentration (pCi/g)		
	1986[a]	1987[b]	1988
Co-60	2.8	1.2	0.7
Sr-90	<0.4	<0.4	<0.1
Cs-137	<0.8	0.7	0.4
U-234	4.3	1.5	1.6
U-235	0.2	0.1	<0.1
U-238	2.8	1.6	1.4

[a]Reference 1.
[b]Reference 2.

TABLE 17

RADIONUCLIDE CONCENTRATIONS IN WINTER WHEAT FROM STUDY SITES
ROYERSFORD, PENNSYLVANIA

Radionuclide[a]	Concentration (pCi/kg)					
	Site 1		Site 2			
	June 21		April 20		June 21	
	Uptake	Wash Fraction	Uptake	Wash Fraction	Uptake	Wash Fraction
Co-60	<6	<4	<2	<2	<4	<4
Sr-90	49 ± 3[b]	8 ± 7	9 ± 11	<4	59 ± 3	8 ± 7
Cs-137	<3	<4	2 ± 1	4 ± 4	<4	5 ± 3
U-234	<1	2 ± 1	13 ± 3	6 ± 3	5 ± 2	1 ± 1
U-235	<1	<1	1 ± 1	2 ± 2	<1	<1
U-238	<1	<1	2 ± 1	4 ± 2	2 ± 1	<1

[a]Levels of other radionculides were less than the instrument sensitivities.
[b]Uncertainties represent the 95% confidence levels, based only on counting statistics; additional laboratory 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. Murphy, G.L. and Berger, J.D., Radiological Impacts of Effluent Releases to the Sanitary Sewer from Interstate Nuclear Services Corporation, Royersford, Pennsylvania, (Phase II), Oak Ridge Associated Universities, June 1988.

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

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

5. 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.

6. 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.

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

8. 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.

9. 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)

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

Surface Scans

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 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 several 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 $\pm$ 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' Environmental Survey and Site Assessment Program: "Survey Procedures Manual", Revision 4, August 1988; "Laboratory Procedures Manual", Revision 4, August 1988 and "Quality Assurance Manual", Revision 2, December 1988.

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 Program.

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 17 μR/h on Site 1, the ORAU measurements throughout the year indicated a more likely average exposure rate of 14 μR/h, slightly less than the 1986 and 1987 data. This is 3 μR/h above the average background level measured in the area. Exposure is assumed to be 4 hr/d, 240 d/y; the total annual increase in gamma exposure due to the sludge-treated field would be 2.9 mR, which would result in an annual dose equivalent of 2.5 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 $\mu g/m^5$. Airborne dust particles were assumed to be entirely from the contaminated soil and to contain the same concentrations of radionuclides as measured in the surface layer of soil. Average concentrations of the six radionuclides of concern, measured in the upper 15 cm of soil were:

Co-60	0.7 pCi/g
Sr-90	<0.1 pCi/g
Cs-137	0.4 pCi/g
U-234	1.6 pCi/g
U-235	<0.1 pCi/g
U-238	1.4 pCi/g

Assuming an inhalation rate of 20 l/m and an occupancy of 4 h/d, 240 d/y, 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	0.3 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.[6] 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	0.7 pCi/g
Sr-90	0.1 pCi/g*
Cs-137	0.4 pCi/g
U-234	1.6 pCi/g
U-235	0.1 pCi/g*
U-238	1.4 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	6.6 pCi/kg
Sr-90	1.7 pCi/kg
Cs-137	4.0 pCi/kg
U-234	4.0 pCi/kg
U-235	0.3 pCi/kg
U-238	3.5 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.[6] The total activities ingested annually were calculated to be:

Co-60	340 pCi
Sr-90	88 pCi
Cs-137	210 pCi
U-234	210 pCi
U-235	16 pCi
U-238	180 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	4.3 pCi/kg
Sr-90	0.05 pCi/kg
Cs-137	0.8 pCi/kg
U-234	0.07 pCi/kg
U-235	0.01 pCi/kg
U-238	0.06 pCi/kg

Annual consumption of meat for the maximally exposed individual is 110kg.[6] It is assumed that 50% of the individuals meat diet is from this source. Total radionuclide intake by this pathway is therefore:

Co-60	240 pCi
Sr-90	2.8 pCi
Cs-137	44 pCi
U-234	3.9 pCi
U-235	.55 pCi
U-238	3.3 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	0.4	pCi/l
Sr-90	0.08	pCi/l
Cs-137	2.4	pCi/l
U-234	0.13	pCi/l
U-235	0.009	pCi/l
U-238	0.11	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.[6] The annual radionuclide ingestion via this pathway is:

Co-60	120	pCi
Sr-90	25	pCi
Cs-137	740	pCi
U-234	40	pCi
U-235	2.8	pCi
U-238	34	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 15 cm of soil (Section 2 above, of the maximally exposed individual calculations), the total radionuclide intake would be:

Co-60	70	pCi
Sr-90	10	pCi

Cs-137	40 pCi
U-234	160 pCi
U-235	10 pCi
U-238	140 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.[6] Total annual intake would be:

Co-60	130	pCi
Sr-90	26	pCi
Cs-137	790	pCi
U-234	43	pCi
U-235	3	pCi
U-238	36	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 1988, no sludge from the Royersford Wastewater Treatment Plant was applied to the study plots; however, 9 truckloads (2.1×10^5 l) of sludge was applied to other agricultural lands. The 1988 population dose estimate was

derived from direct radiation levels and soil concentrations determined from the study plots. For the purpose of this estimate, it was assumed that the areas of treatment are similar in size (0.5 ha or larger), number (20 sites), and application concentration (approximately 11.5 l/m^2).

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 2.5 mrem x 20 areas x 2 persons/area = 100 person-mrem.

Previous 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 14 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)[7]:

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 270 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	1.1 E+04 pCi
Sr-90	1.2 E+04 pCi
Cs-137	1.3 E+05 pCi
U-234	2.8 E+02 pCi
U-235	2.1 E+01 pCi
U-238	2.5 E+02 pCi

Fractions of meat production, ingested by each age group are:[7]

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 8 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	2.8E+03 pCi
Sr-90	5.6E+02 pCi
Cs-137	1.7E+04 pCi
U-234	9.1E+02 pCi
U-235	6.3E+01 pCi
U-238	7.7E+02 pCi

Fractional milk consumption by age groups[7] 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 2.3 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 380 person-mrem or 0.38 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.[8]

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.[8]

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.[5,9]

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.[5,9]

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.[5,9]

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.[5,9]

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.[5,9]

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.[5,9]

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	1.4E-01	3.6E-01
LLI Wall	5.8E-06	2.2E-06	1.6E-06	4.4E-05	5.0E-06	8.4E-05	1.4E-04
Kidneys	1.2E-05	9.8E-07	5.1E-06	6.8E-04	3.0E-05	4.5E-04	1.2E-3
Liver	2.4E-05	9.8E-07	5.2E-06	6.5E-6	6.3E-07	5.3E-06	4.2E-05
Gonads	3.4E-06	9.8E-07	5.0E-06	6.4E-6	3.2E-07	4.4E-06	2.1E-05
Red Marrow	1.2E-05	1.6E-04	4.9E-06	9.6E-05	3.8E-06	6.0E-05	3.4E-04
Endostial Bone	1.0E-05	3.5E-04	5.3E-06	1.4E-03	5.8E-05	8.7E-04	2.7E-03
Thyroid	1.2E-05	9.8E-07	4.5E-06	6.4E-06	4.1E-07	4.8E-06	2.9E-05
Effective	3.6E-05	3.0E-05	3.1E-06	2.6E-02	1.2E-03	1.7E-02	4.4E-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[7]; other values from Regulatory Guide 1.109[6].

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	2.9E-03	3.5E-04	9.9E-02	3.7E-03	2.6 E-04	2.7E-04	2.0E-02
LLI Wall	1.4E-02	7.0E-03	1.2E-02	3.7E-02	2.9E-03	2.9E-02	1.0E-01
Kidneys	1.9E-03	3.5E-04	1.1E-02	3.7E-01	2.4E-02	2.7E-01	6.8E-01
Liver	2.3E-03	3.5E-04	1.1E-02	3.4E-03	2.2E-04	2.4E-03	2.0E-02
Gonads	4.2E-03	3.5E-04	1.1E-02	3.4E-03	2.3E-04	2.4E-03	2.2E-02
Red Marrow	1.8E-03	5.8E-02	8.8E-03	4.8E-02	2.9E-03	3.4E-02	1.5E-01
Endostial Bone	1.4E-03	1.3E-01	4.4E-02	7.4E-01	4.6E-02	5.1E-01	1.5E+00
Thyroid	1.1E-03	3.5E-04	9.9E-03	3.4E-03	2.3E-04	2.6E-03	1.8E-02
Effective	2.9E-03	1.2E-02	9.9E-03	5.0E-02	3.2E-03	3.6E-02	1.1E-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	2.1E-03	1.1E-05	2.1E-03	6.7E-05	8.9E-06	5.1E-05	4.3E-03
LLI Wall	9.4E-08	2.3E-04	2.4E-03	6.6E-04	9.9E-05	5.4E-04	3.9E-03
Kidneys	1.4E-03	1.1E-05	2.3E-03	6.6E-03	8.3E-04	5.0E-03	1.6E-02
Liver	1.6E-03	1.1E-05	2.3E-03	6.1E-05	7.6E-06	4.4E-05	4.0E-03
Gonads	3.0E-03	1.1E-05	2.2E-03	6.1E-05	8.0E-06	4.4E-05	5.3E-03
Red Marrow	1.3E-03	1.8E-03	1.9E-03	9.0E-04	9.9E-05	6.3E-04	6.6E-03
Endostial Bone	9.4E-04	4.3E-03	9.1E-03	1.4E-02	1.6E-03	9.3E-03	3.9E-02
Thyroid	7.5E-04	1.1E-05	2.1E-03	6.1E-05	8.0E-06	4.7E-05	3.0E-03
Effective	2.1E-03	3.6E-04	2.1E-03	9.3E-04	1.1E-04	6.7E-04	6.3E-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	1.0E-03	1.0E-04	3.6E-02	6.9E-04	4.5E-05	1.0E-04	3.8E-02
LLI Wall	4.8E-03	2.0E-04	4.1E-02	6.8E-03	5.0E-04	1.1E-03	5.4E-02
Kidneys	6.9E-04	1.0E-04	3.9E-02	6.8E-02	4.2E-03	1.0E-02	1.2E-01
Liver	8.2E-04	1.0E-04	3.9E-02	6.3E-04	3.9E-05	8.8E-05	4.1E-02
Gonads	1.5E-03	1.0E-04	3.6E-02	6.3E-04	4.1E-05	8.8E-05	3.8E-02
Red Marrow	6.3E-04	1.6E-02	3.1E-02	9.2E-03	5.0E-04	1.3E-03	5.9E-02
Endostial Bone	4.8E-04	3.8E-02	1.5E-01	1.4E-01	8.1E-03	1.8E-02	3.5E-01
Thyroid	3.7E-04	1.0E-04	3.6E-02	6.3E-04	4.1E-05	9.1E-05	3.7E-02
Effective	1.0E-03	3.2E-03	3.5E-02	9.6E-03	5.6E-04	1.3E-03	5.1E-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	3.2E+00	3.6E-01	2.0E-02	4.3E-03	3.8E-02	3.6E+00
LLI Wall	3.2E+00	1.4E-04	1.0E-01	3.9E-03	5.4E-02	3.4E+00
Kidneys	3.2E+00	1.2E-03	6.8E-01	1.6E-02	1.2E-01	4.0E+00
Liver	3.2E+00	4.2E-05	2.0E-02	4.0E-03	4.1E-02	3.3E+00
Gonads	3.2E+00	2.1E-05	2.2E-02	5.3E-03	3.8E-02	3.3E+00
Red Marrow	3.2E+00	3.4E-04	1.5E-01	6.6E-03	5.9E-02	3.4E+00
Endostial Bone	3.2E+00	2.7E-03	1.5E+00	3.9E-02	3.5E-01	5.1E+00
Thyroid	3.2E+00	2.9E-05	1.8E-02	3.0E-03	3.7E-02	3.3E+00
Effective	3.2E+00	4.4E-02	1.1E-01	6.3E-03	5.1E-02	3.4E+00

TABLE C-8

DOSE COMMITMENT TO CHILD FROM INGESTION OF SOIL

Organ	Dose Commitment (mrem/year exposure)						Total
	Co-60	Sr-90	Cs-137	U-234	U-235	U-238	
Lung	6.5E-04	1.5E-04	1.3E-03	1.3E-02	7.8E-04	9.9E-03	2.6E-02
LLI Wall	9.3E-03	2.7E-03	1.4E-03	1.1E-01	6.8E-03	9.1E-02	2.2E-01
Kidneys	---[a]	1.5E-04	1.4E-03	1.1E+00	5.9E-02	8.2E-01	2.0E+00
Liver	1.6E-03	1.5E-04	1.4E-03	1.1E-02	6.1E-04	8.2E-03	2.4E-02
Gonads	2.4E-03	1.5E-04	1.4E-03	1.2E-02	7.0E-04	9.1E-03	2.6E-02
Red Marrow	7.7E-04	6.0E-03	1.4E-03	8.8E-02	4.3E-03	6.4E-02	1.6E-01
Endostial Bone	---	1.5E-02	6.0E-03	2.4E-02	1.3E-01	1.6E+00	1.8E+00
Thyroid	---	1.5E-04	1.4E-03	1.2E-02	7.0E-04	9.9E-03	2.4E-02
Effective	1.7E-03	1.5E-03	1.4E-03	1.5E-01	7.6E-03	1.1E-01	2.7E-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)						Total
	Co-60	Sr-90	Cs-137	U-234	U-235	U-238	
Lung	1.2E-03	3.9E-04	2.5E-02	3.5E-03	2.3E-04	2.6E-03	3.3E-02
LLI Wall	1.7E-02	7.1E-03	2.8E-02	2.9E-02	2.1E-03	2.3E-02	1.1E-01
Kidneys	---[a]	3.9E-04	2.7E-02	2.9E-01	1.8E-02	2.1E-01	5.5E-01
Liver	2.9E-03	3.9E-04	2.8E-02	3.0E-03	1.8E-04	2.2E-03	3.7E-02
Gonads	4.4E-03	3.9E-04	2.9E-02	3.2E-03	2.1E-04	2.3E-03	4.0E-02
Red Marrow	1.4E-03	1.5E-02	2.7E-02	2.4E-02	1.3E-03	1.6E-02	8.5E-02
Endostial Bone	---	3.9E-02	1.2E-01	6.5E-01	3.8E-02	4.3E-01	1.3E+00
Thyroid	---	3.9E-04	2.8E-02	3.2E-03	2.1E-04	2.4E-02	5.6E-02
Effective	3.1E-03	3.93-03	2.6E-02	4.1E-02	2.3E-03	2.8E-02	1.0E-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	9.4E+04	1.4E+05	1.1E+05
Sr-90	0	2.4E+04	3.7E+04	2.8E+04
Cs-137	0	5.7E+04	8.7E+04	6.6E+04
U-234	0	5.7E+04	8.7E+04	6.6E+04
U-235	0	4.3E+03	6.5E+03	4.3E+03
U-238	0	5.0E+04	7.6E+04	5.7E+04

TABLE C-11

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

Radionuclide	Age Group			
	Infants	Children	Teenagers	Adults
Co-60	0	2.2 E+00	1.5 E+00	9.2 E-01
Sr-90	0	3.5 E+00	9.4 E+00	3.6 E+00
Cs-137	0	1.9 E+00	4.3 E+00	3.1 E+00
U-234	0	5.5 E+01	6.5 E+01	1.6 E+01
U-235	0	3.3 E+00	2.6 E+00	2.9 E+00
U-238	0	3.9 E+01	4.7 E+01	1.1 E+01
TOTAL	0	1.0 E+02	1.3 E+02	3.8 E+01

TABLE C-12

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

Radionuclide	Age Group			
	Infants	Children	Teenagers	Adults
Co-60	0	8.6E+02	1.6E+03	8.5E+03
Sr-90	0	9.4E+02	1.8E+03	9.3E+03
Cs-137	0	1.0E+04	1.9E+04	1.0E+05
U-234	0	2.2E+01	4.2E+01	2.2E+02
U-235	0	1.6E+00	3.1E+00	1.6E+01
U-238	0	2.0E+01	3.7E+01	1.9E+02

TABLE C-13

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

Radionuclide	Age Group			
	Infants	Children	Teenagers	Adults
Co-60	0	2.0 E-02	1.8 E-02	7.4 E-02
Sr-90	0	1.4 E-01	4.5 E-01	1.2 E+00
Cs-137	0	3.3 E-01	9.4 E-01	4.7 E+00
U-234	0	2.1 E-02	3.1 E-02	5.2 E-02
U-235	0	1.2 E-03	1.2 E-03	3.2 E-03
U-238	0	1.5 E-02	2.2 E-02	3.8 E-02
TOTAL	0	5.3 E-01	1.5 E+00	6.1 E+00

TABLE C-14

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

Radionuclide	Age Group			
	Infants	Children	Teenagers	Adults
Co-60	5.0 +01	5.2E+02	7.6E+02	1.5E+03
Sr-90	1.0E+01	1.0E+02	1.5E+02	2.9E+02
Cs-137	3.0E+02	3.1E+03	4.6E+03	8.9E+03
U-234	1.6E+01	1.7E+02	2.5E+02	4.8E+02
U-235	1.1E+00	1.2E+01	1.7E+01	3.3E+01
U-238	1.4E+01	1.4E+02	2.1E+02	4.0E+02

TABLE C-15

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

Radionuclide	Age Group			
	Infants	Children	Teenagers	Adults
Co-60	3.4 E-03	1.3 E-02	8.2 E-03	1.3 E-02
Sr-90	7.1 E-03	1.6 E-01	3.7 E-02	3.7 E-02
Cs-137	4.9 E-02	1.1 E-01	2.3 E-01	4.2 E-01
U-234	2.5 E-01	1.6 E-01	1.9 E-01	1.2 E-01
U-235	1.4 E-02	9.1 E-03	6.8 E-03	6.6 E-03
U-238	1.8 E-01	1.1 E-01	1.3 E-01	8.0 E-02
TOTAL	5.0 E-01	5.6 E-01	6.0 E-01	6.8 E-01