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Evaluation of Exposure Pathways to Man From Disposal of Radioactive Materials Into Sanitary Sewer Systems

Prepared by
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Pacific Northwest Laboratory
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Abstract

The discharge of radioactive materials to municipal sewer systems is regulated by the U.S. Nuclear Regulatory Commission (NRC) in accordance with 10 CFR 20, or by agreement states in accordance with state regulations. There is a need to evaluate the radiological hazard to the public resulting from release of various radionuclides into sanitary sewer systems at the maximum limits specified in 10 CFR 20.

The results of a study conducted by Pacific Northwest Laboratory (PNL) for the NRC are described in this report. The generic study was conducted to evaluate potential public doses from exposure to radionuclides in sewage sludge during its treatment and disposal. This report considers release of licensee wastes apart from excreta from individuals undergoing medical diagnostic or therapeutic uses of radioactive material. A separate study will be conducted to more carefully evaluate the potential doses resulting from discharge of such patient excreta. The majority of the deterministic results from this evaluation indicated a comfortable margin between the prudently conservative estimates of annual doses and applicable permissible levels.

Using Latin Hypercube sampling methods, a stochastic uncertainty and sensitivity analysis was conducted to establish potential ranges over which individual doses may vary and to identify the most sensitive parameters and assumptions used in the analysis.

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Summary

In accordance with 10 CFR 20, the U.S. Nuclear Regulatory Commission (NRC) regulates licensees' discharges of small quantities of radioactive materials into sanitary sewer systems. This generic study was initiated by Pacific Northwest Laboratory (PNL) for the NRC to examine the potential radiological hazard to the public resulting from exposure to radionuclides in sewage sludge during its treatment and disposal. Licensee wastes, except excreta from individuals undergoing medical diagnostic or therapeutic uses of radioactive material, are considered in this study. A separate study will be conducted to more carefully evaluate the potential doses resulting from discharge of such patient excreta.

Eleven scenarios were developed to characterize potential exposures to radioactive materials during sewer system operations and sewage sludge treatment and disposal activities and during the extended time frame following sewage sludge disposal. The scenarios, assumptions, and parameter values were selected in a manner to produce prudently conservative (not worst-case) estimates of the individual radiation doses. Two sets of deterministic dose calculations were performed; one to evaluate potential doses based on the radionuclides and quantities associated with documented case histories of sewer system contamination and a second, somewhat more conservative set, based on theoretical discharges at the maximum allowable levels for a more comprehensive list of 63 radionuclides. This approach provided an evaluation of actual radionuclide discharges and a screening of radionuclides and exposure situations to identify and separate those that were clearly of no concern from those that may be of potential concern.

The results of the deterministic evaluation of theoretical discharges at the currently regulated levels indicated that there were only five radionuclides with the potential to exceed the permissible individual dose levels that are produced and used in large enough quantities to be of concern. These radionuclides are ^{60}Co, ^{90}Sr, ^{137}Cs, ^{192}Ir, and ^{241}Am. As a partial verification of the modeling and scenario approach used for this study, a limited comparison with scenarios considered in the IMPACTS-BRC (O'Neal and Lee 1990) code was conducted.

A stochastic uncertainty and sensitivity analysis, using Latin Hypercube sampling methods, was conducted to identify the most sensitive parameters and assumptions in the analysis and to establish potential ranges over which the individual doses may vary. Inventory of radioactive material in a sanitary sewer system was found to be the most sensitive parameter in the analysis. River flow rate, Chi/Q, and radioactive decay time were found to be the next most sensitive parameters.

The results of the stochastic uncertainty and sensitivity analysis were also used to develop a collective dose estimate. The collective doses for the various radionuclides and scenarios range from 0.4 person-rem for ^{137}Cs in Scenario No. 5 (sludge incinerator effluent) to 420 person-rem for ^{137}Cs in Scenario No. 3 (sewage treatment plant liquid effluent). None of the 22 scenario/radionuclide combinations considered have collective doses greater than 1000 person-rem/yr. However, the total collective dose from these 22 combinations was found to be about 2100 person-rem.

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Acronyms

ALARA	as low as reasonably achievable
ALI	annual limit on intake
ANSI	American National Standards Institute
EPA	U.S. Environmental Protection Agency
ICRP	International Commission on Radiological Protection
NPDES	National Pollutant Discharge Elimination System
NRC	U.S. Nuclear Regulatory Commission
NSPS	New Source Performance Standard
PNL	Pacific Northwest Laboratory
PRCC	partial rank correlation coefficient
QA	quality assurance
STP	sewage treatment plant
TEDE	total effective dose equivalent

1 Introduction

During the past several years, increased attention has been focused on the presence and control of hazardous materials in the environment. As a result, numerous advances in pollution control technology have been implemented to ensure continued protection of the environment. Among these advances are improvements in sewage treatment processes that have achieved higher levels of retention of potentially hazardous contaminants found in municipal sewer systems. Dissolved and dispersable contaminants are retained and concentrated in the sewage sludge, while the resulting purified water is released to the environment.

In a number of recent instances, low-level concentrations of radioactive materials have been found in municipal sewer systems into which radioactive materials had been discharged. Although the discharges were in accordance with applicable regulations, elevated levels of radioactivity were found between the discharge sources and the treatment facilities, and within the treatment facilities. These situations raise the concern that while sewage treatment processes have improved and become more effective, these improvements may result in the undesirable reconcentration of radioactive or other hazardous materials.

The discharge of radioactive materials into municipal sewer systems has been regulated by the U.S. Nuclear Regulatory Commission (NRC) in accordance with 10 CFR 20 and, in some instances, by state agencies in accordance with state regulations. These regulations were developed because of concerns were developed because of concerns about potential harmful concentrations of radioactive materials in sewage treatment facilities and in the effluents from treatment facilities.

Pacific Northwest Laboratory (PNL)[1] conducted a generic study to evaluate potential public doses from exposure to radionuclides in sewage sludge during its treatment and disposal, and resulting from release of radionuclides into sanitary sewer systems at the maximum limits specified in 10 CFR 20. This report considers release of licensee wastes apart from excreta from individuals undergoing medical diagnostic or therapeutic uses of radioactive material. A separate study will be conducted to more carefully evaluate the potential doses resulting from discharge of such patient excreta. Current sewage treatment and sludge disposal practices were examined and several potential exposure scenarios were developed, focusing primarily on sludge incineration and sludge application as a soil supplement.

A radiation pathway and exposure scenario analysis was conducted for potential exposure situations involving releases to sanitary sewer systems. The scenario analysis was conducted in a manner similar to the one used to develop a technical basis to translate residual contamination levels in buildings and soil to annual dose for decommissioning purposes (Kennedy and Peloquin, 1990). Eleven scenarios were defined to address potential exposure to radionuclides during 1) sewer system operations, 2) sewage sludge treatment and disposal operations, and 3) the extended time period following sludge disposal. Deterministic and stochastic calculational methods were used.

Deterministic calculations use single values for input parameters, data, and assumptions to produce single value results. Deterministic analyses may use conservative values for parameters and assumptions when they are intended to overestimate potential radiation doses. This is an acceptable practice when dealing with large quantities of radioactive materials that pose significant hazards. However, when trivial quantities are present, overestimates of the potential radiation doses may be counter-productive. In these situations, stochastic analyses may produce useful results. Stochastic analyses use ranges of parameter values with assigned distributions instead of single values to produce a distribution of results. The distribution of results can be compared with the deterministic result to estimate the degree of conservatism in the analysis if the assigned distributions are well justified statistically. The results of the stochastic analysis can also be used to determine the arithmetic mean, which, when coupled with the estimated number of individuals exposed, can yield potential collective doses. This report contains both deterministic and stochastic dose estimates for potential public exposures to radionuclides in sewage sludge during its treatment and disposal.

Two sets of deterministic dose calculations were performed; one to evaluate potential doses based on the radionuclides and quantities found in documented cases of sewer contamination, and a second set to evaluate potential doses based on theoretical discharges at the maximum allowable levels for a more comprehensive list of 63 radionuclides. The deterministic evaluations relied on prudently conservative assumptions and parameters for each exposure pathway and scenario to provide a prudently conservative estimate of the radiation dose to an average individual in a population. In the context of this study, prudently conservative dose estimates do not represent doses to the maximum individual (or worst case). Nor do they represent doses to the average individual, but rather they signify a conservative compromise between the two. In each case, an attempt has been made to select values with an expected range — not at the extremes of the expected range. The deterministic results were compared with a 10-mrem/yr individual dose criterion. This approach provides an evaluation of actual discharges and a screening of radionuclides and exposure conditions that may be of concern. A limited comparison of the dose results was conducted for selected radionuclides using scenarios found in IMPACTS-BRC, Version 2.0 (O'Neal and Lee, 1990). To help understand the results of the dose analysis, a stochastic uncertainty and sensitivity analysis, using Latin Hypercube sampling, was conducted. Finally, the arithmetic mean of the total doses for critical radionuclides and exposure scenarios were used to estimate the potential collective dose from releases to sanitary sewer systems.

This report on the evaluation of exposure pathways to man via sanitary sewer systems contains the following:

- description of the effluent treatment and disposal regulations that govern the operations of potential municipal and industrial sources of radioactive effluents (Section 2)
- description of current sewage treatment disposal practices (Section 3)
- summaries of five documented case histories of radioactive contamination in sewer systems or sewage sludge (Section 4)
- definitions of potential exposure pathways by which people may become exposed to radiation or radioactive materials, and description of their associated exposed scenarios (Section 5)
- description of the deterministic dose evaluation process, as applied to estimate the potential radiation doses to municipal workers and the public, and the evaluation results (Section 6)
- description of the stochastic dose evaluation process (Section 7)
- discussion of study findings (Section 8).

In addition, Appendixes A through C, respectively, contain supplemental information on modeling input parameters and assumptions, dose calculation results, and results of the stochastic uncertainty and sensitivity analyses.

2 Effluent Treatment and Disposal Regulations

Potential sources of radioactive effluents include such licensed facilities as hospitals, research facilities, decontamination laundries, manufacturers of smoke detectors and other devices and materials, and nuclear power plants. All such sources require an NRC or agreement state license to use and dispose of radioactive materials. The discharges, except for some hospital effluents, are regulated by establishing annual radioactivity limits and maximum concentrations in water discharged to the sewer.

The current national regulations governing effluent streams, existing sewage treatment systems, and sludge reuse options and disposal methods are discussed in the following sections.

2.1 Current Regulations

Chemical effluent streams discharged to sewer systems are regulated by the U.S. Environmental Protection Agency (EPA) in 40 CFR 257, and by the NRC in 10 CFR 20 or agreement state radiation control programs, if radioactive materials are present. Additional regulations may be imposed by other state or local agencies.

2.2 Radioactive Material Disposal

A detailed analysis of the 10 CFR 20.2003 (56 FR 98: 23360) regulations was performed in order to fully understand the circumstances that control discharges of radioactive materials at maximum allowable levels. A summary of this analysis is given in the following paragraphs.

Paragraph (a)(1) of 10 CFR 20.2003 requires that discharged material be readily soluble or readily dispersible biological material in water. Soluble is defined as capable of being dissolved, while dispersible is defined as capable of being uniformly distributed.

Paragraph (a)(2) defines the concentration limits, over a 1-month period, that can be discharged into the sewer. The paragraph states that the quantity of licensed or other radioactive material that a licensee releases in a month to the sewer divided by the average monthly volume of water released into the sewer by the licensee must not exceed the concentration listed in Table 3 of Appendix B to parts 20.1001-20.2401 (56 FR 98:23360). These concentrations were derived by taking the most restrictive occupational annual limit of intake (ALI) for drinking water and dividing it by 7.3 E+06 mL. This factor is composed of 7.3 E+05 mL — the annual water intake by "Reference Man," and a factor of 10 to relate the 5-rem annual occupational dose limit to the 0.1-rem (1 mSr) annual dose limit for individual members of the public.

Paragraph (a)(3) outlines procedures to use when more than one radionuclide is released. In paragraphs (a)(3)(i) and (a)(3)(ii) the sum-of-fractions rule is described. By this rule, the licensee shall determine the fraction of the limit (Table 3 of Appendix B) represented by discharges to sewers by dividing the actual monthly average concentration of each radionuclide released by the concentration listed for each radionuclide in Table 3 of Appendix B. The sum of these fractions over all radionuclides must not exceed unity.

Paragraph (a)(4) defines the total annual discharge limit into a sanitary sewer system as 5 Ci (185 GBq) of ^{3}H, 1 Ci (37 GBq) of ^{14}C, and 1 Ci (37 GBq) of all other radionuclides combined. Thus, a licensee who handles all radionuclides is limited to a combined release not to exceed 7 Ci (260 GBq). An example of the volume of sewage discharge required to dilute the annual limit of discharge for example radionuclides is provided in Table 2.1.

Paragraph (b) provides an exclusion for excreta from individuals undergoing medical diagnosis or therapy with radioactive materials.

A comparison of the concentration limits in Table 3 of Appendix B of revised 10 CFR 20 with the values used in the former version of 10 CFR 20 is given in Table 2.2 for several commonly used radionuclides that are released into sanitary sewers. The new concentration limits are reduced to levels that range between 0.3% and 70% of the old limits.

Table 2.1 Volume of sewage required to dilute annual discharge limit to 10 CFR 20, Appendix B, Table 3 concentrations[(a)]

Radionuclide	Annual limit (Ci)	Table 3 concentration (μCi/mL)	Volume of sewage (mL)	Volume of sewage (gal)
^{3}H	5	1.0 E-02	5.0 E+08	1.3 E+05
^{14}C	1	3.0 E-04	3.3 E+09	8.7 E+05
^{24}Na	1	5.0 E-04	2.0 E+09	5.2 E+05
^{59}Fe	.1	1.0 E-04	1.0 E+10	2.6 E+06
^{60}Co	1	3.0 E-05	3.3 E+10	8.7 E+06
^{65}Zn	1	5.0 E-05	2.0 E+10	5.2 E+06
^{90}Sr	1	5.0 E-06	2.0 E+11	5.2 E+07
^{99m}Tc	1	1.0 E-02	1.0 E+08	2.6 E+04
^{131}I	1	1.0 E-05	1.0 E+11	2.6 E+07
^{137}Cs	1	1.0 E-05	1.0 E+11	2.6 E+07
^{140}La	1	9.0 E-05	1.1 E+10	2.9 E+06
$^{152/154}Eu$	1	7.0 E-05	1.4 E+10	3.7 E+06
^{210}Po	1	4.0 E-07	2.5 E+12	6.5 E+08
^{226}Ra	1	6.0 E-07	1.7 E+12	4.3 E+08
Th(NAT)	1	3.0 E-07	3.3 E+12	8.7 E+08
U(NAT)	1	3.0 E-06	3.3 E+11	8.7 E+07
^{241}Am	1	2.0 E-07	5.0 E+12	1.3 E+09

(a) The dilution volumes shown in this table are based on an assumption that only the radionuclide shown is released by a licensee. However, the 10 CFR 20 annual discharge limit to sanitary sewage is 1 Ci/yr for all materials released by a licensee, not each radionuclide. Exceptions to this are a 5-Ci/yr limit for ^{3}H and a 1-Ci/yr limit for ^{14}C. Thus, a 7-Ci/yr limit may be reached by a licensee who discharges all radionuclides at the maximum quantities (56 FR 98:23360).

2.3 Sludge Disposal

The discharge and disposal of solid waste products into the environment are subject to numerous laws, including the following:

- National Environmental Policy Act of 1969 (PL-91-190)
- Clean Air Act of 1970 (PL-91-604)

Table 2.2 Old and revised average concentration limits for releases into sanitary sewer systems[a]

Radionuclide	Old limit (μCi/mL)	Revised limit (μCi/mL)	Ratio of revised-to-old limits
^{3}H	1.0 E-01	1.0 E-02	0.1
^{14}C	2.0 E-02	3.0 E-04	0.02
^{32}P	5.0 E-04	9.0 E-05	0.2
^{35}S	2.0 E-03	1.0 E-03	0.5
^{45}Ca	3.0 E-04	2.0 E-04	0.7
^{51}Cr	5.0 E-02	5.0 E-03	0.1
^{54}Mn	4.0 E-03	3.0 E-04	0.08
^{59}Fe	2.0 E-03	1.0 E-04	0.05
^{60}Co	1.0 E-03	3.0 E-05	0.03
^{65}Zn	3.0 E-03	5.0 E-05	0.02
^{86}Rb	2.0 E-03	7.0 E-05	0.04
^{90}Sr	1.0 E-05	4.0 E-06	0.4
^{99}Mo	5.0 E-03	1.0 E-04	0.02
^{99m}Tc	2.0 E-01	1.0 E-02	0.05
^{125}I	4.0 E-05	2.0 E-05	0.5
^{129}I	1.0 E-05	3.0 E-06	0.3
^{131}I	6.0 E-05	1.0 E-05	0.2
^{137}Cs	4.0 E-04	1.0 E-05	0.03
^{144}Ce	3.0 E-04	3.0 E-05	0.1
^{192}Ir	1.0 E-03	1.0 E-04	0.1
^{241}Am	1.0 E-04	3.0 E-07	0.003

(a) Adapted from Merwin et al. (1988).

- Federal Water Pollution Control Act of 1972 (PL-92-500), which established National Pollutant Discharge Elimination System (NPDES) permits
- Toxic Substances Control Act of 1976 (PL-94-469)
- Resource Conservation and Recovery Act of 1976 (PL-94-580)
- Clean Water Act of 1977 (PL-95-217).

The Federal Water Pollution Control Act of 1972 established levels of treatment required for plants discharging to surface waters. Such plants are required to meet NPDES permit levels for effluent discharges. Meeting these limits required many existing sewage treatment plants to upgrade their facilities to provide more effective extraction of solids from effluent streams. This additional extraction increased the solid waste generated by these plants. As stated by EPA (1979), "stricter discharge limits have had the effect of making solids treatment and disposal more important, more difficult, and more expensive."

New sludge incinerators must comply with the following standards and regulations derived from the Clean Air Act and its many amendments:

- National Ambient Air Quality Standards
- National Emission Standards for Hazardous Air Pollutants, subpart A
- Standards of Performance for New Stationary Sources, parts A and 0
- New Source Review Rule
- Regulations Pertaining to Prevention of Significant Deterioration of Air Quality

Additional state or local requirements that are more stringent than federal regulations also require compliance.

Co-combustion with municipal waste requires compliance with additional EPA regulations that pertain to incineration of solid wastes (EPA, 1986a).

These regulations cover the quantities of pollutants that can be emitted and the opacity of the emissions. Emissions considered include carbon monoxide, hydrocarbons, ozone, nitrous oxides, sulfur dioxide, total suspended particulates, and lead. For example, the New Source Performance Standards (NSPSs) restrict incinerator effluents to less than 1.30 lb/ton of dry solids, with gas discharge of not more than 20% opacity. No specific mention is made of radioactive contaminants in these federal regulations.

Existing regulations for the "Criteria for Classification of Solid Waste Disposal Facilities and Practices" are published in 40 CFR 257. Section 257.3-5, concerning the application to land used for the production of food-chain crops, provides maximum annual application rates for cadmium as a function of pH and soil cation exchange capacity. Cadmium is the only inorganic element currently included in these regulations.

3 Sewage Treatment and Disposal Practices

The components that make up the wastewater from a community depend on the type of collection system used and may include: 1) domestic wastewater, 2) industrial wastewater, 3) infiltration/inflow, and 4) storm water. Three types of systems are used for removal of wastewater and storm water: sanitary sewer systems, storm sewer systems, and combination sewer systems. When separate systems are used for sanitary and storm wastewater, only the first three sources flow to sewage treatment plants (STPs). With a combined system, all four sources flow to the STPs. In both cases, the percentage of the wastewater components and the flow rates vary with local conditions and the time of year.

Sewage treatment plants vary in size (capacity) from about 1 million gallons per day (gpd) to over 1 billion gpd. A capacity of 1 million gpd would serve a small city of about 5000 people and a few small commercial users (Metcalf and Eddy, Inc., 1979). A capacity of 1 billion gpd would accommodate a population of about 5 million people and a substantial industrial base. The mix of domestic and industrial uses of water as a function of population served is illustrated in Figure 3.1. Domestic use of water is higher on a per capita basis where single family homes predominate and lower in large cities where multifamily housing predominates. Industrial uses tend to increase with population, but there are significant differences among types of industries, e.g., the paper and chemical industries generate much larger volumes of wastewater than does the electronics industry.

The primary sludge disposal methods are conversion to a soil supplement, incineration, and burial in a landfill. Incineration is used most commonly by large STPs that have limited solids-disposal facilities. Conversion to fertilizer and burial in a landfill are used about equally by smaller STPs.

The extent of sludge treatment required depends on the types of contaminants in the wastewater and the discharge requirements for the effluent. Sewage that is not treated is called "raw sewage." The Federal Water Pollution Control Act Amendments of 1972 prohibit the discharge of municipal raw sewage into water bodies. In this section, current sewage treatment systems, sludge incineration, and reuse and disposal practices are discussed, and background information useful in establishing scenarios for the dose analysis is presented.

3.1 Sewage Treatment Systems

Municipal sludge production in the United States, estimated to reach about 12 million metric tons (dry weight) a year by the year 2000, represents a huge resource to use where possible, and to dispose of where necessary. Sludge treatment processes may include mechanical dewatering, air drying, heat drying, aerobic digestion, anaerobic digestion, and composting. While most sewage sludge only undergoes some treatment to dewater or reduce its volume, a smaller proportion is further treated to break down the organic materials contained in the sludge. Options for disposal of the resultant sludge products include incineration, burial in a landfill, and conversion to a soil supplement.

Water-borne contaminants in a sewer system may fall into one of three categories: chemical, physical, or biological. The decomposition of organic chemical compounds tends to deplete waterways of dissolved oxygen, which has a detrimental effect on fish and other aquatic populations. Inorganic chemicals may pose a potential toxic threat to aquatic organisms and to terrestrial animals drinking contaminated water. Particulates or dissolved materials may act as physical agents and alter the water's normal temperature, color, turbidity, and foaming action. Transmission of disease through the water supplies may be caused by biological contaminants. When radioactive materials are disposed of in sewer systems, they fall into any of the three categories of contaminants.

Particulate matter is separated from treated liquids in the sewage treatment system and is dewatered, forming a sludge. This sludge may be incinerated to reduce its mass, used as a fertilizer or soil supplement to improve soils, or disposed of in a landfill. Ocean disposal of sludge is not discussed here because the pathways to man are more obscure and the amount of dilution with

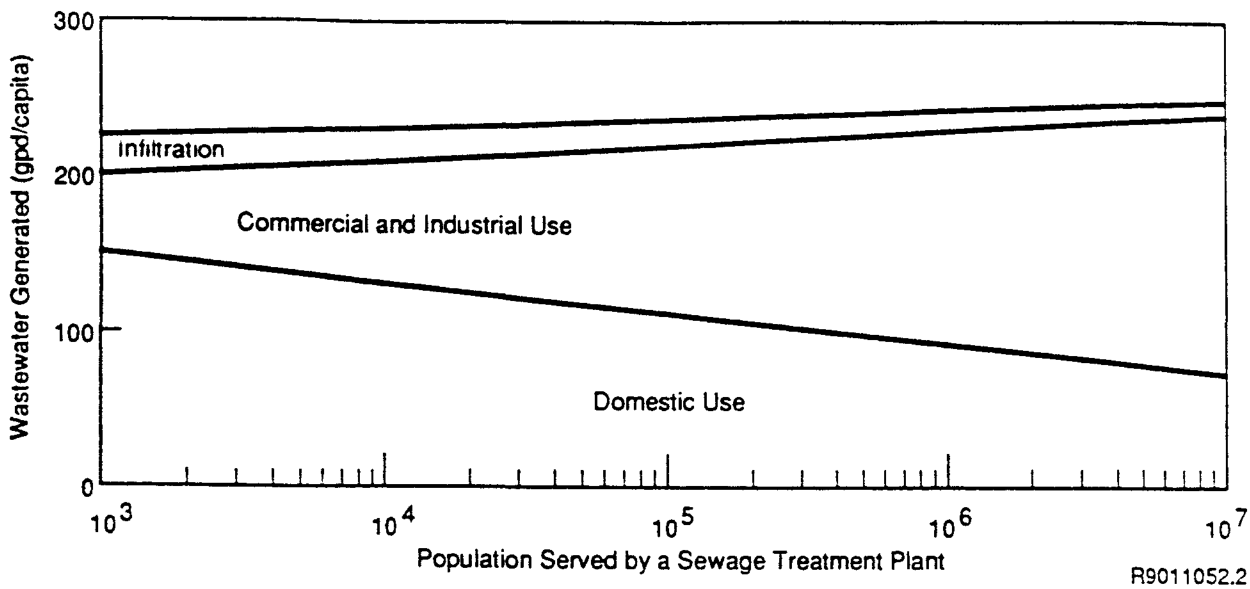

Figure 3.1 The mix of domestic and industrial use of water as a function of population density (adapted from Metcalf and Eddy, Inc. 1979).

ocean water is vast. Also, ocean dumping of sludge is gradually being phased out in the United States because it is considered an unacceptable practice.

Primary sewage treatment employs physical methods of removing suspended solids and floating materials, and it also conditions the wastewater for discharge to a receiving body or to a secondary treatment process. Typical elements of a primary system include screening, sedimentation, flotation, oil separation, and neutralization and/or equalization.

Secondary treatment employs biological processes to break down the organics in the sludge from the primary treatment. Such processes may include one or more of the following treatments: sludge activation, extended aeration, contact stabilization, modifications of conventional activated sludge processes, aerated lagoons, wastewater stabilization ponds, trickling filters, rotating biological contractors, or anaerobic treatments.

Tertiary systems are intended to remove from the wastewater any pollutants that are not removed by conventional biological treatments. Such processes may include microscreening, filtration through specific media, precipitation and coagulation, adsorption onto activated carbon, ion exchange, reverse osmosis, electrodialysis, chlorination and ozonation, nutrient removal, or the onozone process.

A typical process flow diagram for an STP designed to meet secondary treatment standards is shown in Figure 3.2. Typical methods for sludge processing and disposal are diagrammed in Figure 3.3. The reader is referred to texts on wastewater treatment for more details (Metcalf and Eddy, Inc., 1979; Ramalho, 1983).

3.2 Sludge Treatment by Incineration

Incineration is a treatment method that greatly reduces the mass and volume of the sludge to an ash prior to disposal. Incineration is an attractive option prior to disposal when "available land for disposal is scarce, stringent requirements for land disposal exist, destruction of toxic material is required, or the potential exists for recovery of energy, either with wastewater solids alone or combined with municipal refuse" (EPA, 1979). Incineration was the final treatment method for about

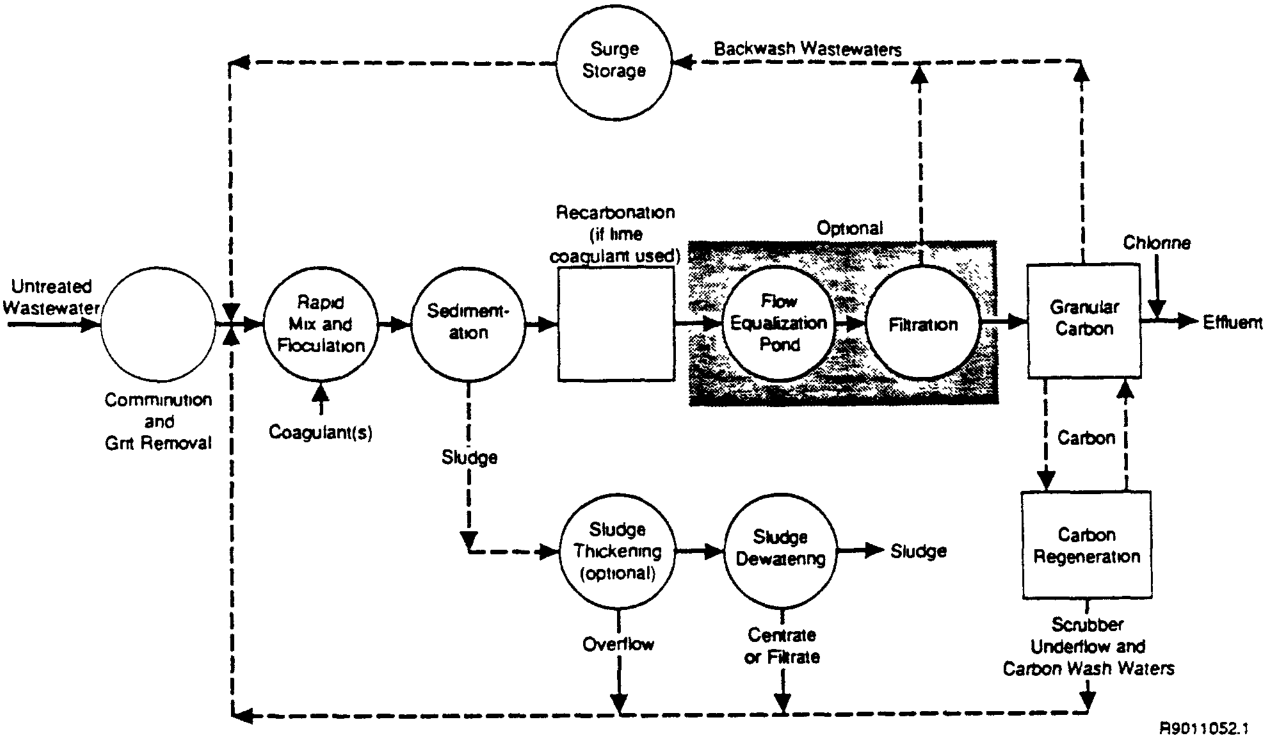

Figure 3.2 Flow diagram for a typical sewage treatment plant

27% of municipal wastewater sludge in 1982 (EPA, 1985). The advantages of this treatment option include a large reduction in mass (up to 95%) compared with the initial mass of the waste, destruction of toxic organic chemicals in the sludge, and the potential for recovery of combustion energy for use in other plant operations. Disadvantages of incineration include high costs for construction, operation, and maintenance, and the need for experienced, trained operators for efficient incinerator operation. Solid, liquid, and gaseous effluents from incinerators that contain high concentrations of toxic materials also require special disposal methods in order to satisfy environmental protection regulations (RCRA, 1976).

Incineration of sludge is typically a two-step process involving first the drying, then combustion of the sludge. The operational efficiency of an incinerator depends on a number of factors such as the sludge quality and the degree of control maintained over the process. Variations in the sludge feed rate, temperature, and airflow can lead to increased emission levels. In most types of furnaces, complete combustion requires air or oxygen in excess of the theoretical amount needed to react with the organic components of sludge. The energy value of sludge comes mainly from carbon and hydrogen, which take the form of volatile organic compounds and fixed (or elemental) carbon. In order to improve its fuel value, sludge may be incinerated along with other municipal, agricultural, or industrial wastes, but is more commonly burned in dedicated facilities. In the United States, sludge incinerators are of three basic designs: multiple hearth, fluidized bed, or electric (infrared) furnaces. Details concerning these furnace types are discussed in sludge treatment manuals published by the EPA (1979; 1986a).

Incinerator operators must meet the emissions standards promulgated in the Clean Air Act of 1970. Emissions from incinerators consist of primary pollutants released directly from the installation, including carbon monoxide, hydrocarbons, nitrogen oxides, sulfur oxides,

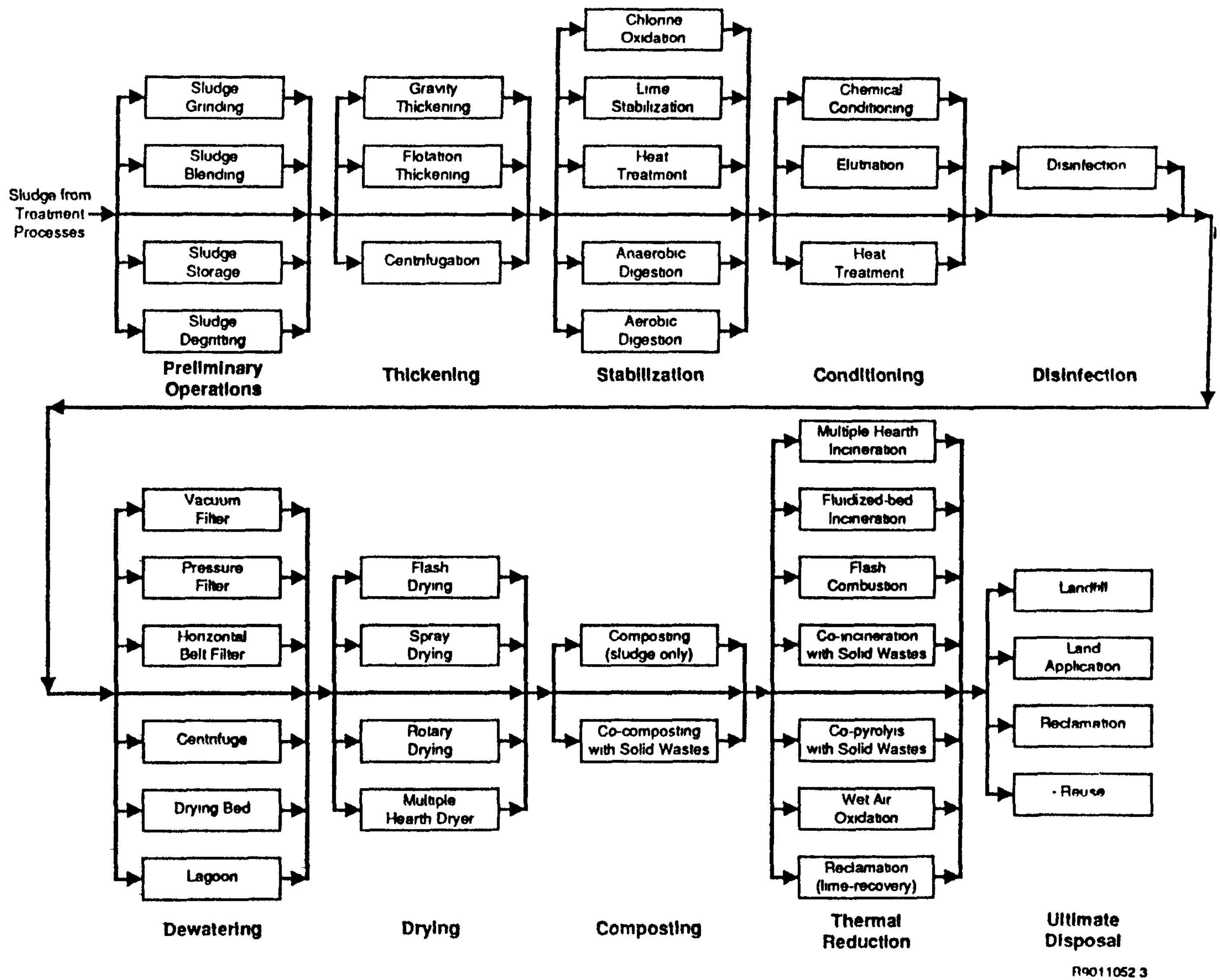

Figure 3.3 Typical methods for sludge processing

lead, and suspended particulates. Secondary pollutants are also regulated and consist of compounds such as photochemical oxidants and nitrogen dioxide produced by reaction of primary emissions with sunlight in the atmosphere. At most incinerators these emissions are controlled by afterburners and wet scrubbers. Newer units use variable throat venturi units combined with a tray-type wet scrubber, which can reduce all pollutants (except nitrogen oxides) to acceptable levels (EPA, 1979; 1986a).

After incineration, the solid residues, consisting of combustion ash and particulates from scrubbers, may contain high concentrations of toxic metals that must be disposed of in a protected or hazardous waste landfill. Such installations must meet stringent requirements for groundwater protection and control of leachate (EPA, 1979).

3.3 Sludge Reuse and Disposal

The selection of the most appropriate disposal option(s) depends on the characteristics of the sludge and availability of suitable disposal sites. Sludge qualities that determine the appropriate type of disposal include the solids concentration, organic content, and the presence of toxic chemicals or pathogenic organisms. The available nitrogen content is often a limiting factor because it can be converted to nitrate, which is highly mobile in soil and a potential groundwater contaminant. Chemical properties such as pH also affect the mobility of heavy metals and other inorganic compounds in the sludge.

Site selection for disposal facilities must take into consideration a number of factors related to safety and economics. The distance over which the sludge must be transported for final disposal is an important factor, as is safe access to the disposal site by the public. Sludge or ash is often disposed at municipal landfills that are accessible to the public for dumping household rubbish. Although sludge and ash are usually buried in separate parts of the landfill, the public may have access to adjacent areas. It is important in siting and designing landfills that sludge and ash disposal areas be separated from public access areas to help assure public safety and health. Sufficient land must be available to provide a reasonable working lifetime for the site, and for a buffer zone to separate the disposal area from publicly accessible locations. Potential effects on surface water and groundwater must be evaluated to determine what measures must be taken to prevent leaching of waste into these reservoirs. The topography, geology, meteorology, and soil characteristics are considered for this reason. Care is also taken to protect environmentally sensitive areas, sites of historical or archeological interest, and land that has the potential for other uses in the future.

As discussed in the following sections, several types of land application comprise the sludge reuse options; burial at a dedicated landfill (with or without incineration) and codisposal with other solid refuse are also reviewed as sludge disposal options.

3.3.1 Land Application

Land application, as used in this report, refers to the use of sludge as a conditioner or nutrient in surface or near-surface soil. Land application represented the end use for 30 to 40% of municipal sewage in 1982 (EPA, 1986b). The sludge is applied to the soil surface or just below the surface in either liquid or semisolid form. Liquid sludge is generally more convenient to handle and requires less pretreatment; however, it can create problems with excess moisture, formation of aerosols, and odor. Sludge is commonly distributed on soil by use of tank trucks or tractor-trailer spreaders. In some cases, the liquid is injected into subsurface furrows or tilled in immediately after distribution. Dried sludge is applied with the same type of spreader used for spreading animal manure.

Land application of sludge is used to improve agricultural, forest, or disturbed soil. Such use generally involves some degree of administrative control by the treatment facility over application rates and subsequent use of the affected area. Distribution and marketing of sludge, on the other hand, involves sales or give-away of treated products to the general public, commercial enterprises, or institutions for use on a more limited scale. In this case, the treatment facility provides recommendations for proper application, but responsibility for their implementation lies with the end user. The assumptions and requirements governing each of these use options are summarized in the following subsections.

Agricultural Use

Agricultural use of sludge involves its application to soil as a nutrient or conditioner to increase crop production. Sludge application is generally limited to the period before crops are planted, or to inactive periods for perennial forage crops. Sludge may be applied to a variety of crops, including grains, animal feeds, and nonfood crops.

Good practices embodied in regulations or recommendations include limiting annual nutrient (i.e., nitrogen or phosphorus) application rates to those that will be offset by crop consumption. These limitations usually correspond to application rates of 2 to 70 Mg/ha dry weight. Larger applications may be permitted if there is a delay in planting or if an established crop for animal forage is used (EPA, 1986b). In some cases, the presence of toxic chemicals or heavy metals is the limiting factor, and there may be site lifetime loading limits for cadmium, lead, zinc, copper, and nickel, primarily to limit plant uptake of these metals within an acceptable level. The characteristics of the site and the soil chemistry must be taken into consideration when determining the acceptability of various levels of sludge application. For example, the soil pH must be at 6.5 or above and permanently maintained at or above 6.2. Other factors may include soil permeability, the site's slope, depth to water table, infiltration rate, and distance from surface water. Certain chemicals are selectively concentrated within specific classes of vegetation. Many of the heavy metals produce a phytotoxic response in the crop before their concentration in plant tissues reaches a level of concern to human or animal health. Cadmium is an exception to this and therefore it is specially regulated.

The facility supplying the sludge may be required to analyze and document the chemical composition of the sludge and to maintain records of the locations and amount of sludge applied to each site. Incorporation of sludge into the soil by tilling or injection is generally required prior to planting crops consumed by humans, and in some other applications.

Non-Agricultural Use

The non-agricultural use of sludge involves the sale or give-away of treated wastes to the general public and commercial or institutional users. These users may apply it as a fertilizer or soil additive in the production of forage grasses for animal feed and turf grass for public lands (parks, schoolyards), golf courses, and commercial sod. Sludge is also commonly used as "potting soil" by nurseries and greenhouses (USDA,1984). Jones (1981) estimated that 25% of the sludge supply is returned to the soil, and much of it is used on grass production.

Pretreatment of the sludge to reduce the potential for human exposure to contaminants varies with the supplier and may consist of digestion, composting, dewatering, or drying. The sludge may then be distributed to end users in bulk or through commercial outlets as a packaged product for public, commercial, or residential uses. There is obvious opportunity for human exposure to contaminants when waste sludges are used on home lawns and gardens, and treated commercial and institutional properties have the potential for future conversion for residential use. Because treatment facilities have no direct control over end use, health risks are minimized by limiting contaminant levels in the distributed product and requiring that information on the nutrient content and proper application rates be provided to the customers.

Typical sludge application rates for turf grasses in the first year of production are 30 to 300 Mg/ha, which is incorporated into the top 10 to 15 cm of soil. Applications for annual maintenance are typically 20 to 40 Mg/ha. Forage grasses and commercial sod production require 150 to 350 Mg/ha to establish the crop and 50 to 65 Mg/ha annually for maintenance. Compost for nursery crops, including shrubs, trees, and ornamental vegetation, requires 90 to 350 Mg/ha applied to the top 15 to 20 cm of soil (USDA, 1984).

Forest Application

Enrichment of forest land by sludge application is carried out under the assumption that the potential for incorporation of contaminants into the human food chain is limited to occasional consumption of wild plants or animals.

Because the forest surface layer has a relatively large storage capacity, loading limits for forest land are higher than for agricultural use. Applications of up to 100 Mg/ha dry weight may be carried out on a 3- to 5-year cycle, and the timing is not limited by farming operations (EPA, 1986b). There are no toxic metal loading limits for forest application; however, the agricultural limits are generally used to preserve the sites for future residential or agricultural use.

Restrictions to control human exposure include posting of signs at public access points to prohibit consumption of wild food products from the area and to require evacuation of the public from downwind locations during spraying. Site characteristics determine the acceptable rates of application. Application of sludge to frozen soil is prohibited. Treatment facilities may be required to keep records of sludge composition and the locations and amounts of application.

Application to Disturbed Land

Wastewater sludge is often applied to land that has been disturbed by mining, quarrying, or being used as a sand or gravel pit; this is done to improve the nutrient value of the soil so that new vegetation can be established. Sludge application may also help to control other problems common to these sites such as acid runoff, erosion, and high concentrations of toxic chemicals. Because the surface soil is generally poor in such locations, a large initial application of sludge may be needed to re-establish the plant cover (EPA, 1986b). Repeated applications are used under some conditions. If the sites are to be used later for agricultural or residential purposes, the loading restrictions for these applications should be followed, or the soil should be tested to determine its suitability before proceeding with conversion to another use.

Restrictions on application of sludge to disturbed land are similar to restrictions for other sites, including the need to evaluate the site geology, topography, and soil characteristics. Access to the site should be limited and use of plant or animal products from the site for human consumption should be prohibited. The treatment facility supplying the sludge would be responsible for analyzing the sludge and maintaining records of its composition and locations and amounts of applications.

3.3.2 Landfilling

Landfilling, as discussed in this report, refers to the burial of wastewater treatment solids at a designated disposal site. This disposal method is used to isolate and stabilize sludge and other wastewater treatment solids when alternatives for reuse of these materials are not feasible. Landfilling provides the final disposal method for 15 to 25% of municipal wastewater sludge (EPA, 1986c). Disposal of raw, treated, or stabilized sewage may take place in facilities dedicated to this type of waste, or it may be codisposed with other solid refuse (EPA, 1986c). Sludge disposal options of burial at dedicated landfills or codisposal with other municipal wastes in landfills are discussed in the following subsections.

Dedicated Landfill

A dedicated land disposal site is used for intensive application of treated or stabilized sludge at rates much greater than those permitted for reclamation or agriculture. In this case, the land functions as part of the overall treatment process to facilitate dewatering and breakdown of organic material in the sludge and provides a sink for metals or other toxic chemicals. For this reason, the characteristics of the site are more restricted than for other uses. The geology and location of the site should be such that potential contamination of groundwater or a domestic water supply is minimized, and there must be provisions for containment or treatment of runoff. The soil should have a high cation exchange capacity and other properties that restrict the mobility of toxic chemicals. Test wells may be required to monitor groundwater and leachate for contaminants.

Control of the disposal site is generally maintained by the waste treatment authority, because the buildup of salts and toxic materials could make the land unsuitable for other uses. Public access is restricted by fences and signs prohibiting use of the land or its products. The treatment facility is again required to maintain records of sludge analysis and the location and amount of each disposal. Before the property can be sold or used for other purposes, the disposal site must be closed and the potential hazards evaluated by established procedures. Future activities are limited by appropriate restrictions placed in the property records or deeds of sale. Unless analysis shows that a hazard does not exist, the land cannot be used legally to grow crops or forage for animals that will be consumed by humans. However, other agricultural use may be permitted after evaluation of the soil and the proposed crops.

Disposal of sludge in a dedicated landfill involves placing the waste in covered trenches of varying widths, or in area fills that are covered except on the working face. Cover material is either clean soil or soil mixed with sludge, in which case the facility is regulated as a land application rather than a landfill. Because the sludge is applied below grade and covered with 1 to 2 m of clean dirt, provisions for trapping and treating runoff water are generally unnecessary (EPA, 1979).

Area fills are used where excavation is not practical because of shallow groundwater or bedrock. In such cases, the sludge is mixed with soil and piled into mounds or spread in a layer approximately 0.3 m thick on the surface, followed by 1 to 2 m of clean cover. A variation of this method uses earthen dikes to contain unmixed sludge on the soil surface. Cover is applied 0.3 to 1 m thick on an interim basis, with a final cover of 1 to 2 m. Stabilized sludge with a solid content of 15 to 20% is required for these applications. Because the waste is applied above grade, drainage control ditches are provided to contain runoff or divert it to a treatment facility. Liners, which consist of a synthetic flexible membrane or low permeability soil, such as clay (EPA, 1979), may be required under certain conditions.

Codisposal

Sludge with more than 3% solids may be mixed with other solid refuse at a landfill, then spread and compacted. Application rates range from 1000 to 8000 m^3/ha, which generally represents 5 to 10% of the total solid waste. Interim cover of 0.3 m of soil is provided, with an additional 0.7 m at the final grading.

Mixtures of sludge and soil may also be used as the cover for a solid refuse landfill to promote vegetation regrowth.

4 Case Histories

The first dose evaluation conducted for this study addressed documented cases of radioactive contamination detected in sewer systems or sewage sludge. For several cases that have been documented, the level of radioactivity in liquid effluents from licensed commercial facilities was quite low. Although the levels in effluents were well within discharge limits, in several documented cases the levels of radioactivity detected in sludge were higher than expected. This demonstrates the tendency for radionuclides to become concentrated in sludge. Presumably, certain dispersible radioactive materials became attached to particulates that were later filtered out of the wastewater. It is also likely that certain soluble radionuclides formed insoluble complexes at some point after discharge and precipitated out of solution (NRC, 1984). The dose evaluation conducted for these case histories, although generic, is intended to provide an initial determination of the adequacy of current regulations and is not intended to be a comprehensive evaluation of the likely doses that could have been received.

In this section, background information relevant to five documented cases where radioactive contamination has been reported in sewer systems or in sludge is summarized. The first case is perhaps more significant than the other four; however, they are all briefly discussed because they demonstrate the efficiency of current STPs in concentrating undissolved contaminants. The radionuclides associated with each of these cases are listed in Table 4.1. The measured concentrations identified for each case will be used in the radiation dose analysis discussed in Section 6.

4.1 Case 1 - Tonawanda, New York

A manufacturer of smoke detectors, which included ^{241}Am foils, operated in the 1970s and early 1980s in Tonawanda, New York. When the facility was being decommissioned in 1983 for release for other use, contamination of the sewer lines leading from the facility was detected. Americium-241 was subsequently detected in the STP, sewage sludge, and incinerated sludge ash residue. It is believed that the contamination occurred over a period of time. State tests ran in 1984 showed levels up to 750 pCi/g in ash taken from a sludge incinerator. Levels of 160 pCi/g were detected in landfill samples. The levels in the sludge at the time of the investigation were up to 100 pCi/g (Rimawi, 1984). After the major release ended, these levels decreased to less than 1 pCi/g by 1986.

These concentrations suggested that exposures to STP workers and the public might have been of concern and should be investigated. However, in vivo counting of STP workers and landfill workers detected no radioactivity over background levels in their lungs or bones (MacClennan, 1984).

4.2 Case 2 - Grand Island, New York

Because of the ^{241}Am contamination at the Tonawanda STP, the New York Department of Health also collected sludge samples in 1984 at the Grand Island STP, which received effluent from another manufacturer that produced devices that used tritium, ^{210}Po, and ^{241}Am. This manufacturing facility discharged about 25 mCi/yr of ^{241}Am into the sanitary sewer that fed into the Grand Island STP. The Grand Island STP uses tertiary treatment prior to discharging effluent. Current sludge production averages 450 ton/yr. The sludge is digested and pressed to increase the solids content to about 20%, and it is subsequently buried in a landfill. The average ^{241}Am concentration in the dry sludge was about 100 pCi/g dry weight when first studied (Rimawi, 1984). The manufacturer reduced the ^{241}Am concentration in its liquid discharges at the request of the New York Department of Labor after the higher levels were identified. By adding filtration to the holding tank, sludge concentrations of ^{241}Am were decreased to about 40 pCi/g. The pressed sludge concentrations actually fell from 20 to 5 pCi/g (wet weight).

Using information provided by the State of New York, calculations of the annual average concentration of ^{241}Am in the wet sludge were based on the assumption that all ^{241}Am entering the plant was concentrated in the sludge. Analysis of STP inflow and outflow showed

Table 4.1 Radionuclides associated with documented cases of sewer system contamination

Contamination case	Licensee facility type	Radionuclides
Tonawanda, NY	Americium foil/smoke detector manufacturing	^{241}Am
Grand Island, NY	Americium foil/smoke detector manufacturing	^{241}Am, ^{210}Po, ^{3}H
Royersford, PA	Decontamination laundry	^{54}Mn, ^{58}Co, ^{60}Co, ^{66}Zn, ^{89}Sr, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{125}Sb, ^{134}Cs, ^{137}Cs, $^{233/234}$U, ^{235}U, ^{238}U, ^{238}Pu, $^{239/240}$Pu
Oak Ridge, TN	Equipment decontamination	^{137}Cs, ^{60}Co, ^{134}Cs, ^{54}Mn
Washington, DC	Research laboratories	^{3}H, ^{14}C, ^{22}Na, ^{32}P, ^{33}P, ^{35}S, ^{36}Cl, ^{44}Ca, ^{46}Sc, ^{51}Cr, ^{59}Fe, ^{57}Co, ^{58}Co, ^{60}Co, ^{67}Ga, ^{75}Se, ^{86}Rb, ^{99m}Tc, ^{111}In, ^{125}I, ^{131}I, ^{141}Ce, ^{137}Cs, ^{195m}Pt, ^{212}Pb, ^{228}Th, ^{238}U

that the americium concentration in water samples was below the detection limits. Soil samples taken in the former sludge storage area showed a low level of ^{241}Am. Wipe samples taken within the STP did not detect ^{241}Am above levels allowed for unrestricted use of materials or facilities. Some of the Grand Island STP workers used dried sludge for a soil supplement in their home gardens. One garden showed measurable amounts of ^{241}Am. Based on the sampling data, it was concluded that there did not appear to be a radiation hazard to the STP employees or landfill employees, and that no specific safety measures beyond those normally taken by employees would be required of such facilities.

For the Tonawanda STP, the NRC suggested a concentration of 30 pCi/g as an appropriate limit for ^{241}Am, below which no remedial action is required. This limit was apparently based on practical (radiation detection) considerations, instead of being directly related to risk. New York State adopted the 30-pCi/g limit for areas where material removal was required for decontamination or for areas needing to be stabilized on site by covering the area with a 4-ft layer of uncontaminated soil.

4.3 Case 3 - Royersford, Pennsylvania

A commercial laundry for radioactively contaminated protective clothing is located in Royersford, Pennsylvania. The wastewater from the laundry is stored (temporarily) in two 5000-gal tanks, where the pH of the wastewater is adjusted. Then the liquid is pumped into a discharge tank where it is recirculated for 30 minutes. A sample from this discharge tank is analyzed for gross alpha and gross beta activity before the contents of the tank are released to the sanitary sewer system. Roughly 15,000 gpd are released to the sewer system in this manner. Inspections by the NRC in late 1985 revealed no violations by the licensee (NRC, 1986a). However, an inspection of the Royersford STP revealed radiation levels up to 1.2 mR/h at the secondary digester in an area where the background radiation is 0.01 mR/h. Because of the levels detected, the NRC proposed a plan to evaluate the impacts of the radionuclides released to the sanitary sewer system by the laundry facility. The evaluation encompassed not only the STP, but sludge application areas as well. It found that the highest doses were to farmers working the fields where the sludge had been applied, but none of the doses were estimated to be significant because all were less than 5 mrem/yr. Radiation levels on the outside of a tanker, used to carry the sludge to application sites, ranged up to 0.3 mR/h.

4.4 Case 4 - Oak Ridge, Tennessee

A company in Oak Ridge specializes in decontamination of nuclear power plant materials that are economically impractical to discard. Most of the radioactivity removed from the items is solidified and sent to permanent low-level waste disposal sites. A slight amount of activity is disposed of as liquids entering the city sewer system. When a new STP was put into operation by the city of Oak Ridge, contamination of the sewer lines leading from the company was discovered. In addition, radionuclides characteristic of those in the company's effluents were detected in the sludge being processed at the sewage treatment facility. The contamination was found at the STP in both its primary and secondary digesters. This sludge was subsequently applied to deforested land at a government facility, resulting in radiation levels of about 0.01 mR/h (2 to 3 times background) in the area (NRC, 1984). Stricter guidelines were issued to the company by Tennessee's Division of Radiological Health, which limited the amount of radioactive material released to the sewer system. Additionally, the company was allowed to release only soluble material, because it was suspected that some of the material previously released had been insoluble.

Shortly thereafter, the company asked for temporary relaxation of the restrictions imposed on them for the release of some contaminated acid that had been accumulating. New tentative limits were negotiated, and neutralized, filtered acid was released. After the temporary limits expired, it was noticed during a biannual inspection that the company had not returned to the original restrictions, but instead had continued with the temporary limitations.

In August 1986, a study (Halsey, 1986) was conducted to evaluate the risk to the general public from the radionuclides released into the sewer system. It was estimated that there were four radionuclides of concern in the sludge, of which ^{137}Cs was the primary contaminant. It was determined that the primary risk was through consumption of vegetables grown in a garden fertilized with sludge from the STP. The concentration of ^{137}Cs was determined to be 80 pCi/g, which would be diluted to about 8 pCi/g when combined 1:10 with garden soil. Using uptake factors in various vegetables and average consumption rates, an estimate of the dose received was calculated. There were other isotopes present in lesser quantities, and the sum of ^{137}Cs, ^{60}Co, ^{134}Cs, and ^{54}Mn detected was estimated to result in a dose of approximately 6 mrem/yr.

4.5 Case 5 - Washington, D.C.

The Blue Plains Wastewater Treatment Plant processes waste from a number of federal research facilities that use a relatively broad spectrum of radionuclides compared with most industrial operations. Some liquid effluents are released directly to the sanitary sewer system, whereas selected wastes are retained in temporary holding tanks to permit decay of short-lived isotopes before release. Inspections of two research facilities and the STP were conducted in early 1986, with no violations of federal regulations or licenses noted (NRC, 1986b). Samples were obtained at both facilities from holding tanks and effluent discharge points and at the STP for influent, liquid effluent, and sludge. Radionuclide concentrations in facility effluents were 2% or less of the limits specified for maximum daily release concentrations in Appendix B, Table I, Column 2 of the older version of 10 CFR 20 (1988a). Analysis of the STP samples revealed that concentrations of soluble isotopes, such as ^{137}Cs and beta-emitters in general, were on the same order of magnitude for liquid influent and effluent, and that concentrations in sludge were about 10% of those in the liquid samples. In contrast, for alpha-emitters the influent concentrations were about

10 times higher than those of the liquid effluent samples. These data, although obtained from a small number of samples, support the conclusion that some radioactive isotopes can accumulate in the solid fraction of STP effluent.

Data on the total quantities of radionuclides released during 1984 and 1985 were also obtained from facility annual reports. One facility discharged a total of 22 Ci of tritium and 7 mCi of other radionuclides (unspecified) during 1984; the second discharged a total of 5.6 Ci of tritium during 1984 and 7.4 Ci in 1985 (under a special license provision permitting discharge of up to 8 Ci total, an exception to the former version of 10 CFR 20.303d). Major radioisotopes released by the second facility included tritium, ^{14}C, ^{22}Na, ^{32}P, ^{35}S, ^{36}Cl, ^{51}Cr, ^{59}Fe, ^{75}Se, ^{125}I, and ^{131}I.

5 Exposure Pathways and Scenarios

A modeling analysis was performed to evaluate the approximate magnitude of potential radiation doses to municipal workers and members of the public from exposure to radioactive materials disposed of via sanitary sewers. Various sewer system operations and sewage sludge processing and disposal activities were considered in the generic analysis. The routes through which people may be exposed to radiation or radioactive materials are called radiation exposure pathways. A collection of exposure pathways is used to construct radiation exposure scenarios. These scenarios are designed to be conceptual representations of patterns of human activity (actions, events, or lifestyles) that result in radiation exposures to individuals or populations. The generic sewage treatment processes, the significant exposure pathways, and the exposure scenarios considered in both the case history analysis and generic evaluation conducted for this study are described in the following sections.

5.1 General Process Description

To calculate potential doses from exposure to radioactive materials during sewer system operations and sewage sludge processing and disposal, it was necessary to characterize generic sewer and sludge processing/disposal operations. The generic characterization was modified for the case history analysis where measured data were available. The reference sewer system operations were developed based on the treatment and disposal practices discussed in Section 3. The reference facilities and processes were used to identify the potential pathways for external and internal exposure. Those pathways were then combined, as appropriate, to form credible exposure scenarios. The pathways are illustrated schematically in Figure 5.1 and are discussed below.

As a base case for this analysis, the reference STP was assumed to process 19 million liters (5 million gallons) of wastewater daily and to generate 1700 metric tons (dry weight) of sludge per year (EPA, 1979). A facility this size would support a community of 35,000 to 40,000 people and represents the minimum size plant likely to receive significant radioactive effluent from an industrial source.

Wet sludge was assumed to contain 30% solids, with the mass reduction upon incineration assumed to be 30% on a dry weight basis (EPA, 1986a; 1986b; 1986c). The particulate release fractions for incineration were taken from literature sources to be: 0.9 for ^{3}H; 0.75 for ^{14}C; 0.1 for strontium and iodine; 0.01 for chlorine, phosphorus, ruthenium, and technetium; 0.001 for sodium and cesium; and 0.005 for all other elements (IAEA, 1987; Oztunali and Roles, 1984). For simplicity, in scenarios involving exposure to ash, all radionuclides (except ^{3}H and ^{14}C) were considered to be contained in the ash. For all scenarios that address inhalation of resuspended particles it was assumed that 20 to 100% of airborne particles were respirable (EPA, 1986c).

For evaluations of potential exposure to sewage sludge, it was assumed that all radioactive materials discharged to the sewer attaches to and remains with the sludge solids. While conservative, this assumption was not unreasonable considering the high sorption coefficients associated with organic materials. When evaluating the potential exposures to STP liquid effluent it was further assumed that all of the radioactive materials discharged to the sewer remains in solution. Thus, this evaluation addresses potential discharges of radioactive materials in highly soluble chemical form. This approach, accounting for the release of the total inventory to both sludge and liquid effluent, provides for a generic analysis without relying on detailed chemical data for a specific STP. Because of these assumptions, it is recognized that the results from this study likely provide overestimates of the potential doses from disposal of radioactive materials into sanitary sewer systems.

5.2 Sewer and Disposal Operation Exposure Pathways and Scenarios

Based on the generic process described previously, radiation exposure pathways and scenarios were next

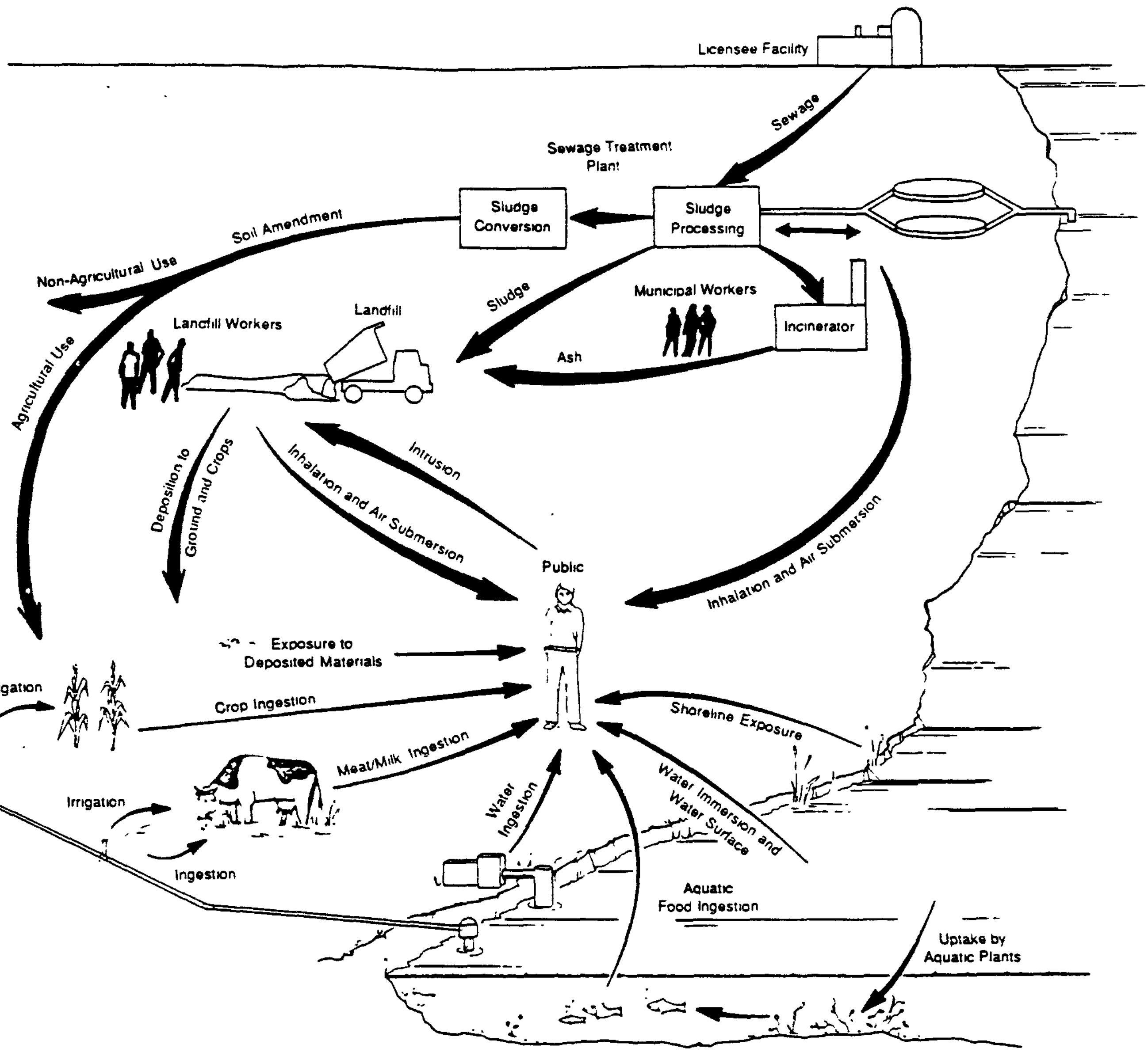

Figure 5.1 Radiation exposure pathways to man from disposal of radioactive materials into sanitary sewer systems

identified so that radiation doses could be determined. Because this report is intended to serve as an initial determination of the adequacy of current regulations, decisions have been made to limit the pathways included in the scenario analysis. The exposure pathways identified for municipal workers included external exposure to radioactive materials in sewer line wastewater, sewage sludge, and ash, and internal exposure to radioactive materials following inhalation of resuspended ash. Pathways identified for members of the public were more complex and included transport through the environment following release from treatment or disposal facilities. For purposes of this initial evaluation, external exposure, inhalation of resuspended material, and ingestion of agricultural products have been considered in the public exposure scenarios. While under some conditions additional pathways could be important, they are beyond the scope of this initial analysis. While it is possible to identify additional scenarios, a set of 11 scenarios was selected as being representative of real situations, while providing conditions that will bound additional exposure situations (i.e., individuals who perform sewer work or members of the public with lesser exposure conditions). The 11 scenarios, and their associated exposure pathways, are summarized in Table 5.1 and are described in detail in the sections that follow.

5.2.1 Scenario No. 1 - Sewer System Inspector

In this scenario, the potential doses to a sewer system inspector from exposure to radionuclides in the wastewater stream were evaluated. An inspector within the sewer system's large interceptor lines was assumed to be the first person potentially exposed to radioactive effluent from a licensee. The exposure pathways considered for this scenario include direct exposure to external radiation and inhalation of airborne materials.

Calculations were performed for an individual drifting in a small boat within a large diameter section of the sewer line. Doses from the external exposure pathway were calculated at a distance of 1 m from the surface of the source, which was modeled as a slab of water 50 cm deep, 200 cm wide, and 600 cm long. (Subsequent calculations showed that, for a given radionuclide concentration in water, the dimensions of the source do not greatly influence the dose rate estimates.) External dose rates were calculated on the basis of radionuclide concentrations in the wastewater equivalent to 10% of the maximum permissible daily release concentrations listed in the revised 10 CFR 20, Appendix B, Table 3 (1991). It was assumed that discharges from the facility (at the maximum concentration allowed) were diluted to the 10% level by other inputs to the sewer system that occurred upstream from the point of exposure. The discharged radionuclides were assumed to travel and decay approximately 0.2 hour before reaching the point of exposure. For the purpose of evaluating potential annual doses for this individual, it was assumed that exposures to these concentrations occurred for 100 hours during the year.

For inhalation, the individual was assumed to be exposed for a shorter time period of 20 hours because workers under these conditions would likely wear respirators the majority of the time. An air concentration of 1.0 E-04 g/m^3 was assumed, with 20% of the material assumed to be respirable.

The time period over which the assumed concentration could be maintained depends on the average daily effluent flow rate from the licensee's facility. The 1-Ci/yr limit could be reached relatively quickly for radionuclides with high concentration limits and moderate effluent flow rates. For example, 1 Ci of ^{99m}Tc would be diluted to its concentration limit by only 10,000 L of water.

5.2.2 Scenario No. 2 - STP Sludge Process Operator

In this scenario, the potential doses to STP workers from radionuclides carried into the facility by the wastewater stream were evaluated. This scenario addressed a worker whose sole function was to operate and maintain sludge processing equipment such as a centrifuge or sludge press. This function requires the worker to be in relatively close contact with dewatered sludge on a full-time basis.

External exposure and inhalation of airborne radioactive materials from the sewage sludge were considered. For external dose estimates, the worker was assumed to be located at a distance of 2 m from a sludge mass 1 m deep and long enough to be modeled as an infinite slab. In practice, this would translate to a length of 3 to 6 m for equipment such as a sludge press or collection bin. The external exposure duration was assumed to be 1500 h/yr. The concentration of radioactive materials in the sludge at this point of the processing was assumed to be 2.1 E-04 Ci/m^3, based on a discharge of 1 Ci/yr. The concentration of radionuclides in the sludge was based on a 30% solids content, which contains essentially all of the incoming radioactive material. The

Table 5.1 Exposure scenario summary

Exposure scenario	Exposure pathways: External	Exposure pathways: Internal
Sewer system operations		
No. 1 - Sewer System Inspector--Worker	Wastewater in pipes	Inhalation via resuspension
No. 2 - STP Sludge Process Operator--Worker	Sludge in processing equipment	Inhalation via resuspension
No. 3 - STP Liquid Effluent--Public	River/shoreline recreation Deposits on ground via irrigation	Inhalation via resuspension Ingestion via drinking water, irrigated crops, fishing
Sewage sludge treatment and disposal operations		
No. 4 - STP Incinerator Operator--Worker	Incinerator ash	Inhalation of dust
No. 5 - Sludge Incinerator Effluent--Public	Deposits on ground from air	Inhalation of effluent Ingestion via air deposition on local crops
No. 6 - Incinerator Ash Disposal Truck Driver--Worker	Ash in truck	Inhalation of dust
No. 7 - Sludge Application to Agricultural Soil--Public	Ground	Inhalation via resuspension Ingestion via local crops
No. 8 - Sludge Application to Non-Agricultural Soil--Public	Ground	Inhalation via resuspension
No. 9 - Landfill Equipment Operator--Worker	Ground	Inhalation via resuspension
Post-sewage sludge disposal		
No. 10 - Landfill Intrusion and Construction--Public	Ground	Inhalation via resuspension
No. 11 - Landfill Intrusion Intrusion and Residence--Public	Ground	Inhalation via resuspension

radionuclides were assumed to travel and decay approximately 3 days before reaching the sludge press.

For inhalation, the worker was assumed to be exposed for a shorter duration of 300 h/yr because workers who maintain equipment would be exposed to airborne materials infrequently. An average air concentration of 1.0 E-04 g/m^3 was assumed, with 20% of the material assumed to be respirable.

5.2.3 Scenario No. 3 - STP Liquid Effluent

In this scenario, the potential radiation doses to a member of the public from exposure to STP liquid effluent were evaluated. All radioactive materials discharged to the sewer system were assumed to be highly soluble, to remain in the liquid phase, and to be released in the STP liquid effluent to a river having a flow rate of 100-m^3/sec. Release of soluble materials was assumed in order to provide a generic analysis that would produce prudently conservative results, without relying on data from any specific operation that may be incorrect for other processes. For a release of 1 Ci/yr, the average concentration in the river was calculated to be about 0.32 pCi/L.

The downstream scenario involved an individual who was assumed to live near the river and to use its water for irrigation. Exposure pathways for this individual included external exposure to radioactive materials in the river (via swimming and boating), on the shoreline, and deposited on the ground by irrigation; and internal exposure from inhalation of resuspended radioactive material deposited on the soil by irrigation and ingestion of contaminated food, including irrigated garden crops and fish from the river.

Radionuclides were assumed to decay approximately 7 hours before being released to the river. Exposure to radioactive material on the ground was assumed to occur about 5 h/day (1800 h/yr), and direct exposure to the water via swimming, boating, or shoreline activities was assumed to last 10, 5, and 17 h/yr, respectively. Inhalation of contaminated dust was assumed to continue for about 5 h/day (1800 h/yr) with a mass loading of 1.0 E-04 g/m^3. Only 20% of the particles were assumed to be respirable. About 50% of the fruit and vegetable diet for this individual was assumed to be grown locally with irrigation water from the river. The irrigation season was assumed to last 6 mo/yr at an application rate of about 76 cm/yr. In addition, about 6.9 kg/yr of fish from the river were assumed to be ingested.

5.2.4 Scenario No. 4 - STP Incinerator Operator

In this scenario, the potential radiation doses for a sludge incinerator operator were evaluated. Sludge incineration was assumed to take place with minimum delay after processing at the STP. Although sludge is sometimes co-incinerated with municipal trash or other organic wastes, in this scenario use of a dedicated multiple-hearth furnace was assumed. The published parameters for incineration of radioactive waste in a rotary kiln furnace (typical of those used for municipal trash) were adjusted where necessary to fit this scenario (IAEA, 1987; Oztunali and Roles, 1984).

Exposure pathways for an incinerator operator included external exposure to radioactive materials in the furnace and internal exposure from inhalation of radioactive materials in resuspended ash. Exposure to incinerator flue gas was not included for personnel within the plant, because they are shielded by the facility, and because the plume was assumed to remain airborne for some distance downwind.

For the external dose calculations for this scenario, exposure was assumed to occur 4 h/day (1000 h/yr), with an infinite slab source geometry correction factor of 0.25 and a shielding correction factor of 0.4 (IAEA, 1987). The radionuclides were assumed to decay approximately 3 days before reaching the incinerator. For inhalation, the individual was assumed to be exposed to airborne ash for 400 h/yr. The airborne particulate ash loading within the plant was assumed to be 1.0 E-03 g/m^3, of which 50% was assumed to be respirable. Concentrations of ^{3}H and ^{14}C in the ash were adjusted based on assumed releases from the incinerator. Releases from the stack were calculated using release fractions of 0.9 for ^{3}H; 0.75 for ^{14}C; 0.1 for strontium and iodine; 0.01 for chlorine, phosphorus, ruthenium, and technetium; 0.001 for sodium and cesium; and 0.005 for all other elements (IAEA, 1987; Oztunali and Roles, 1984). An adjustment was made for the addition of 10% water to stabilize the ash during transport. The concentration in ash, using a release of 1 Ci/yr, was estimated to be 2 nCi/g.

5.2.5 Scenario No. 5 - Sludge Incinerator Effluent

In this scenario, the potential radiation doses to a member of the public living in the vicinity of an operating sludge incinerator were evaluated. Incinerator parameters were similar to those described for the previous operator scenario with the same assumed fractional releases of radionuclides (IAEA, 1987; Oztunali and Roles, 1984).

Doses were calculated for an individual living downwind from the incinerator at the point of maximum plume concentration. Exposure pathways for this individual included: external exposure to ground-deposited radioactive materials, inhalation of airborne radioactive materials, and ingestion of radioactive materials deposited on locally grown foodstuffs.

The external exposure duration was assumed to equal the time spent outdoors, 1800 h/yr. The inhalation exposure duration was assumed to be 6180 h/yr, including the time spent outdoors and the time spent indoors. The average outdoor air concentration was assumed to be 1.0 E-04 g/m^3, with an exposure duration of 1800 h/yr. The average indoor air concentration was assumed to be half of the outdoor air concentration, or 5.0 E-05 g/m^3, with an exposure duration of 4380 h/yr. The radionuclides in the sludge were assumed to decay approximately 3 days before being incinerated. Atmospheric transport parameters included a X/Q value of 1.0 E-06 and a deposition velocity of 1.0 E-03 m/sec. For a release of 1 Ci/yr, the air concentration for individuals in the environment was estimated to be about 3.2 E-05 pCi/L. It was assumed that 100% of the particulates from the incinerator effluent were respirable. Finally, 50% of the individual's total diet (including meat and milk) was assumed to be locally produced.

5.2.6 Scenario No. 6 - Incinerator Ash Disposal Truck Driver

In this scenario, the potential radiation doses to a worker who drives a truck carrying ash from the STP to a final disposal site were evaluated. Transportation of ash was selected for this evaluation because ash will contain higher concentrations of radioactive materials than sludge. The concentration of most radionuclides in the ash was calculated, based on a release of 1 Ci/yr, to be about 0.0028 Ci/m^3. Transporting sludge was estimated to result in lower doses by about a factor of 10 because of the reduced concentrations in the sludge. External exposure and inhalation of airborne radioactive materials were the only exposure pathways considered.

The external and inhalation exposures were assumed to occur for 1000 h/yr. The radionuclides were assumed to decay approximately 3 days before the ash was loaded into the truck. The exposure geometry was modeled as a source with dimensions of 2 x 3 x 1 m (corresponding to the filled truck bed). The driver was assumed to be separated from the load by 1 cm of steel in the bed and cab. For inhalation, an airborne dust loading of 1.0 E-04 g/m^3 was assumed, with 20% of the material in the respirable size range. These exposure conditions are clearly conservative because half of the time would be spent returning to the site with an empty truck, there would be time spent loading the truck, and there would likely be time spent on other activities away from the truck. In addition, the duration of inhalation exposure may be much less than that for external exposure given a well-ventilated truck cab. However, these assumptions provide a prudently conservative basis for the dose estimates.

5.2.7 Scenario No. 7 - Sludge Application to Agricultural Soil

In this scenario, potential radiation doses to members of the public as a result of applying sludge to agricultural land as a soil conditioner and fertilizer were evaluated. The exposed individual was assumed to be a farmer who lives on the site of sludge application and engages in farming activities. Exposure pathways for this individual included external exposure to radioactive material on the ground, inhalation of resuspended radioactive materials, and ingestion of foodstuffs grown at the site.

For external exposure and inhalation, the exposure duration was assumed to be 2000 h/yr. External exposures were estimated for this scenario using a shielding factor of 0.25. The radioactive material is assumed to be uniformly distributed through the top 15 cm of the plow layer, thus avoiding the potential for overestimation of the external exposure. Inhalation exposures were estimated assuming an airborne dust loading of 1.0 E-04 g/m^3, with 20% of the material in the respirable size range. The farmer was assumed to obtain 50% of his fruit and vegetable diet from food grown on the sludge-treated land. This fraction is the same as for Scenario No. 3.

An application rate of 15 Mg/ha (dry weight) was used for this analysis, with immediate tillage after application (EPA 1986c). The radionuclides were assumed to decay approximately 12 days before being applied to the land. For a release of 1 Ci/yr, the soil concentration was calculated to be about 3.7 pCi/g.

5.2.8 Scenario No. 8 - Sludge Application to Non-Agricultural Soil

In this scenario, the potential radiation doses to members of the public from the application of sewage sludge to non-agricultural land were evaluated. In such cases, the sludge is applied at higher rates than are considered acceptable for agricultural land. Non-agricultural applications are made in areas such as forests, parks, or locations that have been severely disturbed by mining and excavation (EPA, 1986b). For this scenario, the application rate was assumed to be 100 Mg/ha (dry weight), and the exposed individual was assumed to be an individual who is employed spreading sludge. For a release of 1 Ci/yr, the resulting concentration in soil was calculated to be about 24 pCi/g.

The exposure pathways considered for this scenario were external exposure and inhalation. This type of sludge application was assumed to be seasonal employment with an external exposure and inhalation exposure duration of about 3 months or 500 hours. The radionuclides were assumed to decay approximately 12 days before being applied to the land. For inhalation, an air concentration of 1.0 E-04 g/m^3 was assumed, with 20% of the material assumed to be respirable.

5.2.9 Scenario No. 9 - Landfill Equipment Operator

In this scenario, the potential radiation doses to individuals working at a landfill were evaluated. The landfill was assumed to be dedicated to the disposal of solids from the STP, either in the form of sludge or incinerator ash. Sludge is sometimes mixed with soil or municipal solid waste for disposal in a sanitary landfill, and this practice results in doses that are an order of magnitude lower than those calculated for a dedicated landfill. For this scenario, ash containing 10% moisture was assumed to be deposited in wide trenches and covered with 1 m of clean soil. The ash was assumed to be diluted to 10% of the original concentration by other municipal wastes disposed of at the same landfill. The wet ash/waste mixture was calculated to have a concentration of 180 pCi/g, assuming a release of 1 Ci/yr. The exposed individual for this scenario was a heavy equipment operator.

Exposure pathways for this individual included external exposure to radioactive material on the ground and inhalation of resuspended material. The exposed individual was assumed to spend 500 h/yr running heavy equipment in the vicinity of the disposed ash. Shielding and geometry factors of 0.2 each were assumed to account for the shielding afforded by the heavy equipment and the overburden materials (IAEA, 1987). The radionuclides were assumed to decay approximately 3.5 days before being applied to the land. Airborne dust mass loading was assumed to be 5.0 E-04 g/m^3, with 20% of the particles assumed to be in the respirable size range.

5.3 Post-Sewage Sludge Disposal Exposure Pathways and Scenarios

The scenarios presented in this section address potential exposure to radioactive materials in the extended time frame following closure of a dedicated ash landfill. Conditions that would control potential access to or movement of radioactive materials at a closed landfill site are difficult to predict and may be highly site specific. Scenarios No. 10 and 11 have been developed and analyzed to evaluate potential long-term implications of incinerator ash disposal. Each scenario incorporates a 5-year delay/decay time to account for a nominal period of institutional control after site closure. The scenarios were designed to be similar to human intruder scenarios developed for low-level radioactive waste disposal evaluations (Oztunali and Roles, 1984). These scenarios rely on the assumption that they will occur. Because they further rely on assumptions regarding the post-disposal radioactive decay period and the type of human activities involved in reuse of the land, their results are presumed to be less likely than the results estimated for the other scenarios considered in this analysis. Therefore, in lieu of a more comprehensive analysis, the results should be viewed only as conservative estimates.

5.3.1 Scenario No. 10 - Landfill Intrusion and Construction

In this scenario, the potential radiation dose to a member of the public from inadvertent intrusion into an ash landfill site was evaluated. The intrusion was assumed to occur when the landfill was excavated for residential construction 5 years after disposal of the ash.

The excavation was assumed to extend 3 m into the ground and remove a total of 900 m^3 of soil, which was then used for backfill or spread in the area adjacent to the house (Oztunali and Roles, 1984). The size of each disposal trench in the landfill was assumed to be larger than the area excavated for construction, and the entire construction was assumed to take place over contaminated soil. Assuming a cover depth of 1 m and complete mixing of the excavated cover and contaminated soil, the radionuclide concentration in the distributed surface soil would be 60% of that in the waste. Assuming a release of 1 Ci/yr, the concentration in soil for this scenario was calculated to be 110 pCi/g before correction for radioactive decay. The contaminated soil was assumed to cover an area extending 25 m from the house. The exposed individual was a worker involved in the excavation and construction activities.

Exposure pathways for this individual included external exposure to radioactive materials in the ground and inhalation of resuspended particles. The exposure time for both pathways was assumed to be 500 hours (typical of a 3-month period for house construction). A correction factor of 0.5 was applied to the external exposure to account for shielding and geometry factors. The airborne dust level was assumed to average 4.0 E-04 g/m^3 over the construction period (IAEA, 1987), with 20% of the particles in the respirable size range.

5.3.2 Scenario No. 11 - Landfill Intrusion and Residence

In this scenario, the potential radiation doses to a member of the public from inadvertent intrusion into an ash landfill site following termination of disposal operations were evaluated. The landfill was assumed to be excavated for residential construction with a 5-year delay after disposal of the ash (as described for Scenario No. 10). This scenario includes an evaluation of the dose to an individual who lives on the site and grows a portion of his food there. A further dilution by non-active soil was assumed using a dilution factor of 0.67. The resulting concentration in soil for this scenario was 80 pCi/g before correcting for radioactive decay.

Exposure pathways for this scenario included external exposure to radioactive material on the ground, inhalation of resuspended dust, and ingestion of foodstuffs grown on the site. For external exposure, the individual was assumed to spend 5850 h/yr indoors, with a shielding factor of 0.33 and 100 h/yr outdoors (unshielded). For inhalation, the individual was assumed to spend 5850 h/yr indoors with an air concentration of 5.0 E-05 g/m^3 and 100 h/yr outdoors with an air concentration of 1.0 E-04 g/m^3. Only 20% of the air concentration was assumed to be in the respirable particle size range.

The exposed individual was assumed to obtain 25% of his fresh fruit and vegetables from a home garden (Oztunali and Roles, 1986). Only 25% of the vegetable diet was assumed to be contaminated, to account for clean cover soil that effectively prevented uptake by plants in areas that were not excavated.

5.4 Selection of Scenario Parameter Values

The input parameters and assumptions for each exposure pathway and scenario were selected to provide a prudently conservative, not worst case, estimate of the radiation dose to an average individual in a population. In each case, an attempt has been made to select values within the expected range — not at the extremes of the expected range. For example, for Scenario No. 11 - Landfill Intrusion and Residence, a backyard garden was assumed to produce 25% of the total diet defined in Regulatory Guide 1.109 (NRC, 1977) instead of the full diet.

The major parameters or assumptions used in this analysis and their potential ranges, based largely on literature values, are listed in Table 5.2. Some parameters in the exposure model are difficult to quantify because little information is available about the distribution of their values. In these cases, best judgment was used. Additional parameters and assumptions for the identified scenarios are discussed in Appendix A. The parameter ranges shown in Table 5.2 also serve as the basis for the stochastic analysis performed as part of the uncertainty and sensitivity analysis (see Section 7).

Table 5.2 Expected range of values for major pathway parameters and the selected values used in this study

Scenario and pathway parameters	Expected range of values	Selected value	Comments
No. 1 - Sewer System Inspector			
Concentration/source term: fraction of 10 CFR 20, Appendix B, Table 3	0.01 - 1.0	0.1	Dilution with wastewater
Decay time (h)	0 - 8	0.2	
External exposure time (h/yr)	40 - 240	100	
Inhalation exposure time (h/yr)	8 - 48	20	External exposure hours x 0.2
Mass loading (g/m^3)	5.0 E-05 - 5.0 E-03	1.0 E-04	
Respirable fraction	0 - 1.0	0.2	
No. 2 - STP Sludge Process Operator			
Concentration/source term (Ci/m^3)	1.1 E-05 - 1.1 E-03	2.1 E-04	Based on 1-Ci/yr input, diluted
Decay time (days)	3 - 50+	3	
External exposure time Operator exposure (h/yr)	500 - 1750	1500	Time in close proximity to equipment
Inhalation exposure time Operator exposure (h/yr)	100 - 350	300	External exposure hours x 0.2

Table 5.2 (Continued)

Scenario and pathway parameters	Expected range of values	Selected value	Comments
<u>No. 3 - STP Liquid Effluent</u>			
Concentration			
Release rate (Ci/yr)	0 - 1.0	1.0	
River flow rate (m^3/s)	100 - 3000	100	
Decay time (h)	6 - 8 h	7	
External exposure time			
Transit time-irrigation (h)	0 - 8	1.0	
Transit time-recreation (h)	0 - 8	1.0	
Exposure time-swimming (h/yr)	0 - 50	10	PNL-3777, Rev. 1 p. 25[a]
Exposure time-boating (h/yr)	0 - 100	5	PNL-3777, Rev. 1 p. 25[a]
Exposure time-shoreline (h/yr)	0 - 100	17	PNL-3777, Rev. 1 p. 25[a]
Exposure Time-ground (h/yr)	100 - 4400	1800	
Inhalation exposure time (h/yr)	100 - 4400	1800	
Mass loading (g/m^3)	1.0 E-05 - 5.0 E-04	1.0 E-04	1.0 E-04 g/m^3 (NUREG/CR-4370)[b]; 5.0 E-05 g/m^3 (NUREG/CR-4370)[b]; 6.0 E-06 g/m^3 IAEA-TECDOC-401 (IAEA, 1987)
Ingestion			
Fish (kg/yr)	0 - 40	6.9	GENII average; distribution from EPA 1989 Exposure Factors Handbook (EPA, 1989a);
Leafy vegetables (kg/yr)	1.0 - 9.8	4.9	50% diet from
Fruit (kg/yr)	0 - 42	21	NUREG/CR-5512, B.17[c]
Other vegetables (kg/yr)	0 - 91	45.5	
Grain (kg/yr)	0 - 47	23.5	
Meat (kg/yr)	0 - 95	47	
Milk (L/yr)	0 - 110	55	
Irrigation rate (cm/yr)	0 - 120	76	PNL-6584 Vol 2[d]
Irrigation duration (mo/yr)	0 - 12	6	PNL-6584 Vol 2[d]

Table 5.2 (Continued)

Scenario and pathway parameters	Expected range of values	Selected value	Comments
No. 4 - STP Incinerator Operator			
Concentration/source term (Ci/kg)	9.8 E-08 - 9.8 E-06	2.0 E-06	Ash from sludge with 1-Ci/yr input, diluted
Decay time (days)	3 - 50+	3	
External exposure time (h/yr)	100 - 2000	1000	IAEA-TECDOC-401 (IAEA, 1987)
Geometry correction	0 - 1.0	0.25	IAEA-TECDOC-401 (IAEA, 1987)
Shielding correction	0 - 1.0	0.4	Nuclide-dependent
Inhalation			
Dust loading (g/m^3)	1.0 E-04 - 5.0 E-03	1.0 E-03	1.0 E-03 from IAEA-TECDOC-401 (IAEA, 1987)
Respiratory protection	0 - 1.0	0.5	0.50 from NEA/OECD (1987)
Dust loading (g/m^3)	1.0 E-04 - 1.0 E-03	1.0 E-03	4.0 E-04 - 2.4 E-03 from NUREG/CR-3585[e]
Retention ^3H in ash	0 - 1.0	0.1	NUREG/CR 3585, 4-13 ^{14}C[e]
Retention ^{14}C in ash	0 - 1.0	0.2	
Retention Ru in ash	-	0.99	
Retention I in ash	-	0.99	
Retention others in ash	0.90 - 1.0	>0.9	

Table 5.2 (Continued)

Scenario and pathway parameters	Expected range of values	Selected value	Comments
No. 5 - Sludge Incinerator Effluent			
Concentration/source term (Ci/yr)	0 - 1.0	1.0	
Decay time (days)	3 - 60+	3	Holdup of sludge to 50+ days; ash holdup may be another 10 days
Atm. dispersion factor (s/m^3)	1.0 E-08 - 1.0 E-06	1.0 E-06	3.0 E-07 from IAEA-TECDOC-401 (IAEA, 1987) 5.0 E-06 (NUREG/CR-3585)[e]
Release fractions			
^3H	0.1 - 1.0	0.9	The greater of release from NUREG/3585[e]
^{14}C	0.1 - 1.0	0.75	
Cl	0.01 - 1.0	0.01	IAEA-TECDOC-401, p. 71
Cs	0.0001 - 1.0	0.001	(IAEA, 1987)
I	0.001 - 1.0	0.1	
Na	0.0001 - 1.0	0.001	
P	0.001 - 1.0	0.01	
Ru	0.0001 - 1.0	0.01	
Sr	0.001 - 1.0	0.1	
Tc	0.001 - 1.0	0.01	
Other	0 - 1.0	0.005	
External exposure time			
Indoors (h/yr)	0 - 8800	5850	EPA/600/8-89/043
Outdoors (h/yr)	0 - 2000	100	(EPA, 1989a)
Inhalation exposure time (h/yr)	2200 - 8800	3990	100% respirable
Dust loading (g/m^3)			
Outdoors	1.0 E-05 - 1.0 E-03	1.0 E-03	
Indoors	1.0 E-06 - 1.0 E-03	5.0 E-04	

Table 5.2 (Continued)

Scenario and pathway parameters	Expected range of values	Selected value	Comments
<u>No. 5 - Sludge Incinerator Effluent</u> (Continued)			
Ingestion			
Leafy vegetables (kg/yr)	0 - 9.8	4.9	50% diet from NUREG/CR-5512, B.17[c]
Other vegetables (kg/yr)	0 - 91	45.5	
Fruit (kg/yr)	0 - 42	21	
Grain (kg/yr)	0 - 47	23.5	
Meat (kg/yr)	0 - 95	47.5	
Milk (L/yr)	0 - 110	55	
<u>No. 6 - Incinerator Ash Disposal Truck Driver</u>			
Concentration/source term (Ci/m^3)	1.6 E-04 - 1.6 E-02	2.8 E-03	Ash concentration (wet) from sludge; 1-Ci/yr input, diluted
Decay time (days)	3 - 60+	3	
External exposure time			
Operator exposure (h/yr)	100 - 1000	1000	
Inhalation exposure time			
Operator exposure (h/yr)	100 - 1000	1000	
Dust loading (g/m^3)	5.0 E-05 - 5.0 E-03	1.0 E-04	(IAEA, 1987)

Table 5.2 (Continued)

Scenario and pathway parameters	Expected range of values	Selected value	Comments
No. 7 - Sludge Application to Agricultural Soil			
Concentration/source term (Ci/m^2)	5.8 E-09 - 7.3 E-06	8.8 E-07	Based on 1-Ci/yr input, diluted
Application rate (Mg/ha)	2 - 35	15	ECAO-CIN-489 (EPA, 1986c)
		11	EPA 625/6-83-016 (EPA, 1983) Typical application rate 5 Mg/ha, EPA600/6-89/001 (EPA, 1989b)
Decay time (days)	0 - 50	12	
External exposure time (h/yr)	500 - 2000	2000	
Shielding factor	0 - 1.0	0.25	
Inhalation exposure time(h/yr)	500 - 2000	2000	
Respirable fraction	0 - 1.0	0.2	
Mass loading (g/m^3)	1.0 E-04 - 1.0 E-03	1.0 E-04	5.0 E-04, IAEA-TECDOC-401, (IAEA, 1987)
Ingestion			
Leafy vegetables	1.0 - 9.8	4.9	50% diet from NUREG/CR-5512, B.17[c]
Other vegetables (kg/yr)	9.1 - 91	45.5	
Fruit (kg/yr)	4.2 - 42	21	
Grain (kg/yr)	4.7 - 47	23.5	

Table 5.2 (Continued)

Scenario and pathway parameters	Expected range of values	Selected value	Comments
<u>**No. 8 - Sludge Application to Non-Agricultural Soil**</u>			
Concentration/source term (Ci/m^2)	2.9 E-08 - 2.9 E-05	5.8 E-06	Based on 1-Ci/yr input, diluted
Application rate (Mg/ha)	10 - 200	100	ECAO-CIN-489 (EPA, 1986b)
Decay time (days)	0 - 50	12	
External exposure time (days)	0 - 2000	500	
Inhalation exposure time (h/yr)	0 - 2000	500	
Respirable fraction	0 - 1.0	0.2	
Mass loading (g/m^3)	1.0 E-04 - 1.0 E-03	1.0 E-04	5.0 E-04, IAEA-TECDOC-401 (IAEA, 1987)
<u>**No. 9 - Landfill Equipment Operator**</u>			
Concentration/Source term (Ci/kg)	8.8 E-09 - 8.8 E-07	1.8 E-07	Based on ash from sludge, incineration, diluted
Source term dilution	0.001 - 1.0	0.1	
Decay time (days)	2 - 20	3.5	
Ash moisture	1.0 - 20	10%	
External exposure time (h/yr)	100 - 2000	500	1000 IAEA-TECDOC-401 (IAEA, 1987)
Shielding correction	0 - 1.0	0.2	
Inhalation exposure time (h/yr)	100 - 2000	2000	
Respirable fraction	0 - 1.0	0.2	
Mass loading (g/m^3)	1.0 E-05 - 1.0 E-03	4.0 E-04	4.0 E-04 from NUREG/CR-3585[(e)]

Table 5.2 (Continued)

Scenario and pathway parameters	Expected range of values	Selected value	Comments
No. 10 - Landfill Intrusion and Construction			
Concentration/source term (Ci/m^3)	1.6 E-05 - 1.6 E-3	3.1 E-04	Ash from sludge incineration with 1-Ci/yr input, diluted
Source term dilution	0.001 - 1.0	0.1	
Time after closure (yr)	0 - 50	5	0, 10, 50 IAEA-TECDOC-401 (IAEA, 1987)
Cover depth (m)	0.3 - 2	1.0	1 m gives dilution of 0.6 NUREG/CR-3585[e]
Soil dilution factor	0.25 - 0.87	0.4	
External exposure time (h/yr)	100 - 1000	500	
Shielding correction	0 - 1.0	0.5	
Inhalation exposure time (h/yr)	100 - 1000	500	
Respirable fraction	0 - 1.0	0.2	
Mass loading (g/m^3)	1.0 E-04 - 1.0 E-03	5.0 E-04	5.0 E-04, IAEA-TECDOC-401 (IAEA, 1987)

Table 5.2 (Continued)

Scenario and pathway parameters	Expected range of values	Selected value	Comments
<u>No. 11 - Landfill Intrusion and Residence</u>			
Concentration/source term (Ci/m^3)	1.6 E-05 - 1.6 E-03	3.1 E-04	Ash from sludge incineration with 1 Ci/yr input, diluted
Manual redistribution (m^3/m^2)	0.0009 - 0.09	0.09	
Source term dilution	0.001 - 1.0	0.1	
Cover depth (m)	0.3 - 2	1.0	1 m gives dilution of 0.6 NUREG/CR-3585[e]
Time after closure (yr)	0 - 50	5	0, 10, 50 IAEA-TECDOC-401 (IAEA, 1987)
External exposure time			
Indoors (h/yr)	0 - 8760	5850	EPA/600/8-89/043 (EPA, 1989a)
Outdoors	0 - 2000	100	
Shielding correction	0 - 1.0	0.33	NUREG/CR-3585, 6-16[e]
Inhalation exposure time			
Indoors	2950 - 8760	5850	
Outdoors	0 - 1800	80	
Gardening	0 - 120	20	
Respirable fraction	0 - 1.0	0.2	
Mass loading (g/m^3)	1.0 E-05 - 1.0 E-03	1.0 E-04	5.0 E-04, IAEA TECDOC-401 (IAEA, 1987)
Consumption			
Fruit (kg/yr)	0 - 42	10.5	25% Diet from NUREG/CR-5512, B.17[e]
Grain (kg/yr)	0 - 47	11.8	
Leafy vegetables (kg/yr)	0 - 9.8	2.5	
Other vegetables (kg/yr)	0 - 91	22.8	

(a) McCormack, Ramsdell, and Napier (1984).
(b) Oztunali and Roles (1986).
(c) Kennedy and Peloquin (1990).
(d) Napier et al. (1988).
(e) Oztunali and Roles (1984).

6 Deterministic Dose Evaluation

Deterministic calculations were performed to estimate the potential radiation doses that could be received by municipal workers and members of the public from authorized releases of radioactive materials to sanitary sewer systems using the exposure scenarios described in Section 5. It should be remembered that workers at municipal STPs are not radiation workers and are limited to the same exposure levels as any other member of the general public, as defined in 10 CFR 20. Deterministic calculations use single values for input parameters, data, and assumptions to produce specific, single-value results. These calculations are typically produced in most common public dose estimates. By contrast, stochastic calculations involve using ranges of parameter values, with known or assumed distributions, to produce a distribution of potential results. The single parameter values and assumptions used in the deterministic analysis were selected to provide a prudently conservative estimate of the potential radiation doses. The results were calculated in terms of the annual total effective dose equivalent (TEDE) that an individual may receive for each scenario from 1 year's discharge to a sewer system. The TEDE is the sum of the external dose equivalent and the committed effective dose equivalent for internal exposures.

Two sets of deterministic dose calculations were performed: the first used information from the case histories defined in Section 2 for selected scenarios (from Section 5) that best relate to the real situations, and the second used the theoretical discharges at the maximum allowable levels (defined by 10 CFR 20) for a more comprehensive list of 63 radionuclides. These calculations provide a prudently conservative evaluation of doses from actual radionuclide discharges. The calculations also provide an analysis of individual radionuclides and exposure situations at current regulatory limits to identify those that may be of concern. As a partial verification of the modeling exercise, selected scenario results were compared with results obtained using the IMPACTS-BRC, Version 2.0 (O'Neal and Lee, 1990). The modeling approach is discussed and the results of the deterministic dose calculations performed are summarized in the following sections.

6.1 Modeling Approach

In this study, computerized models were used to produce deterministic estimates of the radiation doses from potential exposures to radioactive materials disposed of via sanitary sewers. The models include consideration of radiation doses from potential exposure to external sources of radiation, such as radioactive material deposited on the ground or in sewer pipes, and from exposure to internal sources of radiation, such as radioactive material that has been inhaled or ingested.

Initial screening studies were conducted using the ONSITE/MAXI1 (Kennedy et al., 1987) computer software for scenarios related to sewage treatment and disposal. This program was selected because of its flexibility in allowing the user to define various exposure scenarios and because it was developed and documented for NRC modeling applications.

During the development of this document, the capabilities of the ONSITE/ MAXI1 computer program were included as part of an updated computerized model, the GENII software package (Napier et al., 1988). The GENII software is designed to estimate individual and population doses from releases of radionuclides to air, water, or soil and includes an enhanced capability for development of user-defined scenarios. The software package was developed and documented under a strict quality assurance (QA) program based on the American National Standards Institute (ANSI) standard NQA-1 (ASME, 1986). The code has been used for a variety of waste management assessments and has been extensively tested. The tests have included a variety of QA inspections, including comparison of computer-generated results with hand calculations. During its development, the GENII software package was reviewed by an external peer-review panel of national and international environmental health physicists with pathway modeling experience. The code is currently under configuration management providing for change control and documentation of updates to all identified users. The GENII software is described in three volumes of documentation including: 1) a description of the mathematical models,

2) a detailed user manual (including sample problems for benchmarking), and 3) a code maintenance manual (Napier et al., 1988).

GENII internal dose calculations are based on methods recommended by the International Commission on Radiological Protection (ICRP) in Publications 26 and 30 (ICRP, 1977; 1979-1988), and Publication 48 (ICRP, 1986) for plutonium and related elements. Dosimetric information for the "Reference Man," as described by the ICRP (1975), was used in all calculations. The dose from individual radionuclides includes corrections for radioactive decay and contributions, if any, from daughter radionuclides. Within the GENII software package, the models used to calculate doses from external exposure to radioactive material contained within components of the sewer and sludge treatment systems were those incorporated in the ISOSHLD computer program (Engel, Greenborg, and Hendrikson, 1966; Simmons et al., 1967). Results of these calculations were verified, in selected cases, by comparing them with results from a Monte Carlo radiation transport program (Briesmeister, 1983). The GENII program was also used in calculating potential doses resulting from inhalation of radioactive materials within the sewer and sludge treatment facilities.

In all cases, the calculations were performed for an average individual in an exposed population using single value parameters, assumptions, or data to produce prudently conservative (not worst-case) deterministic results. The scenarios were selected after consideration of potential conditions of exposure as discussed in Section 5. Detailed lists of exposure and consumption assumptions and parameters are provided in the input files for the GENII software package (see Appendix A).

6.2 Deterministic Results for Case Histories

For the five case histories described in Section 4, potential annual TEDEs to individuals were estimated using a deterministic scenario analysis and the reported radionuclide concentrations and/or discharges. The case histories were initially evaluated to determine which scenarios best related to the reported conditions. The results of this evaluation are summarized in Table 6.1, showing which of the 11 radiation exposure scenarios (defined in Section 5) were considered for each case history.

The results of the deterministic analysis of the potential annual TEDEs for the case histories are summarized for the limiting scenarios in Table 6.2. This table is organized by case history, showing the dominant exposure pathway, the dominant radionuclide, and the calculated TEDE for the limiting scenario. For Blue Plains, two case histories were available and are shown. More detailed results for the case histories are in Appendix B.

As shown in Table 6.2, the scenario and case history with the largest estimated annual TEDE is Scenario No. 4 - STP Incinerator Operator, for the Tonawanda case history. The estimated annual TEDE is 93 mrem. This dose is through the inhalation pathway from the release of ^{241}Am. As shown in Tables B.1 through B.5, 5 out of the 32 scenarios for the different case histories exceeded 10-mrem/yr and equaled 10 mrem/yr for a sixth scenario. Of these, the Royersford case history produced two scenarios with TEDEs exceeding 10-mrem/yr and equaled 10-mrem/yr in a third scenario, all associated with the release of ^{60}Co. Two scenarios for the Tonawanda case history resulted in TEDEs exceeding 10-mrem/yr.

Table 6.1 Determination of which scenarios apply to the case histories described in the literature

Scenario	Tonawanda	Grand Island	Royersford	Oak Ridge	Blue Plains
No 1 - Sewer System Inspector	-[a]	-[a]	X	X	X
No 2 - STP Sludge Process Operator	X	X	X	X	X
No 3 - STP Liquid Effluent	-[a]	-[a]	-[a]	-[a]	X
No 4 - Incinerator Operator	X		X[b]		
No 5 - Sludge Incinerator Effluent	X				
No 6 - Incinerator Ash Disposal Truck Driver	X		X[b]		
No 7 - Sludge Application to Agricultural Soil			X	X	X
No 8 - Sludge Application to Non Agricultural Soil			X	X	X
No 9 Landfill Equipment Operator	X	X[c]	X[c]		
No 10 Landfill Intrusion and Construction	X	X[c]	X[c]		
No 11 Landfill Intrusion and Residence	X	X[c]	X[c]		

(a) Concentration not known
(b) Hypothetical only, sludge not incinerated.
(c) Sludge disposed in landfill (not ash)

Table 6.2 Summary of limiting TEDEs for the reported case histories

Case history	Limiting scenario	Dominant pathway	Dominant radionuclide	TEDE (mrem/yr)
Tonawanda	No. 4 - Incinerator	Inhalation	^{241}Am	93
Grand Island	No. 2 - STP Sludge Process Operator	Inhalation	^{241}Am	3.3
Royersford	No. 2 - STP Sludge Process Operator	External	^{60}Co	30
Oak Ridge	No. 2 - STP Sludge Process Operator	External	^{60}Co	55
Blue Plains				
(a)	No. 3 - STP Liquid Effluent	Ingestion	^{32}P	0.17
(b)	No. 3 - STP Liquid Effluent	Ingestion	^{32}P	0.44

6.3 Deterministic Results for Theoretical Radionuclide Discharges

The full list of 63 radionuclides considered in this study is shown as part of the input to the GENII computer code in Appendix A. The complete results of calculations for theoretical radionuclide discharges at the maximum allowable levels are found in Appendix B. A review of the annual TEDE results in Appendix B for the full list of radionuclides indicates that several of them could lead to radiation doses in excess of 10 mrem/yr for selected scenarios if a licensee disposed of 1 Ci in a given year and if other key assumptions in the prudently conservative analysis occur. To produce a meaningful summary for this section, the currently identified uses of licensed radionuclides were reviewed. The purpose of the review was to screen the complete list of radionuclides to identify the critical radionuclides, or those of most potential concern from a public dose perspective. A summary of the radionuclides reviewed and the deterministic results for the critical radionuclides is presented in the following sections.

6.3.1 Review of Currently Produced or Used Radionuclides

Radionuclides that are currently produced or used can be estimated from production and procurement records. Although total use does not necessarily equate to disposal via the sanitary sewer system, it does help establish an upper bound. As a result of this exercise, five key radionuclides of greatest potential concern, from a production or use point of view, were identified: ^{60}Co, ^{90}Sr, ^{137}Cs, ^{192}Ir, and ^{241}Am.

The radionuclides that produce the largest TEDEs for the scenarios considered in this study (as presented in Appendix B) include: ^{22}Na, ^{24}Na, ^{36}Cl, ^{46}Sc, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{65}Zn, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{99}Tc, ^{129}I, ^{134}Cs, ^{137}Cs, ^{140}La, ^{152}Eu, ^{154}Eu, ^{192}Ir, ^{210}Pb, ^{226}Ra, ^{228}Th, ^{233}U, ^{235}U, ^{237}Np, ^{238}Pu, ^{240}Pu, and ^{241}Am.

None of the radionuclides in this group are used for current nuclear medicine procedures (NCRP, 1985). Thus, dilute liquid waste from nuclear medicine operations, in quantities not exceeding 1 Ci/yr, does not contribute to calculated doses in excess of 10 mrem/yr.

However, contaminated excreta from patients undergoing nuclear medicine procedures is another issue. There is no regulatory control over such disposal.

There may be isolated cases where quantities of ^{99m}Tc may be released in excess of 1 Ci/yr, especially where there are several large hospitals located in close proximity in large cities (NCRP, 1985).

Other radionuclides, like ^{24}Na and ^{140}La, have such short half-lives (15 and 40.2 hours, respectively), that they have little practical value to licensees. Consequently, it is very unlikely that any licensee would procure multi-curie amounts of these radionuclides and process them in a manner to produce liquid effluents approaching 1 Ci/yr.

Other radionuclides in the list, including ^{233}U, ^{235}U, and ^{238}Pu, are defined as "special nuclear materials" and are regulated by the NRC as specified in 10 CFR 70. Very stringent accountability requirements would tend to preclude the disposal of significant quantities of special nuclear materials to sanitary sewer systems. In addition, 10 CFR 70.59 requires semiannual reporting of unrestricted releases of special nuclear materials in liquid and gaseous effluents. Currently, ^{233}U and the isotopes of plutonium are not used by NRC licensees in significant quantities.

U.S. Department of Energy Radioisotope Customers with Summaries of Radioisotope Shipments, FY 1988 (Van Houten 1989) and the product catalogs of major commercial radioisotope suppliers were reviewed. This review indicated that many of the radionuclides that potentially produce significant radiation doses via disposal to sanitary sewer systems are not produced or sold in appreciable quantities. The total U.S. production of ^{22}Na, ^{99}Tc, ^{129}I, and ^{152}Eu in 1988 was only 2.2 Ci, 7.7 Ci, 1 mCi, and 3 mCi, respectively (Van Houten, 1989). The ^{22}Na was supplied to six customers, one of which is a major commercial supplier of radionuclides. The ^{99}Tc was supplied to 20 different customers. Again, one of these customers is a major commercial supplier who distributes radionuclides to numerous other customers. Thus, the probability is quite low that any single licensee could have used or disposed of these radionuclides in quantities approaching 1 Ci/yr. There was no reported production or sales of the remaining radionuclides identified to be of potential dose concern.

Of the initial list of radionuclides of potential dose concern, the radionuclides that are produced and used in significant quantities are ^{60}Co, ^{90}Sr, ^{137}Cs, ^{192}Ir, and ^{241}Am. The quantities of these radionuclides produced in fiscal year 1988 are estimated to have been 1 MCi of ^{60}Co, 0.5 MCi of ^{90}Sr, 0.2 MCi of ^{137}Cs, 0.6 MCi of ^{192}Ir, and 0.2 MCi of ^{241}Am (Van Houten, 1989). Most of the ^{60}Co, ^{137}Cs, and ^{192}Ir produced goes into sealed gamma sources used for irradiation facilities or industrial radiography. Most of the ^{90}Sr produced goes into sealed beta sources that have industrial applications. Most of the ^{241}Am produced goes into plated or laminated alpha sources used in smoke detectors. There is a finite probability that the few licensees who process larger quantities of these radionuclides could have liquid effluents approaching 1 Ci/yr that are disposed of to sanitary sewer systems. However, there is no direct evidence that any licensees are currently disposing of liquid wastes in excess of a few millicuries per year (NRC, 1986a; 1986b).

Based on this review of current industry practice, the critical radionuclides (i.e., those of most concern from a potential public dose perspective) are ^{60}Co, ^{90}Sr, ^{137}Cs, ^{192}Ir, and ^{241}Am. These radionuclides are used to produce the summary results discussed in the following section.

6.3.2 Deterministic Radiation Doses for Critical Radionuclides

The results of the deterministic calculations for the critical radionuclides at the theoretical discharge limits are summarized in Table 6.3. This table lists the dose by pathway and the annual TEDE for the five critical radionuclides for each of the 11 radiation exposure scenarios defined in Section 5. For each scenario, the radionuclides are listed in order of decreasing annual TEDE. As shown by the summary results in Table 6.3, the deterministic annual TEDEs exceed the 10-mrem/yr criterion for at least one radionuclide for all but three scenarios (Scenarios No. 1, 3, and 5), where all values are less than 10 mrem/yr.

The potential exposures associated with work conditions for a sewer system inspector and a treatment plant operator are described in Scenarios No. 1 and 2. The potential exposures to a member of the public

Table 6.3 Radiation exposure scenario annual total committed effective dose equivalent results for theoretical radionuclide discharges

Scenario	Radio-nuclide	Estimated radiation doses (mrem/yr) Inhalation	Ingestion	External	TEDE
No. 1 - Sewer System Inspector					
	^{60}Co	7.8 E-07	-[a]	1.2 E-01	1.2 E-01
	^{192}Ir	--[b]	-	8.5 E-02	8.5 E-02
	^{137}Cs	--	-	7.0 E-03	7.0 E-03
	^{241}Am	2.2 E-02	-	2.4 E-06	2.4 E-06
	^{90}Sr	--	-	1.1 E-06	1.1 E-06
No. 2 - STP Sludge Process Operator					
	^{60}Co	8.1 E-03	-	3.6 E+02	3.6 E+02
	^{192}Ir	1.0 E-03	-	1.2 E+02	1.2 E+02
	^{137}Cs	1.1 E-03	-	8.0 E+01	8.0 E+01
	^{241}Am	1.8 E+01	-	5.4 E+01	1.9 E+01
	^{90}Sr	8.3 E-03	-	1.4 E-02	2.2 E-02
No. 3 - STP Liquid Effluent					
	^{137}Cs	--	1.6 E+00	7.3 E-04	1.6 E+00
	^{241}Am	1.7 E-05	9.6 E-01	5.5 E-06	9.6 E-01
	^{90}Sr	--	3.0 E-02	7.6 E-06	3.0 E-02
	^{60}Co	--	1.2 E-02	2.9 E-03	1.5 E-02
	^{192}Ir	--	9.0 E-04	3.2 E-04	1.2 E-03
No. 4 - STP Incinerator Operator					
	^{241}Am	3.4 E+02	-	5.3 E-01	3.4 E+02
	^{60}Co	1.6 E-01	-	3.0 E+02	3.0 E+02
	^{192}Ir	2.0 E-02	-	1.1 E+02	1.1 E+02
	^{137}Cs	2.1 E-02	-	7.1 E+01	7.1 E+01
	^{90}Sr	1.6 E-01	-	1.3 E-02	1.7 E-01
No. 5 - Sludge Incinerator Effluent					
	^{241}Am	2.7 E-01	4.5 E-03	1.1 E-07	2.7 E-01
	^{137}Cs	1.7 E-05	4.9 E-04	1.4 E-05	5.2 E-04
	^{90}Sr	1.2 E-04	3.2 E-04	1.5 E-07	4.4 E-04
	^{60}Co	1.2 E-04	6.5 E-05	5.6 E-05	2.4 E-04
	^{192}Ir	1.6 E-05	5.3 E-06	6.1 E-06	2.7 E-05
No. 6 - Incinerator Ash Disposal Truck Driver					
	^{60}Co	7.2 E-03	-	2.1 E+02	2.1 E+02
	^{192}Ir	9.3 E-04	-	3.3 E+01	3.3 E+01
	^{137}Cs	9.9 E-04	-	3.0 E+01	3.0 E+01
	^{241}Am	1.7 E+01	-	2.5 E-06	1.7 E+01
	^{90}Sr	7.3 E-03	-	1.2 E-03	8.5 E-03

Table 6.3 (Continued)

Scenario	Radio-nuclide	Estimated radiation doses (mrem/yr) Inhalation	Ingestion	External	TEDE
No. 7 - Sludge Application to Agricultural Soil	^{90}Sr	3.0 E-05	1.7 E+01	1.3 E-04	1.7 E+01
	^{60}Co	3.0 E-05	6.2 E-02	2.9 E+00	3.0 E+00
	^{192}Ir	3.6 E-06	2.8 E-02	9.8 E-01	9.8 E-01
	^{137}Cs	4.1 E-06	6.5 E-02	6.9 E-01	7.6 E-01
	^{241}Am	6.6 E-02	4.8 E-01	5.2 E-03	5.5 E-01
No. 8 - Sludge Application to Non-Agricultural Soil	^{60}Co	5.0 E-05	-	1.9 E+01	1.9 E+01
	^{192}Ir	6.0 E-06	-	6.3 E+00	6.3 E+00
	^{137}Cs	6.8 E-06	-	4.6 E+00	4.6 E+00
	^{241}Am	1.1 E-01	-	3.5 E-02	1.4 E-01
	^{90}Sr	5.1 E-05	-	8.6 E-04	9.1 E-04
No. 9 - Landfill Equipment Operator	^{60}Co	1.4 E-03	-	6.4 E+01	6.4 E+01
	^{192}Ir	1.7 E-04	-	2.2 E+01	2.2 E+01
	^{137}Cs	1.9 E-04	-	1.5 E+01	1.5 E+01
	^{241}Am	3.0 E+00	-	1.2 E-01	3.2 E+00
	^{90}Sr	1.4 E-03	-	2.9 E-03	4.3 E-03
No. 10 - Landfill Intrusion and Construction	^{60}Co	6.0 E-04	-	7.1 E+01	7.1 E+01
	^{137}Cs	1.5 E-04	-	1.8 E+01	1.8 E+01
	^{241}Am	2.6 E+00	-	1.4 E-01	2.8 E+00
	^{90}Sr	1.1 E-03	-	1.8 E-01	1.8 E-01
	^{192}Ir	--	-	1.1 E-06	1.1 E-06
No. 11 - Landfill Intrusion and Residence	^{60}Co	4.8 E-04	3.2 E-04	1.7 E+02	1.7 E+02
	^{90}Sr	8.9 E-04	1.5 E+02	6.4 E-01	1.5 E+02
	^{137}Cs	1.2 E-04	5.9 E-01	6.5 E+01	6.6 E+01
	^{241}Am	2.1 E+00	5.0 E-01	4.4 E-01	7.5 E+00
	^{192}Ir	--	-	4.9 E-06	4.9 E-06

(a) A dash indicates that the pathway is not included in the scenario shown.
(b) Two dashes indicate a value less than 1.0 E-07 mrem.

downstream from a liquid effluent discharge point are described in Scenario No. 3. The individuals in the first two scenarios are exposed by inhalation and direct external radiation. Individuals in the third scenario are exposed by these pathways plus ingestion of food crops and aquatic foods (fish from the river). As shown in Table 6.3, the largest estimated annual TEDE for Scenario No. 1 is 0.12 mrem (from ^{60}Co) and the largest estimated annual TEDE for Scenario No. 3 is 1.6 mrem (from ^{137}Cs). These exposures are clearly less than the individual dose criterion of 10 mrem/yr. The estimated annual TEDEs for Scenario No. 2 exceed 10 mrem/yr for four of the five critical radionuclides, the exception being the low value for ^{90}Sr. The largest estimated annual TEDE for Scenario No. 2 is 360 mrem/yr for ^{60}Co. This is the largest TEDE estimated for any of the 11 scenarios evaluated.

The potential exposures resulting from incineration are described in Scenarios No. 4, 5, and 6. Potential doses to incinerator operators by inhalation of airborne ash and direct exposure to external sources of radiation are described in Scenario No. 4. Potential exposures of the public downwind from an operating incinerator through inhalation, direct exposure from ash deposited on the ground, and ingestion of local farm crops after air deposition are described in Scenario No. 5. Potential external exposures to a truck driver who transports incinerator ash to a burial ground are described in Scenario No. 6. As shown in Table 6.3, the largest estimated annual TEDE for Scenarios No. 4 and 6 are 340 mrem/yr (from ^{241}Am) and 210 mrem/yr (from ^{60}Co), respectively. Both of these values exceed the criterion of 10 mrem/yr. Again, for Scenarios No. 4 and 6, the 10-mrem/yr criterion is exceeded by four of the five critical radionuclides, the exception for both scenarios being the low doses from ^{90}Sr. The largest estimated downwind annual TEDE for Scenario No. 5 is 0.27 mrem/yr from ^{241}Am; a value clearly within the 10-mrem/yr criterion.

Potential exposures resulting from sludge application to soils are described in Scenarios No. 7 and 8. In Scenario No. 7, the exposures described are those to an individual living on a site after agricultural soil application of sludge. The individual is exposed to direct external radiation, inhales resuspended dust, and ingests local crops grown in the contaminated soil. In Scenario No. 8, exposures described are those to an individual who applies sludge to non-agricultural land. The exposure pathways for this scenario include direct exposure and inhalation of dust. As shown in Table 6.3, only ^{90}Sr, with an annual TEDE of 17 mrem/yr for Scenario No. 7, and ^{60}Co, with an annual TEDE of 19 mrem/yr for Scenario No. 8, exceed the 10-mrem/yr criterion. All other critical radionuclides for these scenarios are less than 10 mrem/yr.

The potential exposure conditions for an equipment operator at a landfill during sludge disposal operations are described in Scenario No. 9. The exposure pathways for this scenario are similar to those for the individual who applies sludge to non-agricultural land; i.e., direct exposure to external radiation and inhalation of dust. As shown in Table 6.3, the estimated annual TEDEs for three of the five critical radionuclides exceed the 10-mrem/yr dose criterion. The largest estimated annual TEDE is for ^{60}Co with a value of 64 mrem/yr.

Scenarios No. 10 and 11 are used to describe potential long-term exposures to individuals who may reuse a municipal disposal site previously used for disposal of ash from sludge incineration for a housing development. For these scenarios, a radioactive decay period of 5 years is assumed to account for a nominal period of institutional control. Because these scenarios rely on additional assumptions regarding the decay period, dilution with other municipal wastes, and the type of human activities involved in reuse of the land, their results are judged to be less likely than the results estimated for the other scenarios. Results for these scenarios may serve only as bounding estimates. For Scenario No. 10 the exposure conditions involve doses to a construction worker who digs a basement for a house into an abandoned landfill trench. The exposure pathways are direct exposure to external radiation and inhalation of airborne dust. Scenario No. 11 is used to describe the exposure conditions of an individual who may reside in a house constructed on an abandoned landfill. The exposure pathways are direct exposure to external radiation, inhalation of airborne dust, and ingestion of vegetables grown in a backyard garden. As shown in Table 6.3, for Scenarios No. 10 and 11 only two of the five critical radionuclides for each scenario exceed the 10-mrem/yr criterion. For Scenarios No. 10 and 11 the largest estimated annual TEDEs are for ^{60}Co with values of 71 and 170 mrem/yr, respectively.

6.4 Comparison with Impacts-BRC

As a partial verification of the modeling analysis, the selected scenario results from this study (using the GENII software package) were compared with results obtained using the IMPACTS-BRC, Version 2.0, computer program (O'Neal and Lee 1990). Because IMPACTS-BRC, Version 2.0, was developed to model a somewhat different situation, only two scenarios were similar enough to permit a comparison. These were Scenario No. 2 - STP Sludge Process Operator and Scenario No. 6 - Incinerator Ash Disposal Truck Driver.

The comparison was conducted using the critical radionuclides identified in Section 6.3.1, with the exception of ^{192}Ir, which is not contained in the IMPACTS-BRC, Version 2.0, data library. For ^{60}Co the results for the two scenarios were within a factor of 2 and for the other critical radionuclides the results were within an order of magnitude. Generally, the results produced using the GENII software produced smaller doses than IMPACTS-BRC, Version 2.0, reflecting the intent of this study to produce prudently conservative (not worst-case) results. This was considered to be a reasonable modeling comparison, given the different approaches and data used by the two computer programs. No further comparisons were attempted because they would require a rather extensive effort to revise or modify input data, basic assumptions, or scenario options.

7 Stochastic Dose Evaluation

A stochastic evaluation of the potential individual and collective doses from disposal of radioactive materials to sanitary sewer systems was conducted after the deterministic dose evaluation. Stochastic analyses use ranges of parameter values with assigned distributions instead of single values to produce a distribution of results. The purpose of performing a stochastic analysis is to provide measures of the potential range in the calculated results, and of the relative contribution, or importance, of each of the various input parameters to the calculated dose variations. In addition, the range of output can be statistically expressed so that both median doses and mean doses can be identified. The arithmetic means of the doses are useful in performing collective dose estimates. The stochastic analysis and the distributions of results for the critical radionuclides, as well as the collective dose estimates performed for this study, are described in the following sections. As discussed in Section 6.3.1, five radionuclides, namely, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{192}Ir, and ^{241}Am, were selected as those with doses high enough to be of concern and were used in the stochastic analysis. Not all five radionuclides were used in all scenarios. This decision was based primarily on the results of the theoretical deterministic doses described in Section 6.3.

7.1 Stochastic Methods

Four major steps are involved in the performance of a uncertainty and sensitivity analysis:

1. development or selection of a mathematical model for dose estimation (discussed in Section 6.1)
2. identification of parameter distributions for key model input parameters
3. performance of the uncertainty analysis
4. performance of the sensitivity analysis.

An uncertainty and sensitivity analysis of selected input parameters to the GENII computer code was performed for the exposure scenarios identified in Section 5. The uncertainty analysis was performed by defining either fixed parameter values or parameter distributions for each of the identified input parameters for each scenario (see Section 5.4). Where parameter distributions were used, the distributions were sampled to generate a set of input values. Generation of the sample sets was performed using the Latin Hypercube computer code developed by Iman and Shortencarier (1984). Each sample set was used in the GENII code to generate a set of individual dose results for each scenario and radionuclide of interest. The outputs from the GENII code were then analyzed to obtain the distribution of resultant doses. The input parameter data sets and calculated dose results were further analyzed to provide an estimate of the sensitivity of the dose results to each input parameter. The sensitivity analysis was performed using another computer code developed by Iman, Shortencarier, and Johnson (1985). Steps 2 through 4 are described in greater detail in the following sections.

7.1.1 Parameter Distribution

The parameters selected for uncertainty and sensitivity analysis were those that may have a variation or uncertainty in their value or range of values. Tables C.1 through C.11 in Appendix C contain summaries of the input parameters and the associated distributions used for each exposure scenario included in the analysis. These tables present data on the form of each distribution (i.e., lognormal, uniform, and uniform step distributions) and the numerical values used to define the distribution (i.e., minimum and maximum values). For comparison, the input parameter values used in the deterministic dose estimations are also included in these tables. Any input parameters not included in Tables C.1 through C.11 were assumed to be quite well known and contain minimal variation or uncertainty. These parameters were set to a fixed value in the uncertainty and sensitivity analysis because little can be done to improve their definition. For example, radiological decay constants are examples of parameters that are well defined and are not included in the uncertainty and sensitivity analysis.

Many of the parameters in the exposure model are difficult to quantify because little information is available about the distribution of their values. Such parameters have been represented by uniform or loguniform distributions over ranges thought to be reasonable, considering the context of their use. The selection of parameter distributions and ranges are discussed in greater detail in Section 5.4. In general, parameters whose values cover approximately $\leq$1 order of magnitude are assumed to have a uniform distribution, and parameters whose values cover $>$1 order of magnitude are assumed to have a loguniform distribution. For Scenario No. 3 - STP Liquid Effluent, more realistic data were available (EPA, 1989) and were used for the parameters of fish consumption and time spent swimming, boating, and on the shoreline. This was accomplished by assuming uniform distributions within the step ranges indicated in Tables C.1 through C.11.

7.1.2 Uncertainty Analysis

The procedure used in the uncertainty analysis involves repetitive calculations of individual doses from sample sets of GENII input parameter values generated using the Latin Hypercube code. The distributions of the resultant doses provide an indication of the variability in dose over the indicated range of input parameter values.

The input parameter distributions, described in Section 7.1.1 and shown in Tables C.1 through C.11, form the basis of the uncertainty analysis. It should be reemphasized that many of the parameter ranges used in the various exposure models are difficult to quantify because little information is available about the distribution of their values. Such parameters have been represented by uniform or loguniform distributions over ranges thought to be reasonable, considering the context of their use.

A total of 100 sample sets were generated for each scenario using the Latin Hypercube sampling computer code (Iman and Shortencarier, 1984). One advantage of using this structured Monte Carlo method is that reasonable statistics can be obtained with a lower number of sample sets than would be required by a random Monte Carlo method. A sample set size of 100 was selected based on the requirements for the Latin Hypercube computer code, on obtaining enough data to adequately describe the resulting dose distributions, and on the total time to run all of the sample sets through the GENII code. The Latin Hypercube sampling output was used to prepare input files for the GENII code. Each input file for the GENII code contained data for 100 sample sets for the parameters and radionuclides unique to each given scenario.

The doses calculated by the GENII code for each of these sample sets were analyzed to determine the frequency distribution of the calculated doses. In addition to the total dose, the doses from inhalation, ingestion, and external exposures were analyzed, where applicable. Statistical results of this analysis are presented in Appendix C, Table C.12. The resulting dose distribution data were also plotted to show the results graphically and are presented in Appendix C, Figures C.1 through C.29.

As an example of the statistical results, dose values for Scenario No. 1 - Sewer System Inspector are given in Table 7.1. The key radionuclides for this scenario were found to be ^{60}Co and ^{192}Ir. In this example, inhalation and external doses contributed to the total dose; ingestion doses were not considered. The graphic representation of the results of the uncertainty analysis for ^{60}Co in this scenario is given in Figure 7.1. Also indicated in the figure is the total dose from the deterministic analysis of ^{60}Co, as described in Section 6. The deterministic total dose of 0.00012 rem for ^{60}Co corresponds to the 52nd percentile ranking for dose values derived from the uncertainty analysis of this scenario. This indicates that 52% of the time the total dose would be less than or equal to the deterministic dose value, a value that is prudently conservative.

As with the example given above, similar tabular and graphic representations of the results from the uncertainty analyses for all 11 scenarios are given in Appendix C. The total dose calculated for the deterministic cases (from Section 6.3.2) are indicated in the figures for each scenario/radionuclide sample set (Appendix C, Figures C.1 through C.29). As shown in Table 7.2, the deterministic total doses for all sample sets generally fall within the 50th to 97th percentile ranking, which is judged to be prudently conservative.

Table 7.1 Statistical results of uncertainty analysis for Scenario No. 1 - Sewer System Inspector

Radio-nuclide	Dose	Total dose (rem)							
		Mean	SD	Minimum	5%	Median	95%	99%	Maximum
^{60}Co	Inhalation	1.7 E-08	3.0 E-08	5.6 E-11	1.9 E-10	3.6 E-09	7.6 E-08	1.4 E-07	1.4 E-07
	External	2.8 E-04	3.7 E-04	7.2 E-06	1.2 E-05	1.0 E-04	1.1 E-03	1.5 E-03	1.8 E-03
	Total	2.8 E-04	3.7 E-04	7.2 E-06	1.2 E-05	1.0 E-04	1.1 E-03	1.5 E-03	1.8 E-03
^{192}Ir	Inhalation	7.9 E-09	1.4 E-08	2.7 E-11	8.8 E-11	1.7 E-09	3.7 E-08	6.2 E-08	6.5 E-08
	External	2.1 E-04	2.9 E-04	5.5 E-06	8.5 E-06	7.6 E-05	7.7 E-04	1.2 E-03	1.4 E-03
	Total	2.1 E-04	2.9 E-04	5.5 E-06	8.5 E-06	7.6 E-05	7.7 E-04	1.2 E-02	1.4 E-03

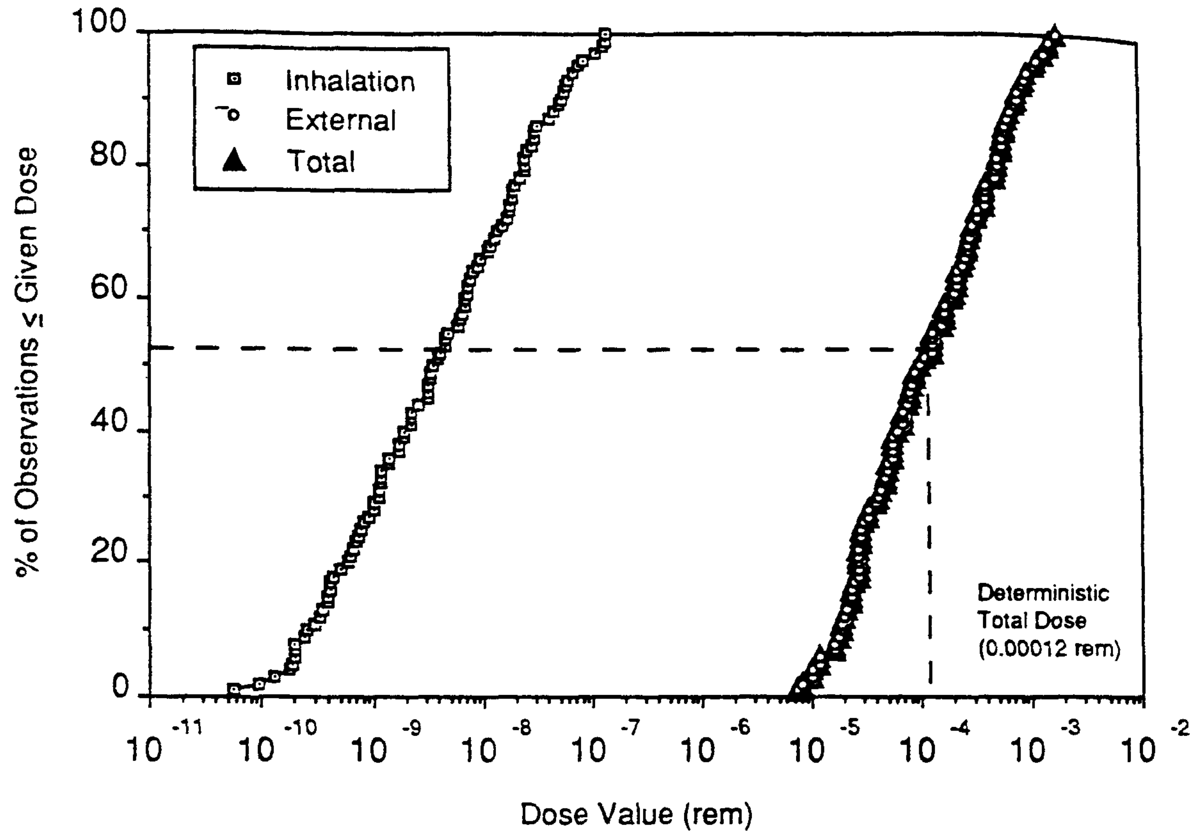

Figure 7.1 Frequency distribution of inhalation, external, and total doses from ^{60}Co from uncertainty analysis of Scenario No. 1 - Sewer System Inspector

7.1.3 Sensitivity Analysis

The doses resulting from the uncertainty analysis were further evaluated using a sensitivity analysis computer code (Iman, Shortencarier, and Johnson, 1985) to estimate the sensitivity of the calculated dose results to variation in the given input parameters. The sensitivity analysis also provided information on the relative contribution, or importance, of each of the various input parameters to the resulting output doses.

Data files containing all input parameter values and doses resulting from the uncertainty analysis were used as input to the sensitivity analysis computer code. The sensitivity analysis was performed on the rank of each parameter sample value rather than on the value itself, because the rank transformation is usually more revealing when nonlinear relationships are involved in the model. The Latin Hypercube uncertainty code calculated the ranking of sample input values and the ranking was then used in the sensitivity analysis. This was accomplished by assigning a rank of 1 to the smallest doses value of each parameter, a rank of 2 to the next smallest, and so on. The rank of the largest value of each parameter will be equal to the number of sample sets, i.e., 100 for the present analysis.

A full correlation analysis was performed for the data sets for each scenario and its associated key radionuclides. The output from the sensitivity analysis computer code includes the partial rank correlation coefficients, plus a ranking of the order of parameters based on how well they correlated with each dose type (inhalation, ingestion, external, and TEDE as appropriate for each exposure scenario). The results of these analyses are presented in Appendix C, Tables C.13 through C.30.

Table 7.2 Uncertainty dose ranges and deterministic doses

Scenario	Radio-nuclide	Annual TEDE (rem/yr) Minimum	Maximum	Deterministic	Ranking
1	^{60}Co	7.2 E-06	1.8 E-03	1.2 E-04	52
1	^{192}Ir	5.5 E-06	1.4 E-03	8.5 E-05	51
2	^{60}Co	8.9 E-03	1.5 E+00	3.6 E-01	75
2	^{137}Cs	2.0 E-03	3.4 E-01	8.0 E-02	75
2	^{192}Ir	3.0 E-03	5.0 E-01	1.2 E-01	75
3	^{60}Co	1.1 E-07	2.5 E-05	1.5 E-05	97
3	^{90}Sr	4.8 E-07	4.4 E-05	3.0 E-05	96
3	^{137}Cs	5.2 E-07	3.9 E-03	1.6 E-03	95
4	^{60}Co	1.9 E-03	1.6 E+00	3.0 E-01	81
4	^{192}Ir	6.8 E-04	5.9 E-01	1.1 E-01	81
4	^{241}Am	3.4 E-04	1.2 E+00	3.4 E-01	87
5	^{137}Cs	2.2 E-09	2.5 E-06	5.7 E-07	72
5	^{241}Am	2.0 E-06	2.0 E-03	2.7 E-04	77
6	^{60}Co	2.0 E-03	7.1 E-01	2.1 E-01	86
6	^{192}Ir	3.3 E-04	1.2 E-01	3.3 E-02	85
7	^{90}Sr	5.6 E-05	1.5 E-01	1.7 E-02	74
8	^{60}Co	4.1 E-05	3.8 E-01	1.9 E-02	70
8	^{137}Cs	9.9 E-06	9.2 E-02	4.6 E-03	70
8	^{192}Ir	1.3 E-05	1.3 E-01	6.3 E-03	70
9	^{60}Co	3.0 E-04	3.0 E-01	6.4 E-02	85
9	^{137}Cs	7.2 E-05	7.1 E-02	1.5 E-02	85
9	^{192}Ir	1.1 E-04	1.1 E-01	2.2 E-02	84
9	^{241}Am	3.2 E-05	3.0 E-02	3.2 E-03	72
10	^{60}Co	2.5 E-05	6.1 E-01	4.7 E-02	89
10	^{137}Cs	2.5 E-04	2.4 E-01	1.8 E-02	72
11	^{60}Co	2.5 E-05	6.1 E-01	1.7 E-01	96
11	^{90}Sr	1.5 E-04	8.5 E-01	1.5 E-01	90
11	^{137}Cs	2.5 E-04	2.4 E-01	6.6 E-02	92

As an example of the sensitivity results, the data for ^{60}Co in Scenario No. 1 are presented in Table 7.3. The partial rank correlation coefficients (PRCCs) indicate how well a given input parameter is correlated to the calculated doses. In the example in Table 7.3, the PRCC between the input parameter, "dust loading," and the output, "inhalation dose," is 0.99. A value near unity indicates good correlation. On the other hand, the correlation between "dust loading" and "external dose" indicates poor correlation (0.15). These results are in agreement with the equations for calculating these doses because the external dose calculation does not use the "dust loading" to estimate dose, and, therefore, this parameter should not be related to the "external dose."

The R^2 values indicate the proportion of the uncertainty in a given dose estimate that can be attributed to the indicated input parameters. In the example, an R^2 value of 0.99 for TEDE indicates that the listed input parameters explain 99% of the uncertainty associated with this dose calculation.

The "rank" values for the PRCC indicate which parameter contributes most to the uncertainty in the dose. The parameter with a rank of "1" is the most important contributor to uncertainty. In the Scenario No. 1 example in Table 7.3, "inventory" was the most sensitive parameter for "total dose."

Table 7.3 Sensitivity analysis results for ^{60}Co for Scenario No. 1 - Sewer System Inspector

	Dose Type		
	Inhalation	**External**	**TEDE**
Partial rank correlation coefficients (PRCC)			
Inventory	0.99	1.00	1.00
External (h)	0.96	0.98	0.98
Dust loading	0.99	0.15	0.15
R^2	0.99	0.99	0.99
Ranks of PRCC			
Inventory	1	1	1
External (h)	3	2	2
Dust loading	2	3	3

The ranking of the PRCCs for all the scenarios is presented in Appendix C, Table C.31. The top three most sensitive input parameters are given for the 29 possible scenario/radionuclide combinations. In 21 out of the 29 given scenario/radionuclide sample sets, "inventory" was the most sensitive input parameter for the GENII code. "River flow rate," "Chi/Q," and "decay time" were found to be the most important input parameters for the other cases. As discussed in Section 5.4, the ranges for the various parameters and assumptions were based on values found in the literature. While detailed information on the ranges and distributions of each parameter is desirable, this information is, at the same time, often limited. In this study, parameters having little information have been represented by uniform or loguniform distributions over ranges thought to be reasonable, considering the context of their use. The results presented in this section and Appendix C indicate that additional information is needed for most parameters, especially those identified as key contributors to the uncertainty in the dose values.

7.2 Collective Dose Considerations

An evaluation of the potential collective dose from discharge of the critical radionuclides at the currently allowable maximum levels was conducted for comparison with the individual dose criterion. The collective doses are estimated by the product of the arithmetic mean of the dose values for the critical radionuclides reported in Table C.12 (see Appendix C) and the total number of individuals that potentially could be exposed for each scenario. The arithmetic means of dose estimates are used for the collective dose estimates because they are more representative of typical exposure conditions than the prudently conservative individual doses and are more appropriate for use with nonlinear parameter distributions (Aitchison and Brown, 1963).

The total number of individuals that potentially could be exposed across the country from all municipal sewer systems is estimated using judgment concerning each scenario. The estimates are rounded to the nearest order of magnitude as shown in Table 7.4. As stated in Section 4, there is some variability in the types of processes and the sizes of STPs. For many of the scenarios involving workers in these plants, it is estimated that fewer than 1,000 workers nationwide could be exposed to the work conditions described by the scenarios. These scenarios include Scenarios No. 2, 4, 6, 8, and 9.

For Scenario No. 1, only larger cities would have large diameter sewer lines (up to 3 m) that could be inspected by workers as described. It is estimated that across the country no more than about 100 workers could be involved in this work activity during a year. Liquid effluents from STPs and airborne effluents from an incinerator have the potential to expose a rather large population. For this estimate, 1 million people are assumed to live near these plants and be exposed to effluents as described in Scenarios No. 3 and 5.

Because the market for sewage sludge as an agricultural soil additive varies across the country, and because the EPA restricts the use of sludge as a soil additive (see Section 4), it is estimated that no more than 10,000 people nationwide could be exposed to sludge as described in Scenario No. 7.

Finally, as described in Section 6.2.2, Scenarios No. 10 and 11 (reuse of municipal landfill sites) are less likely than the other scenarios because they rely on additional assumptions concerning radioactive decay and dilution with other wastes. In addition, it is difficult to estimate how many individuals across the country could be exposed to the conditions described by these scenarios. For these reasons, Scenarios No. 10 and 11 are not included in the collective dose analysis.

Table 7.4 contains a summary of the collective dose analysis conducted for this study. For some of the scenarios, the mean individual doses were less than 0.1 mrem/yr (as shown by a dash in the table). The collective doses for the various scenario/radionuclide combinations range from 0.4 person-rem for ^{137}Cs in Scenario No. 5 to 420 person-rem for ^{137}Cs in Scenario No. 3. Eight of the 22 combinations listed have collective doses greater than 100 person-rem.

If disposal were to occur across the country at the currently regulated levels (from 10 CFR 20), a first approximation of the total collective dose from the particular mixture of radionuclides described would be about 2100 person-rem, which is approximately double the collective dose criterion of 1000 person-rem. For this approximation, no consideration has been given to the degree of partitioning of each radionuclide into the different products, the difference between amounts of radionuclides produced annually and amounts used (discharged) annually, mass balances, or the potential for inclusion of mutually exclusive uses of the contaminated materials. However, best judgment was used to estimate the number of individuals exposed annually from discharges at the 1-Ci/yr limit.

Table 7.4 Collective dose estimates for the critical radionuclides disposed of via sanitary sewer systems

Scenario	Number of people	Collective dose (person-rem/yr)				
		^{60}Co	^{90}Sr	^{137}Cs	^{192}Ir	^{241}Am
No. 1 - Sewer System Inspector	10^2	-[(a)]	-	-	-	-
No. 2 - STP Sludge Process Operator	10^3	2.7 E+02	-	6.1 E+01	9.0 E+01	-
No. 3 - STP Liquid Effluent	10^6	4.0 E+00	9.3 E+00	4.2 E+02	-	2.7 E+02
No. 4 - Incinerator Operator	10^3	1.8 E+02	-	-	6.4 E+01	1.3 E+02
No. 5 - Sludge Incinerator Effluent	10^6	-	-	4.0 E-01	-	7.7 E+01
No. 6 - Incinerator Ash Disposal Truck Driver	10^3	1.0 E+02	-	-	1.6 E+01	-
No. 7 - Sludge Application to Agricultural Soil	10^4	1.5 E+02	-	-	-	-
No. 8 - Sludge Application to Non-Agricultural Soil	10^3	3.2 E+01	-	7.6 E+00	1.0 E+01	-
No. 9 - Landfill Equipment Operator	10^3	3.2 E+01	-	7.6 E+00	1.2 E+01	3.9 E+00
Total		7.8 E+02	9.0 E+00	5.0 E+02	1.9 E+02	6.4 E+02
		Overall total: 2.1 E+03 person-rem/yr.				

(a) A dash indicates an average individual dose of less than 0.1 mrem/yr.

8 Discussion

PNL conducted an evaluation of the potential public doses from exposure to radionuclides during treatment and disposal of sewage sludge following release into sanitary sewer systems at the limits specified in 10 CFR 20. Current sewage treatment and sludge disposal practices were examined and 11 generic radiation exposure scenarios were developed for members of the public, including workers at sewage treatment and sludge disposal facilities. The scenario analysis was conducted to provide a prudently conservative, deterministic analysis of: 1) the potential doses to individuals resulting from documented case histories of sewer contamination, and 2) the potential doses that could result from discharges at current maximum allowed levels. The input parameters and assumptions were selected within an expected range — not at the extremes of the expected range — for each exposure pathway and scenario to provide a prudently conservative estimate of the radiation dose to an average individual in a population. These individual doses were compared with a 10-mrem/yr the individual dose criterion. To better understand the deterministic results, a stochastic uncertainty and sensitivity analysis was conducted. This analysis also permitted the calculation of collective doses from disposal of radioactive materials via sanitary sewer systems for comparison with a 1000 person-rem/yr.

The deterministic results of the case histories produced some results that were in excess of the individual dose criterion of 10 mrem/yr. As discussed in Section 6.2, the highest dose estimated was an annual TEDE of 93 mrem/yr for the Tonawanda case history. This dose was estimated for Scenario No. 4 - Incinerator Operator. The dose was estimated using the average reported concentration of ^{241}Am in the ash and was delivered through the inhalation pathway from suspended dust. The Royersford case history also produced several scenario results that were $\geq$10 mrem/yr. These results do not necessarily imply that the individual dose criterion was exceeded because the scenarios account for exposures at a constant (average) concentration during a year, and the concentrations reported for the case histories may have been of a shorter duration. However, the results do indicate that doses in excess of 10 mrem/yr were possible.

A second set of deterministic results was produced for hypothetical discharges of 63 individual radionuclides at the current maximum discharge limits (as allowed by 10 CFR 20). The full list of the annual TEDE results for all 11 generic scenarios is in Appendix B. A review of these results indicates that doses in excess of 10 mrem/yr were possible for several radionuclides and scenarios. To better estimate the real potential of this occurrence, a review of currently produced or used radionuclides was conducted. This review resulted in the identification of a list of five critical radionuclides that are produced and used in significant quantities and have potential doses (as shown in Appendix B) in excess of 10 mrem/yr. The critical radionuclides were: ^{60}Co, ^{90}Sr, ^{137}Cs, ^{192}Ir, and ^{241}Am. A review of the results for these critical radionuclides, summarized in Table 6.2, reveals that the calculated dose to a limited population of municipal workers at STPs could exceed 10 mrem/yr <u>if</u> licensees disposed of wastes in quantities approaching 1 Ci/yr. The highest of these calculated doses was 360 mrem/yr to a sludge processing operator (Scenario No. 2 - STP Sludge Process Operator) from ^{60}Co. The scenarios producing the next highest calculated doses were for incinerator operators (Scenario No. 4 with 340 mrem/yr from ^{241}Am) and truck drivers hauling incinerator ash to landfills (Scenario No. 6 with 210 mrem/yr from ^{60}Co). External exposure to gamma-emitters and inhalation exposure to alpha-emitters were equally significant for the top three scenarios.

The generic analysis contained two scenarios that described the potential long-term exposures to individuals who may reuse a municipal disposal site after disposal of ash from sludge incineration. For these scenarios, a radioactive decay period of 5 years was assumed to account for a nominal period of institutional control prior to reuse of the land. These scenarios produced calculated doses that exceeded the 10-mrem/yr dose criterion for members of the public who do not work at sewage treatment and disposal facilities. As shown in Table 6.2, the doses from ^{60}Co and ^{137}Cs were primarily from external exposure, whereas the doses from ^{90}Sr and ^{241}Am resulted primarily from ingestion. However, because these scenarios rely on additional assumptions regarding the decay period, dilution with other municipal wastes, and the type of human activities involved in future reuse of the land their results are judged to be less likely than the results estimated for the other scenarios. The results may serve as bounding estimates only.

The deterministic results for the maximum discharge limits (as allowed by 10 CFR 20) were next evaluated with a stochastic uncertainty and sensitivity analysis. The uncertainty analysis was conducted using Latin Hypercube sampling for the five critical radionuclides. The analysis considered ranges of parameter values with assigned distributions for the 11 scenarios so that a distribution of potential results could be produced. Many of the parameters used in the generic scenario analysis are difficult to quantify because little information is available about the distribution of their values. To permit a stochastic analysis, several parameters were represented by uniform or log-uniform distributions and judgment was used in establishing their reasonable ranges. A sample set of 100 was selected for the Latin Hypercube analysis to obtain enough data to adequately describe the resulting dose distributions for each critical radionuclide and for each of the 11 scenarios. Statistical results of the analysis are presented in Appendix C. The dose distribution results were plotted to provide a visual indication of the potential range of results and a comparison with the deterministic (single value) results. The uncertainty analysis showed that calculated doses for a given scenario and radionuclide typically varied over 2 to 4 orders of magnitude. The variation was less where the scenarios and their parameters were well defined, such as the scenarios describing work conditions at the sewage treatment and sludge disposal facilities. The variation was wider for the scenarios that involved public exposure over long periods of time, such as the landfill intrusion scenarios. The deterministic results for the maximum discharge limits for all scenarios generally fell within the 50th to 97th percentile of the full range of calculated doses. This range is judged to be consistent with the intent of the deterministic analysis to produce prudently conservative (not worst-case) results. The scenarios that exceeded the 90th percentile were Scenario No. 3 - STP Liquid Effluent and Scenario No. 11 - Landfill Intrusion and Residence. Because these scenarios rely on additional assumptions concerning the dilution and environmental transport of the radioactive materials, additional conservatism was used in the scenario analysis.

In addition to providing measures of the potential range in the calculated doses, the stochastic analysis was used to produce a sensitivity analysis. In this analysis, an evaluation was made of the relative contribution or importance of each of the input parameters to the calculated dose variations. The analysis ranked the importance of each parameter by assigning numerical values. The full results of the sensitivity analysis are presented in Appendix C. The PRCCs were also calculated. (The PRCCs indicate how well a given input parameter is correlated to the calculated doses.) The PRCCs were then ranked to determine the relative contribution of each parameter to the uncertainty in the result for each critical radionuclide and scenario. The three most sensitive input parameters were developed for 29 possible scenario/radionuclide combinations. In 21 of the 29 scenario/radionuclide sample sets, the "inventory" was the most sensitive input parameter. The inventory corresponds to the basic assumption of the maximum annual release rate, 1 Ci/yr for most radionuclides. For the remaining eight combinations, "river flow rate," "Chi/Q," and "decay time" were found to be the most important parameters. These parameters generally account for environmental dilution of the inventory for use in scenarios that describe potential exposure conditions for members of the public who do not work at sewage treatment or disposal facilities.

Finally, the results of the sensitivity analysis were used to estimate the collective doses from the critical radionuclides that could result from discharges to sanitary sewer systems in the United States at the maximum annual discharge limits. The collective doses are estimated by multiplying the arithmetic mean of the dose values (determined in the uncertainty analysis) by the total number of individuals that potentially could be exposed for each scenario. The arithmetic means of dose estimates are used for the collective dose estimates because they are more representative of typical exposure conditions than the prudently conservative individual doses, and they are more appropriate for use with nonlinear parameter distributions. Best judgment was used to estimate the number of individuals exposed annually from discharges at the 1-Ci/yr limit. Dose contributions from Scenarios No. 1 through 9 were considered in the analysis. Contributions from Scenarios No. 10 and 11 were not included, because they involved potential future intrusion at closed landfill sites and were judged to be less likely than the other scenarios. The collective doses were summed over the nine scenarios for each of the critical radionuclides, then they were summed over all five radionuclides to provide an estimate of the total collective dose across the United States. The mean individual doses for several of the scenarios were less than 0.1-mrem/yr and were not included in this estimate. The collective doses for the various scenario/radionuclide combinations range from 0.4 person-rem for ^{137}Cs in Scenario No. 5 to 420 person-rem for ^{137}Cs in Scenario No. 3. Eight of the twenty-two combinations listed have collective doses greater than 100 person-rem. A first approximation of the total collective dose from the specific mixture of radionuclides and scenarios described in Table 7.4 would be about 2100 person-rem. It should be emphasized that the generic nature of this study has precluded consideration of several key items, such as the degree of partitioning of each radionuclide into the different products, the difference between amounts of radionuclides produced annually and amounts used (discharged) annually, mass balances, and the potential for inclusion of mutually exclusive uses of the contaminated materials.

The intent of this generic study was to examine the potential radiological hazard to the public resulting from exposure to radionuclides in sewage sludge during its treatment and disposal following their release into sanitary sewer systems at the limits specified in 10 CFR 20. This was accomplished using a prudently conservative methodology to describe and estimate scenarios, assumptions, and parameter values used in deterministic and stochastic dose calculations for documented case histories and theoretical discharges at the maximum discharge limits. Comparison was also made with the individual and collective dose criteria. The results of this study indicate that some doses resulting from sewer disposal of radioactive materials may not be trivial and further study is needed.

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Appendix A

Modeling Input

This appendix contains detailed information regarding the calculation of doses presented in this document, and includes lists of input files, source terms and their derivation, and a modified external dose factor table used in some of the dose calculations.

Calculations for the scenarios were performed using the GENII software package (Napier et al., 1988). For each scenario, a GENII input file was created. The calculations were performed for each radionuclide in the source term, using the input file template. GENII input files for the 11 scenarios are given in Tables A.1 through A.14. (Separate input files were required to calculate inhalation from surface contamination for three cases with customized external dose factors.) These standard input files were used in calculating doses for both the case studies and the deterministic unit releases.

The input for source term concentrations for the deterministic cases are given in Table A.15. Assumptions regarding sewage treatment plant (STP) capacity and sludge and ash production are given in Table A.16. Table A.17 gives environmental concentrations corresponding to the GENII input values in Table A.15. Table A.18 lists the radionuclide source term used in case history dose calculations for each applicable scenario. Table A.19 lists the source term for the deterministic dose calculations based on theoretical discharges for each scenario.

For three scenarios (Sewer System Inspector, Sewage Treatment Plant Operator, and Incinerator Ash Disposal Truck Driver), the EXTDF portion of GENII was run to create dose factors for external exposure. Assumptions concerning geometry for each scenario are summarized in Table A.20. The modified dose factor library used in the three scenarios is given in Table A.21. The modified dose factors for the three scenarios were incorporated into a dose factor library that normally contains dose factors for waste buried at different depths.

A list of the tables and their page locations is provided to help the reader turn directly to the tables of interest.

Tables

Tables

Tables

Table A.1 GENII input file for Scenario No. 1 - STP Sewer System Inspector

```
NRC Sewer Study - Exposure Pathways
Title:      12             Sewer Line Maintenance
       C12.TPL   13-Aug-90
OPTIONS======================== Default ====================================
T    Near-field scenario?      (Far-field)    NEAR-FIELD: narrowly-focused
F    Population dose?         (Individual)                release, single site
F    Acute release?             (Chronic)     FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                     multiple sites
                              Complete                                 Complete
TRANSPORT OPTIONS=========== Section   EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport                 1     F  Finite plume, external       5
F  Surface Water Transport       2     F  Infinite plume, external     5
F  Biotic Transport (near-field) 3,4   T  Ground, external             5
F  Waste Form Degradation (near) 3,4   F  Recreation, external         5
                                       F  Inhalation uptake            5,6
REPORT OPTIONS======================   F  Drinking water ingestion     7,8
T  Report AEDE only                    F  Aquatic foods ingestion      7,8
F  Report by radionuclide              F  Terrestrial foods ingestion  7,9
F  Report by exposure pathway          F  Animal product ingestion     7,10
F  Debug report on screen              F  Inadvertent soil ingestion

INVENTORY ##################################################################

 4   Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 0   Surface soil source units (1- m2  2- m3  3- kg)
     Equilibrium question goes here

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when|  transport selected   |  near-field scenario, optionally      |
     --------|-----------------------|---------------------------------------|
     Release |        Surface Buried |        Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air     Soil    Soil    Water   Water  |
     nuclide |/yr     /yr     /m3    |/m3     /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239                                            5.0E-08
     --------|----Derived Concentrations-----|
     Use when|  measured values are known    |
     --------|-------------------------------|
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /L      /kg    |
     --------|------- ------- ------- -------|


TIME #######################################################################

1    Intake ends after (yr)
50   Dose calc. ends after (yr)
0    Release ends after (yr)
0    No. of years of air deposition prior to the intake period
0    No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) ###################################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line
```

Table A.1 (Continued)

```
NEAR-FIELD SCENARIOS ###########################################################

           Prior to the beginning of the intake period: (yr)
0            When was the inventory disposed?  (Package degradation starts)
0            When was LOIC?  (Biotic transport starts)
0          Fraction of roots in upper soil (top 15 cm)
0          Fraction of roots in deep soil
0.0        Manual redistribution: deep soil/surface soil dilution factor
1250       Source area for external dose modification factor (m2)

TRANSPORT ######################################################################

           ====AIR TRANSPORT===================================SECTION 1=====
                   0-Calculate PM              ¦0        Release type (0-3)
1          Option: 1-Use chi/Q or PM value     ¦F        Stack release (T/F)
                   2-Select MI dist & dir      ¦0        Stack height (m)
                   3-Specify MI dist & dir     ¦0        Stack flow (m3/sec)
0          Chi/Q or PM value                   ¦0        Stack radius (m)
0          MI sector index (1=S)               ¦0        Effluent temp. (C)
0          MI distance from release point (m)¦0        Building x-section (m2)
T          Use jf data, (T/F) else chi/Q grid¦0        Building height (m)

           ====SURFACE WATER TRANSPORT=========================SECTION 2=====
0          Mixing ratio model: 0-use value, 1-river, 2-lake
0          Mixing ratio, dimensionless
0          Average river flow rate for: MIXFLG=0 (m3/s), MIXFLG=1,2 (m/s),
0          Transit time to irrigation withdrawl location (hr)
           If mixing ratio model > 0:
0            Rate of effluent discharge to receiving water body (m3/s)
0            Longshore distance from release point to usage location (m)
0            Offshore distance to the water intake (m)
0            Average water depth in surface water body (m)
0            Average river width (m), MIXFLG=1 only
0            Depth of effluent discharge point to surface water (m), lake only

           ====WASTE FORM AVAILABILITY=========================SECTION 3=====
0          Waste form/package half life, (yr)
0          Waste thickness, (m)
1.0        Depth of soil overburden, m

           ====BIOTIC TRANSPORT OF BURIED SOURCE===============SECTION 4=====
T          Consider during inventory decay/buildup period (T/F)?
T          Consider during intake period (T/F)?  ¦ 1-Arid non agricultural
0          Pre-Intake site condition.............¦ 2-Humid non agricultural
                                                 ¦ 3-Agricultural

EXPOSURE #######################################################################

           ====EXTERNAL EXPOSURE===============================SECTION 5=====
           Exposure time:                ¦  Residential irrigation:
0            Plume (hr)                  ¦ T       Consider: (T/F)
100.0        Soil contamination (hr)     ¦ 0       Source: 1-ground water
0            Swimming (hr)               ¦                 2-surface water
0            Boating (hr)                ¦ 0       Application rate (in/yr)
0            Shoreline activities (hr)   ¦ 0       Duration (mo/yr)
0          Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
0          Transit time for release to reach aquatic recreation (hr)
0          Average fraction of time submersed in acute cloud (hr/person hr)
```

Table A.1 (Continued)

```
                ====INHALATION======================================SECTION 6=====
0               Hours of exposure to contamination per year
0               0-No resus-  1-Use Mass Loading           2-Use Anspaugh model
0                 pension      Mass loading factor (g/m3)   Top soil available (cm)

                ====INGESTION POPULATION============================SECTION 7=====
0               Atmospheric production definition (select option):
0                 0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
                  1-Use population-weighted chi/Q
                  2-Use uniform production
                  3-Use chi/Q and production grids (PRODUCTION will be overridden)
0               Population ingesting aquatic foods, 0 defaults to total (person)
0               Population ingesting drinking water, 0 defaults to total (person)
F               Consider dose from food exported out of region (default=F)

                Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                          3-Derived concentration entered above
                ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F               Salt water? (default is fresh)

                USE         TRAN-  PROD-     -CONSUMPTION- |
                ?   FOOD    SIT    UCTION    HOLDUP   RATE |
                T/F TYPE    hr     kg/yr     da      kg/yr |      DRINKING WATER
                --- ------ -----  -------   ------   ----- |------------------------
                F   FISH    0.00  0.0E+00    0.00     0.0 | 0      Source (see above)
                F   MOLLUS  0.00  0.0E+00    0.00     0.0 | T      Treatment? T/F
                F   CRUSTA  0.00  0.0E+00    0.00     0.0 | 0      Holdup/transit(da)
                F   PLANTS  0.00  0.0E+00    0.00     0.0 | 0      Consumption (L/yr)

                ====TERRESTRIAL FOOD INGESTION======================SECTION 9=====

                USE         GROW   --IRRIGATION--          PROD-     --CONSUMPTION--
                ?   FOOD    TIME   S RATE   TIME    YIELD  UCTION    HOLDUP    RATE
                T/F TYPE    da     * in/yr  mo/yr   kg/m2  kg/yr     da        kg/yr
                --- ------ -----   - -----  -----   -----  -------   ------    ------
                F   LEAF V  0.00  0   0.0   0.0     0.0   0.0E+00    0.0       0.0
                F   ROOT V  0.00  0   0.0   0.0     0.0   0.0E+00    0.0       0.0
                F   FRUIT   0.00  0   0.0   0.0     0.0   0.0E+00    0.0       0.0
                F   GRAIN   0.00  0   0.0   0.0     0.0   0.0E+00    0.0       0.0

                ====ANIMAL PRODUCTION CONSUMPTION===================SECTION 10====

                ---HUMAN---- TOTAL  DRINK   ------------STORED FEED-------------
USE             CONSUMPTION  PROD-  WATER   DIET  GROW  -IRRIGATION--        STOR-
?   FOOD        RATE  HOLDUP UCTION CONTAM  FRAC- TIME  S RATE  TIME   YIELD AGE
T/F TYPE        kg/yr  da    kg/yr  FRACT.  TION  da    * in/yr mo/yr  kg/m3 da
--- ------      ------ ----- ------ ------- ----  ----  - ----- -----  ----- -----
F   BEEF          0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
F   POULTR        0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
F   MILK          0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
F   EGG           0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
                                            ------------FRESH FORAGE-----------
    BEEF                                    0.00   0.0  0   0.0  0.00   0.00   0.0
    MILK                                    0.00   0.0  0   0.0  0.00   0.00   0.0

################################################################################
```

Table A.2 GENII input file for Scenario No. 1 - STP Sewer System Inspector--Inhalation Calculation

```
NRC Sewer Study - Exposure Pathways        1 STP Sewer System Inspector INHALATION
Title:      12             ASH TRANS  - Inhalation Calculation
    C32.TPL   07-Oct-90
OPTIONS======================== Default ====================================
T    Near-field scenario?      (Far-field)    NEAR-FIELD: narrowly-focused
F    Population dose?         (Individual)                release, single site
F    Acute release?             (Chronic)     FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                     multiple sites
                              Complete                                Complete
TRANSPORT OPTIONS============ Section      EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport                 1       F  Finite plume, external      5
F  Surface Water Transport       2       F  Infinite plume, external    5
F  Biotic Transport (near-field) 3,4     F  Ground, external            5
F  Waste Form Degradation (near) 3,4     F  Recreation, external        5
                                         T  Inhalation uptake           5,6
REPORT OPTIONS======================     F  Drinking water ingestion    7,8
T  Report AEDE only                      F  Aquatic foods ingestion     7,8
F  Report by radionuclide                F  Terrestrial foods ingestion 7,9
F  Report by exposure pathway            F  Animal product ingestion    7,10
F  Debug report on screen                F  Inadvertent soil ingestion

INVENTORY ###################################################################

 4   Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 2   Surface soil source units (1- m2  2- m3  3- kg)
     Equilibrium question goes here

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when| transport selected    |  near-field scenario, optionally      |
     --------|-----------------------|---------------------------------------|
     Release |        Surface Buried |         Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air      Soil    Soil    Water   Water  |
     nuclide |/yr     /yr     /m3    |/m3      /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239                                     5.0E-08
     --------|----Derived Concentrations-----|
     Use when|  measured values are known    |
     --------|-------------------------------|
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /L      /kg    |
     --------|------- ------- ------- -------|

TIME ########################################################################

1    Intake ends after (yr)
50   Dose calc. ends after (yr)
0    Release ends after (yr)
0    No. of years of air deposition prior to the intake period
0    No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) ####################################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line
```

Table A.2 (Continued)

```
NEAR-FIELD SCENARIOS ##########################################################

          Prior to the beginning of the intake period: (yr)
0           When was the inventory disposed?  (Package degradation starts)
0           When was LOIC?  (Biotic transport starts)
0         Fraction of roots in upper soil (top 15 cm)
0         Fraction of roots in deep soil
0.0       Manual redistribution: deep soil/surface soil dilution factor
1250      Source area for external dose modification factor (m2)

TRANSPORT #####################################################################

          ====AIR TRANSPORT====================================SECTION 1=====
                  0-Calculate PM        |0       Release type (0-3)
 1        Option: 1-Use chi/Q or PM value  |F       Stack release (T/F)
                  2-Select MI dist & dir   |0       Stack height (m)
                  3-Specify MI dist & dir  |0       Stack flow (m3/sec)
0         Chi/Q or PM value                |0       Stack radius (m)
0         MI sector index (1=S)            |0       Effluent temp. (C)
0         MI distance from release point (m)|0      Building x-section (m2)
T         Use jf data, (T/F) else chi/Q grid|0      Building height (m)

          ====SURFACE WATER TRANSPORT==========================SECTION 2=====
0         Mixing ratio model: 0-use value, 1-river, 2-lake
0         Mixing ratio, dimensionless
0         Average river flow rate for: MIXFLG=0 (m3/s), MIXFLG=1,2 (m/s),
0         Transit time to irrigation withdrawl location (hr)
          If mixing ratio model > 0:
0           Rate of effluent discharge to receiving water body (m3/s)
0           Longshore distance from release point to usage location (m)
0           Offshore distance to the water intake (m)
0           Average water depth in surface water body (m)
0           Average river width (m), MIXFLG=1 only
0           Depth of effluent discharge point to surface water (m), lake only

          ====WASTE FORM AVAILABILITY==========================SECTION 3=====
0         Waste form/package half life, (yr)
0         Waste thickness, (m)
0.        Depth of soil overburden, m

          ====BIOTIC TRANSPORT OF BURIED SOURCE================SECTION 4=====
T         Consider during inventory decay/buildup period (T/F)?
T         Consider during intake period (T/F)?  | 1-Arid non agricultural
0         Pre-Intake site condition.............| 2-Humid non agricultural
                                                | 3-Agricultural

EXPOSURE ######################################################################

          ====EXTERNAL EXPOSURE================================SECTION 5=====
          Exposure time:               |  Residential irrigation:
0           Plume (hr)                 | T      Consider: (T/F)
0           Soil contamination (hr)    | 0      Source: 1-ground water
0           Swimming (hr)              |                2-surface water
0           Boating (hr)               | 0      Application rate (in/yr)
0           Shoreline activities (hr)  | 0      Duration (mo/yr)
0         Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
0         Transit time for release to reach aquatic recreation (hr)
0         Average fraction of time submersed in acute cloud (hr/person hr)
```

Table A.2 (Continued)

```
          ====INHALATION=======================================SECTION 6=====
20        Hours of exposure to contamination per year
1         0-No resus-  1-Use Mass Loading         2-Use Anspaugh model
1.0E-04     pension      Mass loading factor (g/m3)   Top soil available (cm)

          ====INGESTION POPULATION===========================SECTION 7=====
0         Atmospheric production definition (select option):
0           0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
            1-Use population-weighted chi/Q
            2-Use uniform production
            3-Use chi/Q and production grids (PRODUCTION will be overridden)
0         Population ingesting aquatic foods, 0 defaults to total (person)
0         Population ingesting drinking water, 0 defaults to total (person)
F         Consider dose from food exported out of region (default=F)

          Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                    3-Derived concentration entered above
          ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F         Salt water? (default is fresh)

          USE         TRAN-  PROD-      -CONSUMPTION- |
          ?   FOOD    SIT    UCTION     HOLDUP   RATE |
          T/F TYPE    hr     kg/yr      da      kg/yr |      DRINKING WATER
          --- ------ -----  -------    ------   ----- |------------------------
          F   FISH    0.00  0.0E+00     0.00     0.0 | 0      Source (see above)
          F   MOLLUS  0.00  0.0E+00     0.00     0.0 | T      Treatment? T/F
          F   CRUSTA  0.00  0.0E+00     0.00     0.0 | 0      Holdup/transit(da)
          F   PLANTS  0.00  0.0E+00     0.00     0.0 | 0      Consumption (L/yr)

          ====TERRESTRIAL FOOD INGESTION======================SECTION 9=====

          USE         GROW   --IRRIGATION--          PROD-    --CONSUMPTION--
          ?   FOOD    TIME   S RATE   TIME    YIELD  UCTION   HOLDUP   RATE
          T/F TYPE    da     * in/yr  mo/yr   kg/m2  kg/yr    da       kg/yr
          --- ------ -----  - -----  -----   -----  -------  ------   ------
          F   LEAF V  0.00  0   0.0    0.0     0.0  0.0E+00    0.0      0.0
          F   ROOT V  0.00  0   0.0    0.0     0.0  0.0E+00    0.0      0.0
          F   FRUIT   0.00  0   0.0    0.0     0.0  0.0E+00    0.0      0.0
          F   GRAIN   0.00  0   0.0    0.0     0.0  0.0E+00    0.0      0.0

          ====ANIMAL PRODUCTION CONSUMPTION===================SECTION 10====

          ---HUMAN---- TOTAL   DRINK   ------------STORED FEED-------------
USE       CONSUMPTION  PROD-   WATER   DIET  GROW  -IRRIGATION--        STOR-
?   FOOD  RATE  HOLDUP UCTION  CONTAM  FRAC- TIME  S RATE  TIME   YIELD AGE
T/F TYPE  kg/yr   da    kg/yr  FRACT.  TION   da   * in/yr mo/yr  kg/m3 da
--- ------ ------ ----- ------ ------- ----  ----  - ----- -----  ----- -----
F   BEEF     0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
F   POULTR   0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
F   MILK     0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
F   EGG      0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
                                       ------------FRESH FORAGE-----------
    BEEF                               0.00   0.0  0   0.0  0.00   0.00   0.0
    MILK                               0.00   0.0  0   0.0  0.00   0.00   0.0

################################################################################
```

Table A.3 GENII input file for Scenario No. 2 - STP Sludge Process Operator

```
NRC Sewer Study - Exposure Pathways
Title:       2              STP Worker - with Inhalation added
       C2.TPL    03-Oct-90
OPTIONS======================== Default ====================================
T    Near-field scenario?      (Far-field)    NEAR-FIELD: narrowly-focused
F    Population dose?         (Individual)                release, single site
F    Acute release?             (Chronic)     FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                     multiple sites
                              Complete                                Complete
TRANSPORT OPTIONS============ Section    EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport                 1       F  Finite plume, external       5
F  Surface Water Transport       2       F  Infinite plume, external     5
F  Biotic Transport (near-field) 3,4     T  Ground, external             5
F  Waste Form Degradation (near) 3,4     F  Recreation, external         5
                                         T  Inhalation uptake            5,6
REPORT OPTIONS=======================    F  Drinking water ingestion     7,8
T  Report AEDE only                      F  Aquatic foods ingestion      7,8
F  Report by radionuclide                F  Terrestrial foods ingestion  7,9
F  Report by exposure pathway            F  Animal product ingestion     7,10
F  Debug report on screen                F  Inadvertent soil ingestion

INVENTORY ###################################################################

 4   Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 0   Surface soil source units (1- m2  2- m3  3- kg)
     Equilibrium question goes here

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when|  transport selected   |  near-field scenario, optionally      |
     --------|-----------------------|---------------------------------------|
     Release |        Surface Buried |        Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air     Soil    Soil    Water   Water  |
     nuclide |/yr     /yr     /m3    |/m3     /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239                                            2.1E-04
     --------|----Derived Concentrations-----|
     Use when|   measured values are known   |
     --------|-------------------------------|
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /L      /kg    |
     --------|------- ------- ------- -------|


TIME ########################################################################

1    Intake ends after (yr)
50   Dose calc. ends after (yr)
0    Release ends after (yr)
0    No. of years of air deposition prior to the intake period
0    No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) ####################################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line
```

Table A.3 (Continued)

```
NEAR-FIELD SCENARIOS ################################################################

        Prior to the beginning of the intake period: (yr)
0         When was the inventory disposed?  (Package degradation starts)
0         When was LOIC?  (Biotic transport starts)
0       Fraction of roots in upper soil (top 15 cm)
0       Fraction of roots in deep soil
0.0     Manual redistribution: deep soil/surface soil dilution factor
1250    Source area for external dose modification factor (m2)

TRANSPORT ###########################################################################
        ====AIR TRANSPORT=====================================SECTION 1=====
                0-Calculate PM              ¦0       Release type (0-3)
 1      Option: 1-Use chi/Q or PM value     ¦F       Stack release (T/F)
                2-Select MI dist & dir      ¦0       Stack height (m)
                3-Specify MI dist & dir     ¦0       Stack flow (m3/sec)
0       Chi/Q or PM value                   ¦0       Stack radius (m)
0       MI sector index (1=S)               ¦0       Effluent temp. (C)
0       MI distance from release point (m)¦0       Building x-section (m2)
T       Use jf data, (T/F) else chi/Q grid¦0       Building height (m)

        ====SURFACE WATER TRANSPORT==========================SECTION 2=====
0       Mixing ratio model: 0-use value, 1-river, 2-lake
0       Mixing ratio, dimensionless
0       Average river flow rate for: MIXFLG=0 (m3/s), MIXFLG=1,2 (m/s),
0       Transit time to irrigation withdrawl location (hr)
        If mixing ratio model > 0:
0         Rate of effluent discharge to receiving water body (m3/s)
0         Longshore distance from release point to usage location (m)
0         Offshore distance to the water intake (m)
0         Average water depth in surface water body (m)
0         Average river width (m), MIXFLG=1 only
0         Depth of effluent discharge point to surface water (m), lake only

        ====WASTE FORM AVAILABILITY==========================SECTION 3=====
0       Waste form/package half life, (yr)
0       Waste thickness, (m)
.15     Depth of soil overburden, m

        ====BIOTIC TRANSPORT OF BURIED SOURCE================SECTION 4=====
T       Consider during inventory decay/buildup period (T/F)?
T       Consider during intake period (T/F)?   ¦ 1-Arid non agricultural
0       Pre-Intake site condition..............¦ 2-Humid non agricultural
                                               ¦ 3-Agricultural

EXPOSURE ############################################################################

        ====EXTERNAL EXPOSURE================================SECTION 5=====
        Exposure time:                   ¦  Residential irrigation:
0         Plume (hr)                     ¦ T       Consider: (T/F)
1500.     Soil contamination (hr)        ¦ 0       Source: 1-ground water
0         Swimming (hr)                  ¦                 2-surface water
0         Boating (hr)                   ¦ 0       Application rate (in/yr)
0         Shoreline activities (hr)      ¦ 0       Duration (mo/yr)
0       Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
0       Transit time for release to reach aquatic recreation (hr)
0       Average fraction of time submersed in acute cloud (hr/person hr)
```

Table A.3 (Continued)

```
               ====INHALATION====================================SECTION 6=====
0              Hours of exposure to contamination per year
1              0-No resus-  1-Use Mass Loading          2-Use Anspaugh model
0                pension      Mass loading factor (g/m3)   Top soil available (cm)


               ====INGESTION POPULATION==========================SECTION 7=====
0              Atmospheric production definition (select option):
0                0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
                 1-Use population-weighted chi/Q
                 2-Use uniform production
                 3-Use chi/Q and production grids (PRODUCTION will be overridden)
0              Population ingesting aquatic foods, 0 defaults to total (person)
0              Population ingesting drinking water, 0 defaults to total (person)
F              Consider dose from food exported out of region (default=F)

               Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                          3-Derived concentration entered above
               ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F              Salt water? (default is fresh)

               USE         TRAN-   PROD-      -CONSUMPTION- |
               ?   FOOD    SIT     UCTION     HOLDUP   RATE |
               T/F TYPE    hr      kg/yr      da      kg/yr |      DRINKING WATER
               --- ------  -----   -------    ------  ----- |-------------------------
               F   FISH     0.00   0.0E+00     0.00     0.0 | 0      Source (see above)
               F   MOLLUS   0.00   0.0E+00     0.00     0.0 | T      Treatment? T/F
               F   CRUSTA   0.00   0.0E+00     0.00     0.0 | 0      Holdup/transit(da)
               F   PLANTS   0.00   0.0E+00     0.00     0.0 | 0      Consumption (L/yr)

               ====TERRESTRIAL FOOD INGESTION=====================SECTION 9=====

               USE         GROW    --IRRIGATION--              PROD-     --CONSUMPTION--
               ?   FOOD    TIME    S RATE    TIME     YIELD    UCTION    HOLDUP    RATE
               T/F TYPE    da      * in/yr   mo/yr    kg/m2    kg/yr     da        kg/yr
               --- ------  -----   - -----   -----    -----    -------   ------    ------
               F   LEAF V   0.00   0   0.0    0.0      0.0     0.0E+00     0.0       0.0
               F   ROOT V   0.00   0   0.0    0.0      0.0     0.0E+00     0.0       0.0
               F   FRUIT    0.00   0   0.0    0.0      0.0     0.0E+00     0.0       0.0
               F   GRAIN    0.00   0   0.0    0.0      0.0     0.0E+00     0.0       0.0

               ====ANIMAL PRODUCTION CONSUMPTION==================SECTION 10====

               ---HUMAN---- TOTAL   DRINK   -------------STORED FEED-------------
USE            CONSUMPTION  PROD-   WATER   DIET  GROW  -IRRIGATION--        STOR-
?   FOOD       RATE  HOLDUP UCTION  CONTAM  FRAC- TIME  S RATE  TIME  YIELD  AGE
T/F TYPE       kg/yr  da    kg/yr   FRACT.  TION  da    * in/yr mo/yr kg/m3  da
--- ------     ------ ----- ------  ------- ----  ----  - ----- ----- -----  -----
F   BEEF        0.0   0.0   0.00     0.00   0.00  0.0   0   0.0  0.00  0.00   0.0
F   POULTR      0.0   0.0   0.00     0.00   0.00  0.0   0   0.0  0.00  0.00   0.0
F   MILK        0.0   0.0   0.00     0.00   0.00  0.0   0   0.0  0.00  0.00   0.0
F   EGG         0.0   0.0   0.00     0.00   0.00  0.0   0   0.0  0.00  0.00   0.0
                                            -------------FRESH FORAGE------------
    BEEF                                    0.00  0.0   0   0.0  0.00  0.00   0.0
    MILK                                    0.00  0.0   0   0.0  0.00  0.00   0.0

##############################################################################
```

Table A.4 GENII input file for Scenario No. 2 - STP Sludge Process Operator--Inhalation Calculation

```
NRC Sewer Study - Exposure Pathways
Title:      2               STP Worker - Inhalation Calculation
       C22.TPL   05-Oct-90
OPTIONS======================== Default ====================================
T    Near-field scenario?      (Far-field)   NEAR-FIELD: narrowly-focused
F    Population dose?         (Individual)               release, single site
F    Acute release?             (Chronic)    FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                    multiple sites
                              Complete                                 Complete
TRANSPORT OPTIONS============ Section    EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport                1        F  Finite plume, external       5
F  Surface Water Transport      2        F  Infinite plume, external     5
F  Biotic Transport (near-field) 3,4     F  Ground, external             5
F  Waste Form Degradation (near) 3,4     F  Recreation, external         5
                                         T  Inhalation uptake            5,6
REPORT OPTIONS======================     F  Drinking water ingestion     7,8
T  Report AEDE only                      F  Aquatic foods ingestion      7,8
F  Report by radionuclide                F  Terrestrial foods ingestion  7,9
F  Report by exposure pathway            F  Animal product ingestion     7,10
F  Debug report on screen                F  Inadvertent soil ingestion

INVENTORY ################################################################

 4   Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 2   Surface soil source units (1- m2  2- m3  3- kg)
     Equilibrium question goes here

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when|  transport selected   |  near-field scenario, optionally      |
     --------|-----------------------|---------------------------------------|
     Release |        Surface Buried |        Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air     Soil    Soil    Water   Water  |
     nuclide |/yr     /yr     /m3    |/m3     /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239                                    2.1E-04
     --------|----Derived Concentrations-----|
     Use when|   measured values are known   |
     --------|-------------------------------|
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /L      /kg    |
     --------|------- ------- ------- -------|


TIME #####################################################################

1    Intake ends after (yr)
50   Dose calc. ends after (yr)
0    Release ends after (yr)
0    No. of years of air deposition prior to the intake period
0    No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) #################################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line
```

Table A.4 (Continued)

```
NEAR-FIELD SCENARIOS #########################################################

           Prior to the beginning of the intake period: (yr)
0            When was the inventory disposed?  (Package degradation starts)
0            When was LOIC?  (Biotic transport starts)
0          Fraction of roots in upper soil (top 15 cm)
0          Fraction of roots in deep soil
0.0        Manual redistribution: deep soil/surface soil dilution factor
1250       Source area for external dose modification factor (m2)

TRANSPORT ####################################################################

           ====AIR TRANSPORT===================================SECTION 1=====
                   0-Calculate PM             |0        Release type (0-3)
 1         Option: 1-Use chi/Q or PM value    |F        Stack release (T/F)
                   2-Select MI dist & dir     |0        Stack height (m)
                   3-Specify MI dist & dir    |0        Stack flow (m3/sec)
0          Chi/Q or PM value                  |0        Stack radius (m)
0          MI sector index (1=S)              |0        Effluent temp. (C)
0          MI distance from release point (m)|0        Building x-section (m2)
T          Use jf data, (T/F) else chi/Q grid|0        Building height (m)

           ====SURFACE WATER TRANSPORT=========================SECTION 2=====
0          Mixing ratio model: 0-use value, 1-river, 2-lake
0          Mixing ratio, dimensionless
0          Average river flow rate for: MIXFLG=0 (m3/s), MIXFLG=1,2 (m/s),
0          Transit time to irrigation withdrawl location (hr)
           If mixing ratio model > 0:
0            Rate of effluent discharge to receiving water body (m3/s)
0            Longshore distance from release point to usage location (m)
0            Offshore distance to the water intake (m)
0            Average water depth in surface water body (m)
0            Average river width (m), MIXFLG=1 only
0            Depth of effluent discharge point to surface water (m), lake only

           ====WASTE FORM AVAILABILITY=========================SECTION 3=====
0          Waste form/package half life, (yr)
0          Waste thickness, (m)
0.         Depth of soil overburden, m

           ====BIOTIC TRANSPORT OF BURIED SOURCE===============SECTION 4=====
T          Consider during inventory decay/buildup period (T/F)?
T          Consider during intake period (T/F)?   | 1-Arid non agricultural
0          Pre-Intake site condition.............| 2-Humid non agricultural
                                                  | 3-Agricultural

EXPOSURE #####################################################################

           ====EXTERNAL EXPOSURE===============================SECTION 5=====
           Exposure time:                | Residential irrigation:
0            Plume (hr)                  | T        Consider: (T/F)
0            Soil contamination (hr)     | 0        Source: 1-ground water
0            Swimming (hr)               |                  2-surface water
0            Boating (hr)                | 0        Application rate (in/yr)
0            Shoreline activities (hr)   | 0        Duration (mo/yr)
0          Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
0          Transit time for release to reach aquatic recreation (hr)
0          Average fraction of time submersed in acute cloud (hr/person hr)
```

Table A.4 (Continued)

```
          ====INHALATION=======================================SECTION 6=====
300       Hours of exposure to contamination per year
1         0-No resus-  1-Use Mass Loading          2-Use Anspaugh model
1.0E-03     pension      Mass loading factor (g/m3)   Top soil available (cm)

          ====INGESTION POPULATION============================SECTION 7=====
0         Atmospheric production definition (select option):
0           0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
            1-Use population-weighted chi/Q
            2-Use uniform production
            3-Use chi/Q and production grids (PRODUCTION will be overridden)
0         Population ingesting aquatic foods, 0 defaults to total (person)
0         Population ingesting drinking water, 0 defaults to total (person)
F         Consider dose from food exported out of region (default=F)

          Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                    3-Derived concentration entered above
          ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F         Salt water? (default is fresh)

          USE         TRAN-  PROD-    -CONSUMPTION- |
          ?   FOOD    SIT    UCTION   HOLDUP  RATE  |
          T/F TYPE    hr     kg/yr    da      kg/yr |      DRINKING WATER
          --- ------  -----  -------  ------  ----- |------------------------
          F   FISH     0.00  0.0E+00    0.00    0.0 | 0     Source (see above)
          F   MOLLUS   0.00  0.0E+00    0.00    0.0 | T     Treatment? T/F
          F   CRUSTA   0.00  0.0E+00    0.00    0.0 | 0     Holdup/transit(da)
          F   PLANTS   0.00  0.0E+00    0.00    0.0 | 0     Consumption (L/yr)

          ====TERRESTRIAL FOOD INGESTION======================SECTION 9=====

          USE         GROW   --IRRIGATION--          PROD-    --CONSUMPTION--
          ?   FOOD    TIME   S RATE   TIME    YIELD  UCTION   HOLDUP   RATE
          T/F TYPE    da     * in/yr  mo/yr   kg/m2  kg/yr    da       kg/yr
          --- ------  -----  - -----  -----   -----  -------  ------   ------
          F   LEAF V   0.00  0   0.0   0.0      0.0  0.0E+00    0.0      0.0
          F   ROOT V   0.00  0   0.0   0.0      0.0  0.0E+00    0.0      0.0
          F   FRUIT    0.00  0   0.0   0.0      0.0  0.0E+00    0.0      0.0
          F   GRAIN    0.00  0   0.0   0.0      0.0  0.0E+00    0.0      0.0

          ====ANIMAL PRODUCTION CONSUMPTION==================SECTION 10====

          ---HUMAN---- TOTAL  DRINK   -------------STORED FEED-------------
USE       CONSUMPTION  PROD-  WATER   DIET  GROW  -IRRIGATION--       STOR-
?   FOOD  RATE  HOLDUP UCTION CONTAM  FRAC- TIME  S RATE  TIME   YIELD AGE
T/F TYPE  kg/yr   da   kg/yr  FRACT.  TION   da   * in/yr mo/yr  kg/m3 da
--- ------ ------ ----- ------ -------  ----  ----  - ----- -----  ----- -----
F   BEEF     0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
F   POULTR   0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
F   MILK     0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
F   EGG      0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
                                       -------------FRESH FORAGE-----------
    BEEF                               0.00   0.0  0   0.0  0.00   0.00   0.0
    MILK                               0.00   0.0  0   0.0  0.00   0.00   0.0

############################################################################
```

Table A.5 GENII input file for Scenario No. 3 - STP Liquid Effluent

```
NRC Sewer Study - Exposure Pathways
Title:      1             WASTEWATER TO RIVER DOWNSTREAM MI
       C1.TPL    10-Aug-90
OPTIONS======================== Default ====================================
F    Near-field scenario?        (Far-field)    NEAR-FIELD: narrowly-focused
F    Population dose?           (Individual)                release, single site
F    Acute release?               (Chronic)     FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                       multiple sites
                              Complete                                Complete
TRANSPORT OPTIONS============ Section    EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport                  1      F  Finite plume, external       5
T  Surface Water Transport        2      F  Infinite plume, external     5
F  Biotic Transport (near-field)  3      T  Ground, external             5
F  Waste Form Degradation (near)  4      T  Recreation, external         5
                                         T  Inhalation uptake            6
REPORT OPTIONS=======================    F  Drinking water ingestion     7,8
T  Report AEDE only                      T  Aquatic foods ingestion      7,8
T  Report by radionuclide                T  Terrestrial foods ingestion  7,9
T  Report by exposure pathway            T  Animal product ingestion     7,10
F  Debug report on screen                F  Inadvertent soil ingestion

INVENTORY ###################################################################

 4   Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 0   Surface soil source units (1- m2  2- m3  3- kg)
     Equilibrium question goes here

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when| transport selected    | near-field scenario, optionally       |
     --------|-----------------------|---------------------------------------|
     Release |        Surface Buried |       Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air    Soil    Soil    Water   Water  |
     nuclide |/yr     /yr     /m3    |/L     /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239            1.0E+00
     --------|----Derived Concentrations-----|
     Use when|  measured values are known    |
     --------|-------------------------------|
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /L      /kg    |
     --------|------- ------- ------- -------|


TIME ########################################################################

1    Intake ends after (yr)
50   Dose calc. ends after (yr)
1    Release ends after (yr)
0    No. of years of air deposition prior to the intake period
0    No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) ####################################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line
```

Table A.5 (Continued)

```
NEAR-FIELD SCENARIOS ##########################################################

          Prior to the beginning of the intake period: (yr)
0           When was the inventory disposed?  (Package degradation starts)
0           When was LOIC?  (Biotic transport starts)
0         Fraction of roots in upper soil (top 15 cm)
0         Fraction of roots in deep soil
0         Manual redistribution: deep soil/surface soil dilution factor

TRANSPORT #####################################################################

          ====AIR TRANSPORT====================================SECTION 1=====
                  0-Calculate PM           |
 1        Option: 1-Use chi/Q or PM value  |F          Stack release (T/F)
                  2-Select MI dist & dir   |0          Stack height (m)
                  3-Specify MI dist & dir  |0          Stack flow (m3/sec
0         Chi/Q or PM value                |0          Stack radius (m)
0         MI sector index (1=S)            |0          Effluent temp. (C)
0         MI distance from release point (m)
T         Use joint frequency data, otherwise chi/Q grid

          ====SURFACE WATER TRANSPORT==========================SECTION 2=====
 0        Mixing ratio model: 0-use value, 1-river, 2-lake, 3-river flow
1.0       Mixing ratio, dimensionless
100.      Average river flow rate for: MIXFLG=0,3 (m3/s), MIXFLG=1,2 (m/s),
0.0       Transit time to irrigation withdrawl location (hr)
          If mixing ratio model > 0:
0           Rate of effluent discharge to receiving water body (m3/s)
0           Longshore distance from release point to usage location (m)
0           Offshore distance to the water intake (m)
0           Average water depth in surface water body (m)
0           Average river width (m), MIXFLG=1 only
0           Depth of effluent discharge point to surface water (m), lake only

          ====WASTE FORM AVAILABILITY==========================SECTION 3=====
0         Waste form/package half life, (yr)
0         Waste thickness, (m)
0         Depth of soil overburden, m

          ====BIOTIC TRANSPORT OF BURIED SOURCE================SECTION 4=====
T         Consider during inventory decay/buildup period (T/F)?
T         Consider during intake period (T/F)?   | 1-Arid non agricultural
0         Pre-Intake site condition..............| 2-Humid non agricultural
                                                 | 3-Agricultural

EXPOSURE ######################################################################

          ====EXTERNAL EXPOSURE================================SECTION 5=====
          Exposure time:                |  Residential irrigation:
0           Plume (hr)                  | T        Consider: (T/F)
1800.0      Soil contamination (hr)     | 2        Source: 1-ground water
10.0        Swimming (hr)               |                  2-surface water
5.0         Boating (hr)                | 30.0     Application rate (in/yr)
17.         Shoreline activities (hr)   | 6.0      Duration (mo/yr)
1         Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
1.0       Transit time for release to reach aquatic recreation (hr)
0         Average fraction of time submersed in acute cloud (hr/person hr)
```

Table A.5 (Continued)

```
            ====INHALATION======================================SECTION 6=====
360.        Hours of exposure to contamination per year
1           0-No resus-  1-Use Mass Loading          2-Use Anspaugh model
.0001         pension      Mass loading factor (g/m3)  Top soil available (cm)

            ====INGESTION POPULATION============================SECTION 7=====
0           Atmospheric production definition (select option):
0             0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
              1-Use population-weighted chi/Q
              2-Use uniform production
              3-Use chi/Q and production grids (PRODUCTION will be overridden)
0           Population ingesting aquatic foods, 0 defaults to total (person)
0           Population ingesting drinking water, 0 defaults to total (person)
F           Consider dose from food exported out of region (default=F)

            Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                      3-Derived concentration entered above
            ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F           Salt water? (default is fresh)

            USE         TRAN-  PROD-     -CONSUMPTION- |
            ?   FOOD    SIT    UCTION    HOLDUP   RATE |
            T/F TYPE    hr     kg/yr     da      kg/yr |      DRINKING WATER
            --- ------ -----  -------   ------   ----- |-------------------------
            T   FISH    0.00  0.0E+00    1.00     6.9  | 2      Source (see above)
            F   MOLLUS  0.00  0.0E+00    0.00     0.0  | T      Treatment? T/F
            F   CRUSTA  0.00  0.0E+00    0.00     0.0  | 1.0    Holdup/transit(da)
            F   PLANTS  0.00  0.0E+00    0.00     0.0  | 0.0    Consumption (L/yr)

            ====TERRESTRIAL FOOD INGESTION======================SECTION 9=====

            USE         GROW   --IRRIGATION--            PROD-     --CONSUMPTION--
            ?   FOOD    TIME   S RATE   TIME    YIELD   UCTION    HOLDUP   RATE
            T/F TYPE    da     * in/yr  mo/yr   kg/m2   kg/yr     da       kg/yr
            --- ------ -----  - -----  -----   -----   -------   ------   ------
            T   LEAF V 90.00  2  35.0   6.0     1.5    0.0E+00    14.0      4.9
            T   ROOT V 90.00  2  40.0   6.0     4.0    0.0E+00    14.0     45.5
            T   FRUIT  90.00  2  35.0   6.0     2.0    0.0E+00    14.0     21.0
            T   GRAIN  90.00  2   0.0   0.0     0.8    0.0E+00   180.0     23.5

            ====ANIMAL PRODUCTION CONSUMPTION===================SECTION 10====

            ---HUMAN---- TOTAL  DRINK   ------------STORED FEED-------------
USE         CONSUMPTION  PROD-  WATER   DIET  GROW  -IRRIGATION--       STOR-
?   FOOD    RATE  HOLDUP UCTION CONTAM  FRAC- TIME  S RATE  TIME  YIELD AGE
T/F TYPE    kg/yr  da    kg/yr  FRACT.  TION  da    * in/yr mo/yr kg/m3 da
--- ------ ------ ----- ------ -------  ----  ----  - ----- ----- ----- -----
T   BEEF     47.5  20.0   0.00    1.00  0.25  90.0  2  35.0  6.00  0.80 180.0
F   POULTR    0.0  34.0   0.00    1.00  1.00  90.0  2   0.0  0.00  0.80 180.0
T   MILK     55.0   2.0   0.00    1.00  0.25  45.0  2  47.0  6.00  2.00 100.0
F   EGG      00.0  18.0   0.00    1.00  1.00  90.0  2   0.0  0.00  0.80 180.0
                                        ------------FRESH FORAGE-----------
    BEEF                                0.75  45.0  2  47.0  6.00  2.00 100.0
    MILK                                0.75  30.0  2  47.0  6.00  1.50   0.0

################################################################################
```

Table A.6 GENII input file for Scenario No. 4 - STP Incinerator Operator

```
NRC Sewer Study - Exposure Pathways
Title:      3               INCINERATOR OPERATOR
       C3.TPL   10-Aug-90
OPTIONS======================== Default ====================================
T    Near-field scenario?      (Far-field)    NEAR-FIELD: narrowly-focused
F    Population dose?         (Individual)                release, single site
F    Acute release?             (Chronic)     FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                     multiple sites
                         Complete                                      Complete
TRANSPORT OPTIONS============ Section  EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport                1      F  Finite plume, external       5
F  Surface Water Transport      2      F  Infinite plume, external     5
F  Biotic Transport (near-field) 3     T  Ground, external             5
F  Waste Form Degradation (near) 4     F  Recreation, external         5
                                       T  Inhalation uptake            6
REPORT OPTIONS======================   F  Drinking water ingestion     7,8
T  Report AEDE only                    F  Aquatic foods ingestion      7,8
T  Report by radionuclide              F  Terrestrial foods ingestion  7,9
T  Report by exposure pathway          F  Animal product ingestion     7,10
F  Debug report on screen              F  Inadvertent soil ingestion

INVENTORY ####################################################################

 4   Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 3   Surface soil source units (1- m2  2- m3  3- kg)
     Equilibrium question goes here

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when|  transport selected   |  near-field scenario, optionally      |
     --------|-----------------------|---------------------------------------|
     Release |        Surface Buried |        Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air     Soil    Soil    Water   Water  |
     nuclide |/yr     /yr     /m3    |/L      /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239                                    2.0E-06
     --------|----Derived Concentrations-----|
     Use when|  measured values are known    |
     --------|-------------------------------|
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /L      /kg    |
     --------|------- ------- ------- -------|

TIME #########################################################################

1    Intake ends after (yr)
50   Dose calc. ends after (yr)
1    Release ends after (yr)
0    No. of years of air deposition prior to the intake period
0    No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) ####################################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line
```

Table A.6 (Continued)

```
NEAR-FIELD SCENARIOS ##########################################################

          Prior to the beginning of the intake period: (yr)
0           When was the inventory disposed?  (Package degradation starts)
0           When was LOIC?  (Biotic transport starts)
0         Fraction of roots in upper soil (top 15 cm)
0         Fraction of roots in deep soil
0         Manual redistribution: deep soil/surface soil dilution factor

TRANSPORT #####################################################################

          ====AIR TRANSPORT==================================SECTION 1=====
                  0-Calculate PM           |
 1        Option: 1-Use chi/Q or PM value  |F          Stack release (T/F)
                  2-Select MI dist & dir   |0          Stack height (m)
                  3-Specify MI dist & dir  |0          Stack flow (m3/sec
0         Chi/Q or PM value                |0          Stack radius (m)
0         MI sector index (1=S)            |0          Effluent temp. (C)
0         MI distance from release point (m)
T         Use joint frequency data, otherwise chi/Q grid

          ====SURFACE WATER TRANSPORT========================SECTION 2=====
 0        Mixing ratio model: 0-use value, 1-river, 2-lake, 3-river flow
1.0       Mixing ratio, dimensionless
100.      Average river flow rate for: MIXFLG=0,3 (m3/s), MIXFLG=1,2 (m/s),
0.0       Transit time to irrigation withdrawl location (hr)
          If mixing ratio model > 0:
0           Rate of effluent discharge to receiving water body (m3/s)
0           Longshore distance from release point to usage location (m)
0           Offshore distance to the water intake (m)
0           Average water depth in surface water body (m)
0           Average river width (m), MIXFLG=1 only
0           Depth of effluent discharge point to surface water (m), lake only

          ====WASTE FORM AVAILABILITY========================SECTION 3=====
0         Waste form/package half life, (yr)
0         Waste thickness, (m)
0         Depth of soil overburden, m

          ====BIOTIC TRANSPORT OF BURIED SOURCE==============SECTION 4=====
T         Consider during inventory decay/buildup period (T/F)?
T         Consider during intake period (T/F)?   | 1-Arid non agricultural
0         Pre-Intake site condition..............| 2-Humid non agricultural
                                                 | 3-Agricultural

EXPOSURE ######################################################################

          ====EXTERNAL EXPOSURE==============================SECTION 5=====
          Exposure time:                 |  Residential irrigation:
0           Plume (hr)                   | F       Consider: (T/F)
100.        Soil contamination (hr)      | 2       Source: 1-ground water
0.          Swimming (hr)                |                 2-surface water
0.          Boating (hr)                 | 0.      Application rate (in/yr)
0.          Shoreline activities (hr)    | 0.      Duration (mo/yr)
1         Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
1.0       Transit time for release to reach aquatic recreation (hr)
0         Average fraction of time submersed in acute cloud (hr/person hr)
```

Table A.6 (Continued)

```
        ====INHALATION======================================SECTION 6=====
400.    Hours of exposure to contamination per year
1       0-No resus-  1-Use Mass Loading          2-Use Anspaugh model
.001      pension     Mass loading factor (g/m3)  Top soil available (cm)

        ====INGESTION POPULATION============================SECTION 7=====
0       Atmospheric production definition (select option):
0         0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
          1-Use population-weighted chi/Q
          2-Use uniform production
          3-Use chi/Q and production grids (PRODUCTION will be overridden)
0       Population ingesting aquatic foods, 0 defaults to total (person)
0       Population ingesting drinking water, 0 defaults to total (person)
F       Consider dose from food exported out of region (default=F)

        Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                  3-Derived concentration entered above
        ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F       Salt water? (default is fresh)

        USE        TRAN-  PROD-    -CONSUMPTION- |
        ?   FOOD   SIT    UCTION   HOLDUP  RATE  |
        T/F TYPE   hr     kg/yr    da      kg/yr |      DRINKING WATER
        --- ------ -----  -------  ------  ----- |------------------------
        F   FISH    0.00  0.0E+00    0.00   40.0 | 2      Source (see above)
        F   MOLLUS  0.00  0.0E+00    0.00    0.0 | T      Treatment? T/F
        F   CRUSTA  0.00  0.0E+00    0.00    0.0 | 1.0    Holdup/transit(da)
        F   PLANTS  0.00  0.0E+00    0.00    0.0 | 0.0    Consumption (L/yr)

        ====TERRESTRIAL FOOD INGESTION======================SECTION 9=====

        USE        GROW   --IRRIGATION--          PROD-    --CONSUMPTION--
        ?   FOOD   TIME   S RATE   TIME   YIELD   UCTION   HOLDUP   RATE
        T/F TYPE   da     * in/yr  mo/yr  kg/m2   kg/yr    da       kg/yr
        --- ------ -----  - -----  -----  -----  -------   ------   ------
        F   LEAF V 90.00  2  35.0  6.0     1.5   0.0E+00     1.0     30.0
        F   ROOT V 90.00  2  40.0  6.0     4.0   0.0E+00     5.0    220.0
        F   FRUIT  90.00  2  35.0  6.0     2.0   0.0E+00     5.0    330.0
        F   GRAIN  90.00  2   0.0  0.0     0.8   0.0E+00   180.0     80.0

        ====ANIMAL PRODUCTION CONSUMPTION===================SECTION 10====

        ---HUMAN---- TOTAL   DRINK   -------------STORED FEED-------------
USE     CONSUMPTION  PROD-   WATER   DIET  GROW  -IRRIGATION--       STOR-
?   FOOD RATE  HOLDUP UCTION CONTAM  FRAC- TIME  S RATE  TIME  YIELD AGE
T/F TYPE kg/yr  da    kg/yr  FRACT.  TION  da    * in/yr mo/yr kg/m3 da
--- ------ ------ ----- ------ ------- ---- ----  - ----- ----- ----- -----
F   BEEF    80.0  15.0  0.00    1.00 0.25  90.0  2  35.0  6.00  0.80 180.0
F   POULTR  18.0   1.0  0.00    1.00 1.00  90.0  2   0.0  0.00  0.80 180.0
F   MILK   270.0   1.0  0.00    1.00 0.25  45.0  2  47.0  6.00  2.00 100.0
F   EGG     30.0   1.0  0.00    1.00 1.00  90.0  2   0.0  0.00  0.80 180.0
                                     -------------FRESH FORAGE-----------
    BEEF                             0.75  45.0  2  47.0  6.00  2.00 100.0
    MILK                             0.75  30.0  2  47.0  6.00  1.50   0.0

#############################################################################
```

Table A.7 GENII input file for Scenario No. 5 - Sludge Incinerator Effluent

```
NRC Sewer Study - Exposure Pathways
Title:      4              INCINERATOR DOWNWIND
       C4.TPL   10-Aug-90
OPTIONS======================== Default ===================================
F    Near-field scenario?      (Far-field)    NEAR-FIELD: narrowly-focused
F    Population dose?         (Individual)                release, single site
F    Acute release?             (Chronic)     FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                     multiple sites
                              Complete                                 Complete
TRANSPORT OPTIONS============ Section   EXPOSURE PATHWAY OPTIONS===== Section
T  Air Transport                  1      F  Finite plume, external       5
F  Surface Water Transport        2      T  Infinite plume, external     5
F  Biotic Transport (near-field)  3      T  Ground, external             5
F  Waste Form Degradation (near)  4      F  Recreation, external         5
                                         T  Inhalation uptake            6
REPORT OPTIONS======================     F  Drinking water ingestion     7,8
T  Report AEDE only                      F  Aquatic foods ingestion      7,8
T  Report by radionuclide                T  Terrestrial foods ingestion  7,9
T  Report by exposure pathway            T  Animal product ingestion     7,10
F  Debug report on screen                F  Inadvertent soil ingestion

INVENTORY ####################################################################

 4   Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 3   Surface soil source units (1- m2  2- m3  3- kg)
     Equilibrium question goes here

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when| transport selected    | near-field scenario, optionally       |
     --------|-----------------------|---------------------------------------|
     Release |        Surface Buried |        Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air     Soil    Soil    Water   Water  |
     nuclide |/yr     /yr     /m3    |/L      /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239    1.0E+00
     --------|----Derived Concentrations-----|
     Use when|  measured values are known    |
     --------|-------------------------------|
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /L      /kg    |
     --------|------- ------- ------- -------|


TIME #########################################################################

1    Intake ends after (yr)
50   Dose calc. ends after (yr)
1    Release ends after (yr)
0    No. of years of air deposition prior to the intake period
0    No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) #####################################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line
```

Table A.7 (Continued)

```
NEAR-FIELD SCENARIOS ##########################################################

          Prior to the beginning of the intake period: (yr)
0           When was the inventory disposed?  (Package degradation starts)
0           When was LOIC?  (Biotic transport starts)
0         Fraction of roots in upper soil (top 15 cm)
0         Fraction of roots in deep soil
0         Manual redistribution: deep soil/surface soil dilution factor

TRANSPORT #####################################################################

          ====AIR TRANSPORT===================================SECTION 1=====
                  0-Calculate PM          |
 1        Option: 1-Use chi/Q or PM value |F         Stack release (T/F)
                  2-Select MI dist & dir  |0         Stack height (m)
                  3-Specify MI dist & dir |0         Stack flow (m3/sec
1.0E-6    Chi/Q or PM value               |0         Stack radius (m)
0         MI sector index (1=S)           |0         Effluent temp. (C)
0         MI distance from release point (m)
F         Use joint frequency data, otherwise chi/Q grid

          ====SURFACE WATER TRANSPORT=========================SECTION 2=====
 0        Mixing ratio model: 0-use value, 1-river, 2-lake, 3-river flow
1.0       Mixing ratio, dimensionless
0.        Average river flow rate for: MIXFLG=0,3 (m3/s), MIXFLG=1,2 (m/s),
0.0       Transit time to irrigation withdrawl location (hr)
          If mixing ratio model > 0:
0           Rate of effluent discharge to receiving water body (m3/s)
0           Longshore distance from release point to usage location (m)
0           Offshore distance to the water intake (m)
0           Average water depth in surface water body (m)
0           Average river width (m), MIXFLG=1 only
0           Depth of effluent discharge point to surface water (m), lake only

          ====WASTE FORM AVAILABILITY=========================SECTION 3=====
0         Waste form/package half life, (yr)
0         Waste thickness, (m)
0         Depth of soil overburden, m

          ====BIOTIC TRANSPORT OF BURIED SOURCE================SECTION 4=====
T         Consider during inventory decay/buildup period (T/F)?
T         Consider during intake period (T/F)?  | 1-Arid non agricultural
0         Pre-Intake site condition.............| 2-Humid non agricultural
                                                | 3-Agricultural

EXPOSURE ######################################################################

          ====EXTERNAL EXPOSURE===============================SECTION 5=====
          Exposure time:                 |  Residential irrigation:
1800.0      Plume (hr)                   | F        Consider: (T/F)
1800.0      Soil contamination (hr)      | 2        Source: 1-ground water
0.          Swimming (hr)                |                  2-surface water
0.          Boating (hr)                 | 40.0     Application rate (in/yr)
0.          Shoreline activities (hr)    | 6.0      Duration (mo/yr)
1         Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
1.0       Transit time for release to reach aquatic recreation (hr)
0         Average fraction of time submersed in acute cloud (hr/person hr)
```

Table A.7 (Continued)

```
         ====INHALATION=======================================SECTION 6=====
3990.    Hours of exposure to contamination per year
0        0-No resus-  1-Use Mass Loading          2-Use Anspaugh model
0          pension     Mass loading factor (g/m3)   Top soil available (cm)

         ====INGESTION POPULATION============================SECTION 7=====
1        Atmospheric production definition (select option):
0          0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
           1-Use population-weighted chi/Q
           2-Use uniform production
           3-Use chi/Q and production grids (PRODUCTION will be overridden)
0        Population ingesting aquatic foods, 0 defaults to total (person)
0        Population ingesting drinking water, 0 defaults to total (person)
F        Consider dose from food exported out of region (default=F)

         Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                 3-Derived concentration entered above
         ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F        Salt water? (default is fresh)

         USE         TRAN-  PROD-     -CONSUMPTION- |
         ?   FOOD    SIT    UCTION    HOLDUP   RATE |
         T/F TYPE    hr     kg/yr     da      kg/yr |       DRINKING WATER
         --- ------ -----  -------   ------   ----- |------------------------
         F   FISH    0.00  0.0E+00     1.00     0.0 | 2      Source (see above)
         F   MOLLUS  0.00  0.0E+00     0.00     0.0 | T      Treatment? T/F
         F   CRUSTA  0.00  0.0E+00     0.00     0.0 | 1.0    Holdup/transit(da)
         F   PLANTS  0.00  0.0E+00     0.00     0.0 | 0.0    Consumption (L/yr)

         ====TERRESTRIAL FOOD INGESTION======================SECTION 9=====

         USE         GROW   --IRRIGATION--           PROD-     --CONSUMPTION--
         ?   FOOD    TIME   S RATE   TIME    YIELD   UCTION    HOLDUP    RATE
         T/F TYPE    da     * in/yr  mo/yr   kg/m2   kg/yr     da        kg/yr
         --- ------ -----  - -----  -----   -----   -------   ------    ------
         T   LEAF V 90.00  2  35.0   6.0      1.5   0.0E+00     1.0       4.9
         T   ROOT V 90.00  2  40.0   6.0      4.0   0.0E+00    14.0      45.5
         T   FRUIT  90.00  2  35.0   6.0      2.0   0.0E+00    14.0      21.0
         T   GRAIN  90.00  2   0.0   0.0      0.8   0.0E+00   180.0      23.5

         ====ANIMAL PRODUCTION CONSUMPTION===================SECTION 10====

         ---HUMAN---- TOTAL   DRINK   -------------STORED FEED-------------
USE      CONSUMPTION  PROD-   WATER   DIET  GROW  -IRRIGATION--      STOR-
?   FOOD RATE  HOLDUP UCTION  CONTAM  FRAC- TIME  S RATE  TIME  YIELD AGE
T/F TYPE kg/yr  da    kg/yr   FRACT.  TION  da    * in/yr mo/yr kg/m3 da
--- ------ ------ ----- ------ ------- ---- ----  - ----- ----- ----- -----
T   BEEF   47.5  20.0   0.00    1.00  0.25  90.0  2  35.0  6.00  0.80 180.0
F   POULTR  0.0   4.0   0.00    1.00  1.00  90.0  2   0.0  0.00  0.80 180.0
T   MILK   55.0   2.0   0.00    1.00  0.25  45.0  2  47.0  6.00  2.00 100.0
F   EGG     0.0  18.0   0.00    1.00  1.00  90.0  2   0.0  0.00  0.80 180.0
                                       ------------FRESH FORAGE-----------
    BEEF                              0.75  45.0  2  47.0  6.00  2.00 100.0
    MILK                              0.75  30.0  2  47.0  6.00  1.50   0.0

##############################################################################
```

Table A.8 GENII input file for Scenario No. 6 - Incinerator Ash Disposal Truck Driver

```
NRC Sewer Study - Exposure Pathways
Title:      10           Ash Transport - Driver
       C10.TPL   13-Aug-90
OPTIONS======================== Default ====================================
T    Near-field scenario?      (Far-field)    NEAR-FIELD: narrowly-focused
F    Population dose?         (Individual)                release, single site
F    Acute release?             (Chronic)     FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                     multiple sites
                               Complete                                Complete
TRANSPORT OPTIONS============ Section   EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport                 1      F  Finite plume, external       5
F  Surface Water Transport       2      F  Infinite plume, external     5
F  Biotic Transport (near-field) 3,4    T  Ground, external             5
F  Waste Form Degradation (near) 3,4    F  Recreation, external         5
                                        F  Inhalation uptake            5,6
REPORT OPTIONS======================    F  Drinking water ingestion     7,8
T  Report AEDE only                     F  Aquatic foods ingestion      7,8
F  Report by radionuclide               F  Terrestrial foods ingestion  7,9
F  Report by exposure pathway           F  Animal product ingestion     7,10
F  Debug report on screen               F  Inadvertent soil ingestion

INVENTORY ##################################################################

 4   Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 0   Surface soil source units (1- m2  2- m3  3- kg)
     Equilibrium question goes here

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when|  transport selected   |  near-field scenario, optionally      |
     --------|-----------------------|---------------------------------------|
     Release |        Surface Buried |        Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air     Soil    Soil    Water   Water  |
     nuclide |/yr     /yr     /m3    |/m3     /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239                                            3.1E-03
     --------|----Derived Concentrations-----|
     Use when|   measured values are known   |
     --------|-------------------------------|
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /L      /kg    |
     --------|------- ------- ------- -------|

TIME ########################################################################

1    Intake ends after (yr)
50   Dose calc. ends after (yr)
0    Release ends after (yr)
0    No. of years of air deposition prior to the intake period
0    No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) ####################################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line
```

Table A.8 (Continued)

```
NEAR-FIELD SCENARIOS ##########################################################

          Prior to the beginning of the intake period: (yr)
0           When was the inventory disposed?  (Package degradation starts)
0           When was LOIC?  (Biotic transport starts)
0         Fraction of roots in upper soil (top 15 cm)
0         Fraction of roots in deep soil
0.0       Manual redistribution: deep soil/surface soil dilution factor
1250      Source area for external dose modification factor (m2)

TRANSPORT #####################################################################

          ====AIR TRANSPORT===================================SECTION 1=====
                  0-Calculate PM           |0         Release type (0-3)
 1        Option: 1-Use chi/Q or PM value  |F         Stack release (T/F)
                  2-Select MI dist & dir   |0         Stack height (m)
                  3-Specify MI dist & dir  |0         Stack flow (m3/sec)
0         Chi/Q or PM value                |0         Stack radius (m)
0         MI sector index (1=S)            |0         Effluent temp. (C)
0         MI distance from release point (m)|0        Building x-section (m2)
T         Use jf data, (T/F) else chi/Q grid|0        Building height (m)

          ====SURFACE WATER TRANSPORT=========================SECTION 2=====
0         Mixing ratio model: 0-use value, 1-river, 2-lake
0         Mixing ratio, dimensionless
0         Average river flow rate for: MIXFLG=0 (m3/s), MIXFLG=1,2 (m/s),
0         Transit time to irrigation withdrawl location (hr)
          If mixing ratio model > 0:
0           Rate of effluent discharge to receiving water body (m3/s)
0           Longshore distance from release point to usage location (m)
0           Offshore distance to the water intake (m)
0           Average water depth in surface water body (m)
0           Average river width (m), MIXFLG=1 only
0           Depth of effluent discharge point to surface water (m), lake only

          ====WASTE FORM AVAILABILITY=========================SECTION 3=====
0         Waste form/package half life, (yr)
0         Waste thickness, (m)
.5        Depth of soil overburden, m

          ====BIOTIC TRANSPORT OF BURIED SOURCE================SECTION 4=====
T         Consider during inventory decay/buildup period (T/F)?
T         Consider during intake period (T/F)?  | 1-Arid non agricultural
0         Pre-Intake site condition.............| 2-Humid non agricultural
                                                | 3-Agricultural

EXPOSURE ######################################################################

          ====EXTERNAL EXPOSURE===============================SECTION 5=====
          Exposure time:                 |  Residential irrigation:
0           Plume (hr)                   | T        Consider: (T/F)
1000.       Soil contamination (hr)      | 0        Source: 1-ground water
0           Swimming (hr)                |                  2-surface water
0           Boating (hr)                 | 0        Application rate (in/yr)
0           Shoreline activities (hr)    | 0        Duration (mo/yr)
0         Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
0         Transit time for release to reach aquatic recreation (hr)
0         Average fraction of time submersed in acute cloud (hr/person hr)
```

Table A.8 (Continued)

```
                ====INHALATION========================================SECTION 6=====
0               Hours of exposure to contamination per year
0               0-No resus-  1-Use Mass Loading          2-Use Anspaugh model
0                 pension      Mass loading factor (g/m3)  Top soil available (cm)

                ====INGESTION POPULATION============================SECTION 7=====
0               Atmospheric production definition (select option):
0                 0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
                  1-Use population-weighted chi/Q
                  2-Use uniform production
                  3-Use chi/Q and production grids (PRODUCTION will be overridden)
0               Population ingesting aquatic foods, 0 defaults to total (person)
0               Population ingesting drinking water, 0 defaults to total (person)
F               Consider dose from food exported out of region (default=F)

                Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                          3-Derived concentration entered above
                ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F               Salt water? (default is fresh)

                USE         TRAN-   PROD-     -CONSUMPTION- |
                ?   FOOD    SIT     UCTION    HOLDUP   RATE |
                T/F TYPE    hr      kg/yr     da       kg/yr|       DRINKING WATER
                --- ------ -----   -------   ------   -----|-------------------------
                F   FISH    0.00   0.0E+00    0.00     0.0 | 0      Source (see above)
                F   MOLLUS  0.00   0.0E+00    0.00     0.0 | T      Treatment? T/F
                F   CRUSTA  0.00   0.0E+00    0.00     0.0 | 0      Holdup/transit(da)
                F   PLANTS  0.00   0.0E+00    0.00     0.0 | 0      Consumption (L/yr)

                ====TERRESTRIAL FOOD INGESTION======================SECTION 9=====

                USE         GROW    --IRRIGATION--           PROD-     --CONSUMPTION--
                ?   FOOD    TIME    S RATE   TIME    YIELD   UCTION    HOLDUP   RATE
                T/F TYPE    da      * in/yr  mo/yr   kg/m2   kg/yr     da       kg/yr
                --- ------ -----   - -----  -----   -----   -------   ------   ------
                F   LEAF V  0.00   0   0.0   0.0     0.0   0.0E+00     0.0      0.0
                F   ROOT V  0.00   0   0.0   0.0     0.0   0.0E+00     0.0      0.0
                F   FRUIT   0.00   0   0.0   0.0     0.0   0.0E+00     0.0      0.0
                F   GRAIN   0.00   0   0.0   0.0     0.0   0.0E+00     0.0      0.0

                ====ANIMAL PRODUCTION CONSUMPTION===================SECTION 10====

                ---HUMAN---- TOTAL   DRINK   ------------STORED FEED-------------
USE             CONSUMPTION  PROD-   WATER   DIET  GROW  -IRRIGATION--        STOR-
?   FOOD        RATE  HOLDUP UCTION  CONTAM  FRAC- TIME  S RATE  TIME   YIELD AGE
T/F TYPE        kg/yr  da    kg/yr   FRACT.  TION  da    * in/yr mo/yr  kg/m3 da
--- ------      ------ ----- ------ -------  ----  ----  - ----- -----  ----- -----
F   BEEF         0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
F   POULTR       0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
F   MILK         0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
F   EGG          0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00   0.00   0.0
                                              ------------FRESH FORAGE------------
    BEEF                                   0.00   0.0  0   0.0  0.00   0.00   0.0
    MILK                                   0.00   0.0  0   0.0  0.00   0.00   0.0

#############################################################################
```

Table A.9 GENII input file for Scenario No. 6 - Incinerator Ash Disposal Truck Driver--Inhalation Calculation

```
NRC Sewer Study - Exposure Pathways
Title:      10            ASH TRANS  - Inhalation Calculation
       C30.TPL   08-Oct-90
OPTIONS======================= Default ====================================
T    Near-field scenario?      (Far-field)   NEAR-FIELD: narrowly-focused
F    Population dose?         (Individual)               release, single site
F    Acute release?             (Chronic)    FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                    multiple sites
                                Complete                                Complete
TRANSPORT OPTIONS=========== Section   EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport                 1     F  Finite plume, external      5
F  Surface Water Transport       2     F  Infinite plume, external    5
F  Biotic Transport (near-field) 3,4   F  Ground, external            5
F  Waste Form Degradation (near) 3,4   F  Recreation, external        5
                                       T  Inhalation uptake           5,6
REPORT OPTIONS======================   F  Drinking water ingestion    7,8
T  Report AEDE only                    F  Aquatic foods ingestion     7,8
F  Report by radionuclide              F  Terrestrial foods ingestion 7,9
F  Report by exposure pathway          F  Animal product ingestion    7,10
F  Debug report on screen              F  Inadvertent soil ingestion

INVENTORY ####################################################################

 4   Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 2   Surface soil source units (1- m2  2- m3  3- kg)
     Equilibrium question goes here

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when|  transport selected   |  near-field scenario, optionally      |
     --------|-----------------------|---------------------------------------|
     Release |        Surface Buried |       Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air    Soil    Soil    Water   Water  |
     nuclide |/yr     /yr     /m3    |/m3    /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239                                   2.8E-03
     --------|----Derived Concentrations-----|
     Use when|   measured values are known   |
     --------|-------------------------------|
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /L      /kg    |
     --------|------- ------- ------- -------|


TIME #########################################################################

1    Intake ends after (yr)
50   Dose calc. ends after (yr)
0    Release ends after (yr)
0    No. of years of air deposition prior to the intake period
0    No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) #####################################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line
```

Table A.9 (Continued)

```
NEAR-FIELD SCENARIOS ###########################################################

                Prior to the beginning of the intake period: (yr)
0                 When was the inventory disposed?  (Package degradation starts)
0                 When was LOIC?  (Biotic transport starts)
0               Fraction of roots in upper soil (top 15 cm)
0               Fraction of roots in deep soil
0.0             Manual redistribution: deep soil/surface soil dilution factor
1250            Source area for external dose modification factor (m2)

TRANSPORT ######################################################################

                ====AIR TRANSPORT===================================SECTION 1=====
                        0-Calculate PM          |0       Release type (0-3)
 1              Option: 1-Use chi/Q or PM value |F       Stack release (T/F)
                        2-Select MI dist & dir  |0       Stack height (m)
                        3-Specify MI dist & dir |0       Stack flow (m3/sec)
0               Chi/Q or PM value               |0       Stack radius (m)
0               MI sector index (1=S)           |0       Effluent temp. (C)
0               MI distance from release point (m)|0     Building x-section (m2)
T               Use jf data, (T/F) else chi/Q grid|0     Building height (m)

                ====SURFACE WATER TRANSPORT=========================SECTION 2=====
0               Mixing ratio model: 0-use value, 1-river, 2-lake
0               Mixing ratio, dimensionless
0               Average river flow rate for: MIXFLG=0 (m3/s), MIXFLG=1,2 (m/s),
0               Transit time to irrigation withdrawl location (hr)
                If mixing ratio model > 0:
0                 Rate of effluent discharge to receiving water body (m3/s)
0                 Longshore distance from release point to usage location (m)
0                 Offshore distance to the water intake (m)
0                 Average water depth in surface water body (m)
0                 Average river width (m), MIXFLG=1 only
0                 Depth of effluent discharge point to surface water (m), lake only

                ====WASTE FORM AVAILABILITY=========================SECTION 3=====
0               Waste form/package half life, (yr)
0               Waste thickness, (m)
0.              Depth of soil overburden, m

                ====BIOTIC TRANSPORT OF BURIED SOURCE===============SECTION 4=====
T               Consider during inventory decay/buildup period (T/F)?
T               Consider during intake period (T/F)?  | 1-Arid non agricultural
0               Pre-Intake site condition.............| 2-Humid non agricultural
                                                      | 3-Agricultural

EXPOSURE #######################################################################

                ====EXTERNAL EXPOSURE===============================SECTION 5=====
                Exposure time:               |  Residential irrigation:
0                 Plume (hr)                 | T       Consider: (T/F)
0                 Soil contamination (hr)    | 0       Source: 1-ground water
0                 Swimming (hr)              |                 2-surface water
0                 Boating (hr)               | 0       Application rate (in/yr)
0                 Shoreline activities (hr)  | 0       Duration (mo/yr)
0               Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
0               Transit time for release to reach aquatic recreation (hr)
0               Average fraction of time submersed in acute cloud (hr/person hr)
```

Table A.9 (Continued)

```
          ====INHALATION======================================SECTION 6=====
200       Hours of exposure to contamination per year
1         0-No resus-  1-Use Mass Loading          2-Use Anspaugh model
1.0E-04     pension      Mass loading factor (g/m3)   Top soil available (cm)

          ====INGESTION POPULATION============================SECTION 7=====
0         Atmospheric production definition (select option):
0           0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
            1-Use population-weighted chi/Q
            2-Use uniform production
            3-Use chi/Q and production grids (PRODUCTION will be overridden)
0         Population ingesting aquatic foods, 0 defaults to total (person)
0         Population ingesting drinking water, 0 defaults to total (person)
F         Consider dose from food exported out of region (default=F)

          Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                    3-Derived concentration entered above
          ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F         Salt water? (default is fresh)

          USE         TRAN-  PROD-     -CONSUMPTION- |
          ?   FOOD    SIT    UCTION    HOLDUP   RATE |
          T/F TYPE    hr     kg/yr     da      kg/yr |      DRINKING WATER
          --- ------  -----  -------   ------  ----- |-------------------------
          F   FISH    0.00   0.0E+00    0.00     0.0 | 0      Source (see above)
          F   MOLLUS  0.00   0.0E+00    0.00     0.0 | T      Treatment? T/F
          F   CRUSTA  0.00   0.0E+00    0.00     0.0 | 0      Holdup/transit(da)
          F   PLANTS  0.00   0.0E+00    0.00     0.0 | 0      Consumption (L/yr)

          ====TERRESTRIAL FOOD INGESTION======================SECTION 9=====

          USE         GROW   --IRRIGATION--          PROD-     --CONSUMPTION--
          ?   FOOD    TIME   S RATE   TIME    YIELD  UCTION    HOLDUP   RATE
          T/F TYPE    da     * in/yr  mo/yr   kg/m2  kg/yr     da       kg/yr
          --- ------  -----  - -----  -----   -----  -------   ------   ------
          F   LEAF V  0.00   0   0.0   0.0     0.0   0.0E+00     0.0      0.0
          F   ROOT V  0.00   0   0.0   0.0     0.0   0.0E+00     0.0      0.0
          F   FRUIT   0.00   0   0.0   0.0     0.0   0.0E+00     0.0      0.0
          F   GRAIN   0.00   0   0.0   0.0     0.0   0.0E+00     0.0      0.0

          ====ANIMAL PRODUCTION CONSUMPTION===================SECTION 10====

          ---HUMAN---- TOTAL   DRINK   -------------STORED FEED-------------
USE       CONSUMPTION  PROD-   WATER   DIET  GROW  -IRRIGATION--     STOR-
?   FOOD  RATE  HOLDUP UCTION  CONTAM  FRAC- TIME  S RATE  TIME  YIELD AGE
T/F TYPE  kg/yr  da    kg/yr   FRACT.  TION  da    * in/yr mo/yr kg/m3 da
--- ------ ------ ----- ------ ------- ----  ----  - ----- ----- ----- -----
F   BEEF     0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00  0.00  0.0
F   POULTR   0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00  0.00  0.0
F   MILK     0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00  0.00  0.0
F   EGG      0.0   0.0   0.00    0.00  0.00   0.0  0   0.0  0.00  0.00  0.0
                                       -------------FRESH FORAGE-----------
    BEEF                               0.00   0.0  0   0.0  0.00  0.00  0.0
    MILK                               0.00   0.0  0   0.0  0.00  0.00  0.0

###########################################################################
```

Table A.10 GENII input file for Scenario No. 7 - Sludge Application to Agricultural Soil

```
NRC Sewer Study - Exposure Pathways
Title:       9                SOIL APPLICATION AGRICULTURE -
       C9.TPL   10-Aug-90
OPTIONS======================== Default ====================================
T    Near-field scenario?      (Far-field)    NEAR-FIELD: narrowly-focused
F    Population dose?         (Individual)                release, single site
F    Acute release?              (Chronic)    FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                     multiple sites
                                 Complete                             Complete
TRANSPORT OPTIONS============ Section   EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport                  1     F  Finite plume, external       5
F  Surface Water Transport        2     T  Infinite plume, external     5
F  Biotic Transport (near-field)  3     T  Ground, external             5
F  Waste Form Degradation (near)  4     F  Recreation, external         5
                                        T  Inhalation uptake            6
REPORT OPTIONS======================    F  Drinking water ingestion     7,8
T  Report AEDE only                     F  Aquatic foods ingestion      7,8
T  Report by radionuclide               T  Terrestrial foods ingestion  7,9
T  Report by exposure pathway           F  Animal product ingestion     7,10
F  Debug report on screen               F  Inadvertent soil ingestion

INVENTORY ####################################################################

 4   Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 1   Surface soil source units (1- m2  2- m3  3- kg)
     Equilibrium question goes here

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when|  transport selected   |  near-field scenario, optionally      |
     --------|-----------------------|---------------------------------------|
     Release |        Surface Buried |       Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air    Soil    Soil    Water   Water  |
     nuclide |/yr     /yr     /m3    |/L     /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239                                   1.5E-06
     --------|----Derived Concentrations-----|
     Use when|   measured values are known   |
     --------|-------------------------------|
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /L      /kg    |
     --------|------- ------- ------- -------|

TIME #########################################################################

1    Intake ends after (yr)
50   Dose calc. ends after (yr)
1    Release ends after (yr)
0    No. of years of air deposition prior to the intake period
0    No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) #####################################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line
```

Table A.10 (Continued)

```
NEAR-FIELD SCENARIOS ##############################################################

          Prior to the beginning of the intake period: (yr)
0           When was the inventory disposed?  (Package degradation starts)
0           When was LOIC?  (Biotic transport starts)
1.        Fraction of roots in upper soil (top 15 cm)
0         Fraction of roots in deep soil
0         Manual redistribution: deep soil/surface soil dilution factor

TRANSPORT #########################################################################

          ====AIR TRANSPORT===================================SECTION 1=====
                  0-Calculate PM              |
 1        Option: 1-Use chi/Q or PM value     |F          Stack release (T/F)
                  2-Select MI dist & dir      |0          Stack height (m)
                  3-Specify MI dist & dir     |0          Stack flow (m3/sec
0         Chi/Q or PM value                   |0          Stack radius (m)
0         MI sector index (1=S)               |0          Effluent temp. (C)
0         MI distance from release point (m)
T         Use joint frequency data, otherwise chi/Q grid

          ====SURFACE WATER TRANSPORT=========================SECTION 2=====
0         Mixing ratio model: 0-use value, 1-river, 2-lake, 3-river flow
0         Mixing ratio, dimensionless
0         Average river flow rate for: MIXFLG=0,3 (m3/s), MIXFLG=1,2 (m/s),
0         Transit time to irrigation withdrawl location (hr)
          If mixing ratio model > 0:
0           Rate of effluent discharge to receiving water body (m3/s)
0           Longshore distance from release point to usage location (m)
0           Offshore distance to the water intake (m)
0           Average water depth in surface water body (m)
0           Average river width (m), MIXFLG=1 only
0           Depth of effluent discharge point to surface water (m), lake only

          ====WASTE FORM AVAILABILITY=========================SECTION 3=====
0         Waste form/package half life, (yr)
0         Waste thickness, (m)
0         Depth of soil overburden, m

          ====BIOTIC TRANSPORT OF BURIED SOURCE================SECTION 4=====
T         Consider during inventory decay/buildup period (T/F)?
T         Consider during intake period (T/F)?   | 1-Arid non agricultural
0         Pre-Intake site condition..............| 2-Humid non agricultural
                                                 | 3-Agricultural

EXPOSURE ##########################################################################

          ====EXTERNAL EXPOSURE===============================SECTION 5=====
          Exposure time:                 |  Residential irrigation:
500.        Plume (hr)                   | F        Consider: (T/F)
500.        Soil contamination (hr)      | 2        Source: 1-ground water
0           Swimming (hr)                |                  2-surface water
0           Boating (hr)                 | 40.0     Application rate (in/yr)
0           Shoreline activities (hr)    | 6.0      Duration (mo/yr)
1         Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
1.0       Transit time for release to reach aquatic recreation (hr)
0         Average fraction of time submersed in acute cloud (hr/person hr)
```

Table A.10 (Continued)

```
          ====INHALATION=======================================SECTION 6=====
400.      Hours of exposure to contamination per year
1         0-No resus-  1-Use Mass Loading         2-Use Anspaugh model
.0001       pension     Mass loading factor (g/m3)   Top soil available (cm)

          ====INGESTION POPULATION============================SECTION 7=====
0         Atmospheric production definition (select option):
0           0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
            1-Use population-weighted chi/Q
            2-Use uniform production
            3-Use chi/Q and production grids (PRODUCTION will be overridden)
0         Population ingesting aquatic foods, 0 defaults to total (person)
0         Population ingesting drinking water, 0 defaults to total (person)
F         Consider dose from food exported out of region (default=F)

          Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                 3-Derived concentration entered above
          ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F         Salt water? (default is fresh)

          USE        TRAN-  PROD-     -CONSUMPTION- |
          ?   FOOD   SIT    UCTION    HOLDUP  RATE  |
          T/F TYPE   hr     kg/yr     da      kg/yr |      DRINKING WATER
          --- ------ -----  -------   ------  ----- |------------------------
          F   FISH    0.00  0.0E+00    1.00   40.0  | 2      Source (see above)
          F   MOLLUS  0.00  0.0E+00    0.00    0.0  | T      Treatment? T/F
          F   CRUSTA  0.00  0.0E+00    0.00    0.0  | 1.0    Holdup/transit(da)
          F   PLANTS  0.00  0.0E+00    0.00    0.0  | 0.0    Consumption (L/yr)

          ====TERRESTRIAL FOOD INGESTION======================SECTION 9=====

          USE        GROW   --IRRIGATION--          PROD-    --CONSUMPTION--
          ?   FOOD   TIME   S RATE   TIME    YIELD  UCTION   HOLDUP   RATE
          T/F TYPE   da     * in/yr  mo/yr   kg/m2  kg/yr    da       kg/yr
          --- ------ -----  - -----  -----   -----  -------  ------   ------
          T   LEAF V 90.00  2  35.0   6.0     1.5   0.0E+00    1.0      4.9
          T   ROOT V 90.00  2  40.0   6.0     4.0   0.0E+00   14.0     45.5
          T   FRUIT  90.00  2  35.0   6.0     2.0   0.0E+00   14.0     21.0
          T   GRAIN  90.00  2   0.0   0.0     0.8   0.0E+00  180.0     23.5

          ====ANIMAL PRODUCTION CONSUMPTION===================SECTION 10====

          ---HUMAN---- TOTAL   DRINK   ------------STORED FEED-------------
USE       CONSUMPTION  PROD-   WATER   DIET  GROW  -IRRIGATION--      STOR-
?   FOOD  RATE  HOLDUP UCTION  CONTAM  FRAC- TIME  S RATE  TIME  YIELD AGE
T/F TYPE  kg/yr   da   kg/yr   FRACT.  TION  da    * in/yr mo/yr kg/m3 da
--- ------ ------ ----- ------ ------- ----  ----  - ----- ----- ----- -----
F   BEEF        34.0   0.00     1.00   0.25  90.0  2  35.0 6.00   0.80 180.0
F   POULTR      34.0   0.00     1.00   1.00  90.0  2   0.0 0.00   0.80 180.0
F   MILK         4.0   0.00     1.00   0.25  45.0  2  47.0 6.00   2.00 100.0
F   EGG         18.0   0.00     1.00   1.00  90.0  2   0.0 0.00   0.80 180.0
                                         ------------FRESH FORAGE-----------
    BEEF                               0.75  45.0  2  47.0 6.00   2.00 100.0
    MILK                               0.75  30.0  2  47.0 6.00   1.50   0.0

############################################################################
```

Table A.11 GENII input file for Scenario No. 8 - Sludge Application to Non-Agricultural Soil

```
NRC Sewer Study - Exposure Pathways
Title:      11              Soil Application - Non-Agricultural
      C11.TPL   13-Aug-90
OPTIONS======================== Default ===================================
T    Near-field scenario?      (Far-field)    NEAR-FIELD: narrowly-focused
F    Population dose?         (Individual)                release, single site
F    Acute release?             (Chronic)     FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                     multiple sites
                              Complete                                Complete
TRANSPORT OPTIONS============ Section   EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport                1       F  Finite plume, external       5
F  Surface Water Transport      2       T  Infinite plume, external     5
F  Biotic Transport (near-field) 3      T  Ground, external             5
F  Waste Form Degradation (near) 4      F  Recreation, external         5
                                        T  Inhalation uptake            6
REPORT OPTIONS======================    F  Drinking water ingestion     7,8
T  Report AEDE only                     F  Aquatic foods ingestion      7,8
T  Report by radionuclide               F  Terrestrial foods ingestion  7,9
T  Report by exposure pathway           F  Animal product ingestion     7,10
F  Debug report on screen               F  Inadvertent soil ingestion

INVENTORY ####################################################################

 4    Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 1    Surface soil source units (1- m2  2- m3  3- kg)
      Equilibrium question goes here

      --------|----Release Terms------|----------Basic Concentrations---------|
      Use when|  transport selected   |  near-field scenario, optionally      |
      --------|-----------------------|---------------------------------------|
      Release |        Surface Buried |        Surface Deep    Ground  Surface|
      Radio-  |Air     Water   Waste  |Air     Soil    Soil    Water   Water  |
      nuclide |/yr     /yr     /m3    |/L      /unit   /m3     /L      /L     |
      --------|------- ------- -------|------- ------- ------- ------- -------|
      PU239                                    5.8E-06
      --------|----Derived Concentrations-----|
      Use when|  measured values are known    |
      --------|-------------------------------|
      Release |Terres. Animal  Drink   Aquatic|
      Radio-  |Plant   Product Water   Food   |
      nuclide |/kg     /kg     /L      /kg    |
      --------|------- ------- ------- -------|


TIME #########################################################################

1     Intake ends after (yr)
50    Dose calc. ends after (yr)
1     Release ends after (yr)
0     No. of years of air deposition prior to the intake period
0     No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) #####################################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line
```

Table A.11 (Continued)

```
NEAR-FIELD SCENARIOS ##########################################################

          Prior to the beginning of the intake period: (yr)
0           When was the inventory disposed?  (Package degradation starts)
0           When was LOIC?  (Biotic transport starts)
0         Fraction of roots in upper soil (top 15 cm)
0         Fraction of roots in deep soil
0         Manual redistribution: deep soil/surface soil dilution factor

TRANSPORT #####################################################################

          ====AIR TRANSPORT===================================SECTION 1=====
                  0-Calculate PM            |
 1        Option: 1-Use chi/Q or PM value   |F         Stack release (T/F)
                  2-Select MI dist & dir    |0         Stack height (m)
                  3-Specify MI dist & dir   |0         Stack flow (m3/sec
0         Chi/Q or PM value                 |0         Stack radius (m)
0         MI sector index (1=S)             |0         Effluent temp. (C)
0         MI distance from release point (m)
T         Use joint frequency data, otherwise chi/Q grid

          ====SURFACE WATER TRANSPORT=========================SECTION 2=====
 0        Mixing ratio model: 0-use value, 1-river, 2-lake, 3-river flow
0         Mixing ratio, dimensionless
0         Average river flow rate for: MIXFLG=0,3 (m3/s), MIXFLG=1,2 (m/s),
0         Transit time to irrigation withdrawl location (hr)
          If mixing ratio model > 0:
0           Rate of effluent discharge to receiving water body (m3/s)
0           Longshore distance from release point to usage location (m)
0           Offshore distance to the water intake (m)
0           Average water depth in surface water body (m)
0           Average river width (m), MIXFLG=1 only
0           Depth of effluent discharge point to surface water (m), lake only

          ====WASTE FORM AVAILABILITY=========================SECTION 3=====
0         Waste form/package half life, (yr)
0         Waste thickness, (m)
0         Depth of soil overburden, m

          ====BIOTIC TRANSPORT OF BURIED SOURCE===============SECTION 4=====
T         Consider during inventory decay/buildup period (T/F)?
T         Consider during intake period (T/F)?  | 1-Arid non agricultural
0         Pre-Intake site condition.............| 2-Humid non agricultural
                                                | 3-Agricultural

EXPOSURE ######################################################################

          ====EXTERNAL EXPOSURE===============================SECTION 5=====
          Exposure time:                  |  Residential irrigation:
500.        Plume (hr)                    | F        Consider: (T/F)
500.        Soil contamination (hr)       | 2        Source: 1-ground water
0.          Swimming (hr)                 |                  2-surface water
0.          Boating (hr)                  | 0.       Application rate (in/yr)
0.          Shoreline activities (hr)     | 0.       Duration (mo/yr)
1         Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
1.0       Transit time for release to reach aquatic recreation (hr)
0         Average fraction of time submersed in acute cloud (hr/person hr)
```

Table A.11 (Continued)

```
              ====INHALATION=======================================SECTION 6=====
100.          Hours of exposure to contamination per year
1             0-No resus-  1-Use Mass Loading          2-Use Anspaugh model
.0001           pension      Mass loading factor (g/m3)   Top soil available (cm)

              ====INGESTION POPULATION=============================SECTION 7=====
0             Atmospheric production definition (select option):
0               0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
                1-Use population-weighted chi/Q
                2-Use uniform production
                3-Use chi/Q and production grids (PRODUCTION will be overridden)
0             Population ingesting aquatic foods, 0 defaults to total (person)
0             Population ingesting drinking water, 0 defaults to total (person)
F             Consider dose from food exported out of region (default=F)

              Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                        3-Derived concentration entered above
              ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F             Salt water? (default is fresh)

              USE        TRAN-  PROD-     -CONSUMPTION- |
              ?   FOOD   SIT    UCTION    HOLDUP   RATE |
              T/F TYPE   hr     kg/yr     da      kg/yr |      DRINKING WATER
              --- ------ -----  -------   ------  ----- |------------------------
              F   FISH   0.00  0.0E+00     0.00   40.0 | 2      Source (see above)
              F   MOLLUS 0.00  0.0E+00     0.00    0.0 | T      Treatment? T/F
              F   CRUSTA 0.00  0.0E+00     0.00    0.0 | 1.0    Holdup/transit(da)
              F   PLANTS 0.00  0.0E+00     0.00    0.0 | 0.0    Consumption (L/yr)

              ====TERRESTRIAL FOOD INGESTION=======================SECTION 9=====

              USE        GROW    --IRRIGATION--          PROD-    --CONSUMPTION--
              ?   FOOD   TIME    S RATE   TIME   YIELD   UCTION   HOLDUP   RATE
              T/F TYPE   da      * in/yr  mo/yr  kg/m2   kg/yr    da       kg/yr
              --- ------ -----   - -----  -----  -----   -------  ------   ------
              F   LEAF V 90.00   2  35.0   6.0    1.5    0.0E+00    1.0     30.0
              F   ROOT V 90.00   2  40.0   6.0    4.0    0.0E+00    5.0    220.0
              F   FRUIT  90.00   2  35.0   6.0    2.0    0.0E+00    5.0    330.0
              F   GRAIN  90.00   2   0.0   0.0    0.8    0.0E+00  180.0     80.0

              ====ANIMAL PRODUCTION CONSUMPTION====================SECTION 10====

              ---HUMAN---- TOTAL   DRINK   -------------STORED FEED-------------
USE           CONSUMPTION  PROD-   WATER   DIET  GROW  -IRRIGATION--       STOR-
?   FOOD      RATE  HOLDUP UCTION  CONTAM  FRAC- TIME  S RATE  TIME  YIELD AGE
T/F TYPE      kg/yr  da     kg/yr  FRACT.  TION  da    * in/yr mo/yr kg/m3 da
--- ------    ------ ----- ------  ------- ----  ----  - ----- ----- ----- -----
F   BEEF       80.0  15.0   0.00     1.00  0.25  90.0  2  35.0  6.00  0.80 180.0
F   POULTR     18.0   1.0   0.00     1.00  1.00  90.0  2   0.0  0.00  0.80 180.0
F   MILK      270.0   1.0   0.00     1.00  0.25  45.0  2  47.0  6.00  2.00 100.0
F   EGG        30.0   1.0   0.00     1.00  1.00  90.0  2   0.0  0.00  0.80 180.0
                                            -------------FRESH FORAGE------------
    BEEF                                   0.75  45.0  2  47.0  6.00  2.00 100.0
    MILK                                   0.75  30.0  2  47.0  6.00  1.50   0.0

################################################################################
```

Table A.12 GENII input file for Scenario No. 9 - Landfill Equipment Operator

```
NRC Sewer Study - Exposure Pathways
Title:       5                 LANDFILL OPERATOR
       C5.TPL   10-Aug-90
OPTIONS======================== Default ===================================
T    Near-field scenario?      (Far-field)    NEAR-FIELD: narrowly-focused
F    Population dose?        (Individual)                release, single site
F    Acute release?            (Chronic)     FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                    multiple sites
                               Complete                              Complete
TRANSPORT OPTIONS============ Section     EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport                  1        F  Finite plume, external       5
F  Surface Water Transport        2        F  Infinite plume, external     5
F  Biotic Transport (near-field)  3        T  Ground, external             5
F  Waste Form Degradation (near)  4        F  Recreation, external         5
                                           T  Inhalation uptake            6
REPORT OPTIONS======================       F  Drinking water ingestion     7,8
T  Report AEDE only                        F  Aquatic foods ingestion      7,8
T  Report by radionuclide                  F  Terrestrial foods ingestion  7,9
T  Report by exposure pathway              F  Animal product ingestion     7,10
F  Debug report on screen                  F  Inadvertent soil ingestion

INVENTORY ####################################################################

 4   Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 3   Surface soil source units (1- m2  2- m3  3- kg)
     Equilibrium question goes here

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when|  transport selected   |  near-field scenario, optionally      |
     --------|-----------------------|---------------------------------------|
     Release |        Surface Buried |       Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air     Soil    Soil    Water   Water  |
     nuclide |/yr     /yr     /m3    |/L      /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239                                  1.8E-07
     --------|----Derived Concentrations-----|
     Use when|   measured values are known   |
     --------|-------------------------------|
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /L      /kg    |
     --------|------- ------- ------- -------|

TIME #########################################################################

1    Intake ends after (yr)
50   Dose calc. ends after (yr)
1    Release ends after (yr)
0    No. of years of air deposition prior to the intake period
0    No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) #####################################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line
```

Table A.12 (Continued)

```
NEAR-FIELD SCENARIOS ##########################################################

          Prior to the beginning of the intake period: (yr)
0           When was the inventory disposed?  (Package degradation starts)
0           When was LOIC?  (Biotic transport starts)
0         Fraction of roots in upper soil (top 15 cm)
0         Fraction of roots in deep soil
0         Manual redistribution: deep soil/surface soil dilution factor

TRANSPORT ####################################################################

          ====AIR TRANSPORT===================================SECTION 1=====
                  0-Calculate PM                 |
 1        Option: 1-Use chi/Q or PM value        |F          Stack release (T/F)
                  2-Select MI dist & dir         |0          Stack height (m)
                  3-Specify MI dist & dir        |0          Stack flow (m3/sec
0         Chi/Q or PM value                      |0          Stack radius (m)
0         MI sector index (1=S)                  |0          Effluent temp. (C)
0         MI distance from release point (m)
T         Use joint frequency data, otherwise chi/Q grid

          ====SURFACE WATER TRANSPORT=========================SECTION 2=====
 0        Mixing ratio model: 0-use value, 1-river, 2-lake, 3-river flow
1.0       Mixing ratio, dimensionless
100.      Average river flow rate for: MIXFLG=0,3 (m3/s), MIXFLG=1,2 (m/s),
0.0       Transit time to irrigation withdrawl location (hr)
          If mixing ratio model > 0:
0           Rate of effluent discharge to receiving water body (m3/s)
0           Longshore distance from release point to usage location (m)
0           Offshore distance to the water intake (m)
0           Average water depth in surface water body (m)
0           Average river width (m), MIXFLG=1 only
0           Depth of effluent discharge point to surface water (m), lake only

          ====WASTE FORM AVAILABILITY=========================SECTION 3=====
0         Waste form/package half life, (yr)
0         Waste thickness, (m)
0         Depth of soil overburden, m

          ====BIOTIC TRANSPORT OF BURIED SOURCE===============SECTION 4=====
T         Consider during inventory decay/buildup period (T/F)?
T         Consider during intake period (T/F)?   | 1-Arid non agricultural
0         Pre-Intake site condition..............| 2-Humid non agricultural
                                                 | 3-Agricultural

EXPOSURE #####################################################################

          ====EXTERNAL EXPOSURE===============================SECTION 5=====
          Exposure time:                     |  Residential irrigation:
0           Plume (hr)                       | F       Consider: (T/F)
250.        Soil contamination (hr)          | 2       Source: 1-ground water
0.          Swimming (hr)                    |                 2-surface water
0.          Boating (hr)                     | 0.      Application rate (in/yr)
0.          Shoreline activities (hr)        | 0.      Duration (mo/yr)
1         Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
1.0       Transit time for release to reach aquatic recreation (hr)
0         Average fraction of time submersed in acute cloud (hr/person hr)
```

Table A.12 (Continued)

```
            ====INHALATION=====================================SECTION 6=====
100.        Hours of exposure to contamination per year
1           0-No resus-  1-Use Mass Loading          2-Use Anspaugh model
.0004         pension     Mass loading factor (g/m3)   Top soil available (cm)

            ====INGESTION POPULATION===========================SECTION 7=====
0           Atmospheric production definition (select option):
0             0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
              1-Use population-weighted chi/Q
              2-Use uniform production
              3-Use chi/Q and production grids (PRODUCTION will be overridden)
0           Population ingesting aquatic foods, 0 defaults to total (person)
0           Population ingesting drinking water, 0 defaults to total (person)
F           Consider dose from food exported out of region (default=F)

            Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                      3-Derived concentration entered above
            ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F           Salt water? (default is fresh)

            USE         TRAN-  PROD-     -CONSUMPTION- |
            ?   FOOD    SIT    UCTION    HOLDUP   RATE |
            T/F TYPE    hr     kg/yr     da       kg/yr |      DRINKING WATER
            --- ------ -----  -------   ------   ----- |------------------------
            F   FISH    0.00  0.0E+00    0.00    40.0 | 2      Source (see above)
            F   MOLLUS  0.00  0.0E+00    0.00     0.0 | T      Treatment? T/F
            F   CRUSTA  0.00  0.0E+00    0.00     0.0 | 1.0    Holdup/transit(da)
            F   PLANTS  0.00  0.0E+00    0.00     0.0 | 0.0    Consumption (L/yr)

            ====TERRESTRIAL FOOD INGESTION=====================SECTION 9=====

            USE         GROW   --IRRIGATION--          PROD-     --CONSUMPTION--
            ?   FOOD    TIME   S RATE   TIME    YIELD  UCTION    HOLDUP   RATE
            T/F TYPE    da     * in/yr  mo/yr   kg/m2  kg/yr     da       kg/yr
            --- ------ -----  - -----  -----   -----  -------   ------   ------
            F   LEAF V 90.00  2  35.0   6.0     1.5   0.0E+00     1.0     30.0
            F   ROOT V 90.00  2  40.0   6.0     4.0   0.0E+00     5.0    220.0
            F   FRUIT  90.00  2  35.0   6.0     2.0   0.0E+00     5.0    330.0
            F   GRAIN  90.00  2   0.0   0.0     0.8   0.0E+00   180.0     80.0

            ====ANIMAL PRODUCTION CONSUMPTION==================SECTION 10====

            ---HUMAN---- TOTAL  DRINK   ------------STORED FEED-------------
USE         CONSUMPTION  PROD-  WATER   DIET  GROW  -IRRIGATION--       STOR-
?   FOOD    RATE  HOLDUP UCTION CONTAM  FRAC- TIME  S RATE  TIME  YIELD AGE
T/F TYPE    kg/yr  da    kg/yr  FRACT.  TION  da    * in/yr mo/yr kg/m3 da
--- ------ ------ ----- ------ -------  ----  ----  - ----- ----- ----- -----
F   BEEF    80.0  15.0   0.00    1.00  0.25  90.0  2  35.0  6.00  0.80 180.0
F   POULTR  18.0   1.0   0.00    1.00  1.00  90.0  2   0.0  0.00  0.80 180.0
F   MILK   270.0   1.0   0.00    1.00  0.25  45.0  2  47.0  6.00  2.00 100.0
F   EGG     30.0   1.0   0.00    1.00  1.00  90.0  2   0.0  0.00  0.80 180.0
                                         ------------FRESH FORAGE-----------
    BEEF                                0.75  45.0  2  47.0  6.00  2.00 100.0
    MILK                                0.75  30.0  2  47.0  6.00  1.50   0.0

################################################################################
```

Table A.13 GENII input file for Scenario No. 10 - Landfill Intrusion and Construction

```
NRC Sewer Study - Exposure Pathways
Title:      6                INTRUDER CONSTRUCTION
       C6.TPL   25-Oct-90
OPTIONS======================== Default ====================================
T    Near-field scenario?      (Far-field)   NEAR-FIELD: narrowly-focused
F    Population dose?         (Individual)               release, single site
F    Acute release?             (Chronic)    FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                    multiple sites
                              Complete                                Complete
TRANSPORT OPTIONS============ Section    EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport                  1      F  Finite plume, external       5
F  Surface Water Transport        2      F  Infinite plume, external     5
F  Biotic Transport (near-field)  3      T  Ground, external             5
F  Waste Form Degradation (near)  4      F  Recreation, external         5
                                         T  Inhalation uptake            6
REPORT OPTIONS=======================    F  Drinking water ingestion     7,8
T  Report AEDE only                      F  Aquatic foods ingestion      7,8
T  Report by radionuclide                F  Terrestrial foods ingestion  7,9
T  Report by exposure pathway            F  Animal product ingestion     7,10
F  Debug report on screen                F  Inadvertent soil ingestion

INVENTORY ####################################################################

 4   Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 2   Surface soil source units (1- m2  2- m3  3- kg)
     Equilibrium question goes here

     --------|----Release Terms------|----------Basic Concentrations--------|
     Use when| transport selected    | near-field scenario, optionally      |
     --------|-----------------------|--------------------------------------|
     Release |        Surface Buried |       Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air    Soil    Soil    Water   Water  |
     nuclide |/yr     /yr     /m3    |/L     /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239                                           3.1E-03
     --------|----Derived Concentrations-----|
     Use when|  measured values are known    |
     --------|-------------------------------|
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /L      /kg    |
     --------|------- ------- ------- -------|

TIME #########################################################################

1    Intake ends after (yr)
50   Dose calc. ends after (yr)
1    Release ends after (yr)
0    No. of years of air deposition prior to the intake period
0    No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) #####################################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line
```

Table A.13 (Continued)

```
NEAR-FIELD SCENARIOS ########################################################

          Prior to the beginning of the intake period: (yr)
5.          When was the inventory disposed?  (Package degradation starts)
0           When was LOIC?  (Biotic transport starts)
1.        Fraction of roots in upper soil (top 15 cm)
0         Fraction of roots in deep soil
0.09      Manual redistribution: deep soil/surface soil dilution factor

TRANSPORT ###################################################################

          ====AIR TRANSPORT===================================SECTION 1=====
                  0-Calculate PM            |
 1        Option: 1-Use chi/Q or PM value   |F          Stack release (T/F)
                  2-Select MI dist & dir    |0          Stack height (m)
                  3-Specify MI dist & dir   |0          Stack flow (m3/sec
0         Chi/Q or PM value                 |0          Stack radius (m)
0         MI sector index (1=S)             |0          Effluent temp. (C)
0         MI distance from release point (m)
T         Use joint frequency data, otherwise chi/Q grid

          ====SURFACE WATER TRANSPORT=========================SECTION 2=====
0         Mixing ratio model: 0-use value, 1-river, 2-lake, 3-river flow
0         Mixing ratio, dimensionless
0         Average river flow rate for: MIXFLG=0,3 (m3/s), MIXFLG=1,2 (m/s),
0         Transit time to irrigation withdrawl location (hr)
          If mixing ratio model > 0:
0           Rate of effluent discharge to receiving water body (m3/s)
0           Longshore distance from release point to usage location (m)
0           Offshore distance to the water intake (m)
0           Average water depth in surface water body (m)
0           Average river width (m), MIXFLG=1 only
0           Depth of effluent discharge point to surface water (m), lake only

          ====WASTE FORM AVAILABILITY=========================SECTION 3=====
0         Waste form/package half life, (yr)
0         Waste thickness, (m)
0         Depth of soil overburden, m

          ====BIOTIC TRANSPORT OF BURIED SOURCE================SECTION 4=====
T         Consider during inventory decay/buildup period (T/F)?
T         Consider during intake period (T/F)?    | 1-Arid non agricultural
0         Pre-Intake site condition..............| 2-Humid non agricultural
                                                  | 3-Agricultural

EXPOSURE ####################################################################

          ====EXTERNAL EXPOSURE===============================SECTION 5=====
          Exposure time:                | Residential irrigation:
0.          Plume (hr)                  | F       Consider: (T/F)
400.        Soil contamination (hr)     | 2       Source: 1-ground water
0.          Swimming (hr)               |                 2-surface water
0.          Boating (hr)                | 0.      Application rate (in/yr)
0.          Shoreline activities (hr)   | 0.      Duration (mo/yr)
1         Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
1.0       Transit time for release to reach aquatic recreation (hr)
0         Average fraction of time submersed in acute cloud (hr/person hr)
```

Table A.13 (Continued)

```
          ====INHALATION=======================================SECTION 6=====
100.      Hours of exposure to contamination per year
1         0-No resus-  1-Use Mass Loading          2-Use Anspaugh model
.0005       pension     Mass loading factor (g/m3)  Top soil available (cm)

          ====INGESTION POPULATION=============================SECTION 7=====
0         Atmospheric production definition (select option):
0           0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
            1-Use population-weighted chi/Q
            2-Use uniform production
            3-Use chi/Q and production grids (PRODUCTION will be overridden)
0         Population ingesting aquatic foods, 0 defaults to total (person)
0         Population ingesting drinking water, 0 defaults to total (person)
F         Consider dose from food exported out of region (default=F)

          Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                    3-Derived concentration entered above
          ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F         Salt water? (default is fresh)

          USE         TRAN-  PROD-    -CONSUMPTION- |
          ?   FOOD    SIT    UCTION   HOLDUP   RATE |
          T/F TYPE    hr     kg/yr    da      kg/yr |      DRINKING WATER
          --- ------ -----  -------  ------   ----- |------------------------
          F   FISH    0.00  0.0E+00   0.00    40.0 | 2      Source (see above)
          F   MOLLUS  0.00  0.0E+00   0.00     0.0 | T      Treatment? T/F
          F   CRUSTA  0.00  0.0E+00   0.00     0.0 | 1.0    Holdup/transit(da)
          F   PLANTS  0.00  0.0E+00   0.00     0.0 | 0.0    Consumption (L/yr)

          ====TERRESTRIAL FOOD INGESTION=======================SECTION 9=====

          USE         GROW   --IRRIGATION--           PROD-    --CONSUMPTION--
          ?   FOOD    TIME   S RATE   TIME    YIELD   UCTION   HOLDUP   RATE
          T/F TYPE    da     * in/yr  mo/yr   kg/m2   kg/yr    da       kg/yr
          --- ------ -----   - -----  -----   -----   -------  ------   ------
          F   LEAF V 90.00   2  35.0   6.0     1.5    0.0E+00    1.0     30.0
          F   ROOT V 90.00   2  40.0   6.0     4.0    0.0E+00    5.0    220.0
          F   FRUIT  90.00   2  35.0   6.0     2.0    0.0E+00    5.0    330.0
          F   GRAIN  90.00   2   0.0   0.0     0.8    0.0E+00  180.0     80.0

          ====ANIMAL PRODUCTION CONSUMPTION====================SECTION 10====

          ---HUMAN---- TOTAL  DRINK    -------------STORED FEED-------------
USE       CONSUMPTION  PROD-  WATER    DIET  GROW  -IRRIGATION--        STOR-
?   FOOD  RATE  HOLDUP UCTION CONTAM   FRAC- TIME  S RATE  TIME   YIELD AGE
T/F TYPE  kg/yr  da    kg/yr  FRACT.   TION   da   * in/yr mo/yr  kg/m3 da
--- ------ ------ ----- ------ -------  ----  ----  - ----- -----  ----- -----
F   BEEF    80.0  15.0   0.00    1.00  0.25  90.0  2  35.0  6.00   0.80 180.0
F   POULTR  18.0   1.0   0.00    1.00  1.00  90.0  2   0.0  0.00   0.80 180.0
F   MILK   270.0   1.0   0.00    1.00  0.25  45.0  2  47.0  6.00   2.00 100.0
F   EGG     30.0   1.0   0.00    1.00  1.00  90.0  2   0.0  0.00   0.80 180.0
                                       ------------FRESH FORAGE-----------
    BEEF                               0.75  45.0  2  47.0  6.00   2.00 100.0
    MILK                               0.75  30.0  2  47.0  6.00   1.50   0.0

##############################################################################
```

Table A.14 GENII input file for Scenario No. 11 - Landfill Intrusion and Residence

```
NRC Sewer Study - Exposure Pathways
Title:       7              RESIDENTIAL GARDEN (Intruder Agriculture)
      C7.TPL   10-Aug-90
OPTIONS======================== Default ==================================
T    Near-field scenario?      (Far-field)    NEAR-FIELD: narrowly-focused
F    Population dose?          (Individual)               release, single site
F    Acute release?            (Chronic)      FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                     multiple sites
                               Complete                             Complete
TRANSPORT OPTIONS=========== Section   EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport               1       F  Finite plume, external      5
F  Surface Water Transport     2       T  Infinite plume, external    5
F  Biotic Transport (near-field) 3     T  Ground, external            5
F  Waste Form Degradation (near) 4     F  Recreation, external        5
                                       T  Inhalation uptake           6
REPORT OPTIONS=====================    F  Drinking water ingestion    7,8
T  Report AEDE only                    F  Aquatic foods ingestion     7,8
T  Report by radionuclide              T  Terrestrial foods ingestion 7,9
T  Report by exposure pathway          F  Animal product ingestion    7,10
F  Debug report on screen              F  Inadvertent soil ingestion

INVENTORY ##############################################################

 4   Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 3   Surface soil source units (1- m2  2- m3  3- kg)
     Equilibrium question goes here

     --------|----Release Terms-----|---------Basic Concentrations--------|
     Use when|  transport selected  | near-field scenario, optionally     |
     --------|----------------------|-------------------------------------|
     Release |        Surface Buried|        Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste |Air     Soil    Soil    Water   Water |
     nuclide |/yr     /yr     /m3   |/L      /unit   /m3     /L      /L    |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239                                           3.1E-03
     --------|----Derived Concentrations-----|
     Use when|  measured values are known    |
     --------|-------------------------------|
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /L      /kg    |
     --------|------- ------- ------- -------|

TIME ###################################################################

1    Intake ends after (yr)
50   Dose calc. ends after (yr)
1    Release ends after (yr)
0    No. of years of air deposition prior to the intake period
0    No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) ##############################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line
```

Table A.14 (Continued)

```
NEAR-FIELD SCENARIOS ########################################################

          Prior to the beginning of the intake period: (yr)
5.          When was the inventory disposed?  (Package degradation starts)
0           When was LOIC?  (Biotic transport starts)
1.        Fraction of roots in upper soil (top 15 cm)
0         Fraction of roots in deep soil
0.059     Manual redistribution: deep soil/surface soil dilution factor

TRANSPORT ###################################################################

          ====AIR TRANSPORT==================================SECTION 1=====
                  0-Calculate PM          |
 1        Option: 1-Use chi/Q or PM value |F          Stack release (T/F)
                  2-Select MI dist & dir  |0          Stack height (m)
                  3-Specify MI dist & dir |0          Stack flow (m3/sec
0         Chi/Q or PM value               |0          Stack radius (m)
0         MI sector index (1=S)           |0          Effluent temp. (C)
0         MI distance from release point (m)
T         Use joint frequency data, otherwise chi/Q grid

          ====SURFACE WATER TRANSPORT========================SECTION 2=====
0         Mixing ratio model: 0-use value, 1-river, 2-lake, 3-river flow
0         Mixing ratio, dimensionless
0         Average river flow rate for: MIXFLG=0,3 (m3/s), MIXFLG=1,2 (m/s),
0         Transit time to irrigation withdrawl location (hr)
          If mixing ratio model > 0:
0           Rate of effluent discharge to receiving water body (m3/s)
0           Longshore distance from release point to usage location (m)
0           Offshore distance to the water intake (m)
0           Average water depth in surface water body (m)
0           Average river width (m), MIXFLG=1 only
0           Depth of effluent discharge point to surface water (m), lake only

          ====WASTE FORM AVAILABILITY========================SECTION 3=====
0         Waste form/package half life, (yr)
0         Waste thickness, (m)
0         Depth of soil overburden, m

          ====BIOTIC TRANSPORT OF BURIED SOURCE==============SECTION 4=====
T         Consider during inventory decay/buildup period (T/F)?
T         Consider during intake period (T/F)?   | 1-Arid non agricultural
0         Pre-Intake site condition..............| 2-Humid non agricultural
                                                 | 3-Agricultural

EXPOSURE ####################################################################

          ====EXTERNAL EXPOSURE==============================SECTION 5=====
          Exposure time:                 |  Residential irrigation:
2030.       Plume (hr)                   | F       Consider: (T/F)
2030.       Soil contamination (hr)      | 2       Source: 1-ground water
0.          Swimming (hr)                |                 2-surface water
0.          Boating (hr)                 | 0.      Application rate (in/yr)
0.          Shoreline activities (hr)    | 0.      Duration (mo/yr)
1         Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
1.0       Transit time for release to reach aquatic recreation (hr)
0         Average fraction of time submersed in acute cloud (hr/person hr)
```

Table A.14 (Continued)

```
        ====INHALATION=======================================SECTION 6=====
605.    Hours of exposure to contamination per year
1       0-No resus-  1-Use Mass Loading           2-Use Anspaugh model
.0001     pension      Mass loading factor (g/m3)   Top soil available (cm)

        ====INGESTION POPULATION============================SECTION 7=====
0       Atmospheric production definition (select option):
0         0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
          1-Use population-weighted chi/Q
          2-Use uniform production
          3-Use chi/Q and production grids (PRODUCTION will be overridden)
0       Population ingesting aquatic foods, 0 defaults to total (person)
0       Population ingesting drinking water, 0 defaults to total (person)
F       Consider dose from food exported out of region (default=F)

        Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                  3-Derived concentration entered above
        ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F       Salt water? (default is fresh)

        USE         TRAN-  PROD-     -CONSUMPTION- |
        ?   FOOD    SIT    UCTION    HOLDUP   RATE |
        T/F TYPE    hr     kg/yr     da      kg/yr |       DRINKING WATER
        --- ------ -----   -------   ------  ----- |--------------------------
        F   FISH    0.00   0.0E+00    0.00    40.0 | 2     Source (see above)
        F   MOLLUS  0.00   0.0E+00    0.00     0.0 | T     Treatment? T/F
        F   CRUSTA  0.00   0.0E+00    0.00     0.0 | 1.0   Holdup/transit(da)
        F   PLANTS  0.00   0.0E+00    0.00     0.0 | 0.0   Consumption (L/yr)

        ====TERRESTRIAL FOOD INGESTION======================SECTION 9=====

        USE         GROW   --IRRIGATION--          PROD-     --CONSUMPTION--
        ?   FOOD    TIME   S RATE    TIME   YIELD  UCTION    HOLDUP    RATE
        T/F TYPE    da     * in/yr   mo/yr  kg/m2  kg/yr     da        kg/yr
        --- ------ -----   - -----   -----  -----  -------   ------    ------
        T   LEAF V 90.00   2  35.0    6.0    1.5   0.0E+00     1.0       2.5
        T   ROOT V 90.00   2  40.0    6.0    4.0   0.0E+00    14.0      22.8
        T   FRUIT  90.00   2  35.0    6.0    2.0   0.0E+00    14.0      10.5
        T   GRAIN  90.00   2   0.0    0.0    0.8   0.0E+00   180.0      11.8

        ====ANIMAL PRODUCTION CONSUMPTION===================SECTION 10====

        ---HUMAN---- TOTAL   DRINK   -------------STORED FEED-------------
USE     CONSUMPTION  PROD-   WATER   DIET  GROW  -IRRIGATION--       STOR-
?   FOOD  RATE  HOLDUP UCTION  CONTAM  FRAC- TIME  S RATE  TIME  YIELD AGE
T/F TYPE  kg/yr  da    kg/yr   FRACT.  TION  da    * in/yr mo/yr kg/m3 da
--- ------ ------ ----- ------ ------- ----  ----  - ----- ----- ----- -----
F   BEEF    47.5  15.0  0.00    1.00   0.25  90.0  2  35.0  6.00  0.80 180.0
F   POULTR   0.0   1.0  0.00    1.00   1.00  90.0  2   0.0  0.00  0.80 180.0
F   MILK    55.0   1.0  0.00    1.00   0.25  45.0  2  47.0  6.00  2.00 100.0
F   EGG      0.0   1.0  0.00    1.00   1.00  90.0  2   0.0  0.00  0.80 180.0
                                      -------------FRESH FORAGE-----------
    BEEF                               0.75  45.0  2  47.0  6.00  2.00 100.0
    MILK                               0.75  30.0  2  47.0  6.00  1.50   0.0
############################################################################
```

Table A.15 Calculation of source term (GENII input) for each scenario

Number	Scenario description	GENII source term	Medium	Calculation of GENII input
1	Sewer System Inspector	varies Ci/m3	Waste Water	.01 x 10CFR20 Appendix B, Table 3
2	STP Operator	2.1E-04 Ci/m3	Wet Sludge	1 Ci/yr /1.7E6 kg dry sludge x .3 (dry/wet) x 1.2E+3 kg/m3
3	STP Liquid Effluent	1.0E+00 Ci/yr	to River	1 Ci/yr (5 Ci H3)
4	Sludge Incinerator Operator	2.0E-06 Ci/kg	Dry Ash	1 Ci/5.1E+5 kg/yr ash (.1 x 5 = .5 Ci 3H; .25 Ci 14C)
5	Sludge Incinerator Effluent	5.0E-03 Ci/yr	to Air	1 Ci/yr x RF 0.005 = RF with the following exceptions: 5 Ci 3H x .9 = 4.5 Ci 3H; 0.75 14C; 0.1 P, S, I; 0.01 Cl, Tc, Ru
6	Incinerator Ash Disposal Truck Driver	2.8E-03 Ci/m3	Wet Ash	1 Ci/5.1E+5 kg Ash x 1600 kg/m3 x 0.9 (dry/wet wt)
7	Sludge Agricultural Soil Application	8.8E-07 Ci/m2	Sludge/soil	1 Ci/yr / 1.7E+6 kg Sludge x 15 Mg/ha x 1E+3 kg/Mg x 1 ha/1E+4 m2
8	Sludge Nonagricultral Soil Application	5.8E-06 Ci/m2	Sludge/soil	1 Ci/yr / 1.7E+6 kg Sludge x 100 Mg/ha x 1E+3 kg/Mg x 1 ha/1E+4 m2
9	Landfill Operator	1.8E-07 Ci/Kg	Wet Ash	1 Ci/5.1E+5 kg x .9 (dry fraction) x 0.1 (b) exceptions: 5 Ci x .1 = .5 Ci H3; 1 Ci x x 0.25 = 0.25 Ci C14
10	Landfill Intrusion and Construction	3.1E-04 Ci/m3	Ash/Soil (b)	1 Ci/5.1E+5 kg ash x 1600 kg/m3 x 0.1 (b),(c)
11	Landfill Intrusion and Residence	3.1E-04 Ci/m3	Ash/Soil (c)	1 Ci/5.1E+5 kg ash x 1600 kg/m3 x 0.1 (b),(d)

(a) External Case: EXTDF calculates dose factors; this is the multiplier used in the subsequent calculations
(b) Dilution factor: 0.1 multiplied by source term to account for non-dedicated landfill
(c) Manual redistribution .59 (cover to ash ratio) x .15 surface/ground conc. (m2/m3) = .09
(d) Manual redistribution 0.59 x .67 (fraction in surface) x .15 surface/ground conc. = .0.059

Table A.16 Basis for calculation of sludge and ash concentrations

Parameter	Value	Calculation
STP capacity		5.0E+00 MG/day
Sludge production	1.7E+06 kg/yr	10320 lb/da x 365 day/yr x 1 kg /2.2 lb
Ash production	5.1E+05 kg/yr	1.7E6 kg(DW) x 0.3
Ash concentration	1.9E-06 Ci/kg	1 Ci/5.1 E+5 kg Ash
Ash concentration	3.1E-03 Ci/m3	1.95E-6 Ci/kg x 1.6E+3 kg/m3
Sludge (dry)	5.8E-07 Ci/kg	1 Ci/yr x 1 yr/1.7E+6 kg sludge
Sludge (dry)	9.3E-04 Ci/m3	5.8E-7 Ci/kg x 1.6E+3 kg/m3
Sludge (wet)	1.7E-07 Ci/kg	5.8E-7 Ci/kg x 0.3 (solids)
Sludge (wet)	2.1E-04 Ci/m3	1.7E-7 Ci/kg * 1.2E+3 kg/m3

Table A.17 Concentrations of contaminated environmental media based on 1 Ci/yr released to a 5-MGD sewage treatment plant

Number	Scenario	Environmental Concentration	Medium	Calculation
1	Sewer System Inspector	0.1 x 10CFR20	Waste Water	0.1 x 10CFR20 Appendix B, Table 3
2	STP Operator	2.1E-4 Ci/m3	Wet Sludge	1 Ci/yr /1.7E6 kg dry sludge x .3 (dry/wet) x 1.2E+3 kg/m3
3	STP Liquid Effluent	0.32 pCi/l	River Water	1 Ci/yr/ (100m3/sec x 3.16E+7 sec/yr) x 1E+9 pCi/l /Ci/m3
4	Sludge Incinerator Operator	2 nCi/g	Dry Ash	1 Ci/5.1E+5 kg/yr ash x RF (H3, C14) x E+6 nCi/g / Ci/kg
5	Sludge Incinerator Effluent	3.2E-5 pCi/l	Air	1 Ci/yr x RF x1E-6 Sec/m3 x yr/3.16E+7 sec x E+9 pCi/l /Ci/m3
6	Incinerator Ash Disposal Truck Driver	1.8 nCi/g	Wet Ash	1Ci/5.1E+5 kg Ash x 1E+6 nCi/g / Ci/kg x 0.9 (dry/wet wt)
7	Sludge Agricultural Soil Application	3.7 pCi/g	Sludge/soil	1 Ci/yr / 1.7E+6 kg Sludge x 15 Mg/ha x 1E+3 kg/Mg x 1ha/1E+4 m2 x m2/240 kg (a)
8	Sludge Nonagricultural Soil Application	24 pCi/g	Sludge/soil	1 Ci/yr / 1.7E+6 kg Sludge x 100 Mg/ha x 1E+3 kg/Mg x 1ha/1E+4 m2 x m2/240 kg
9	Landfill Operator	180 pCi/g	Wet Ash	1 Ci/5.1E+5 kg x .9 (dry fraction) x E+9 pCi/g /Ci/m3 x 0.1 (b)
10	Landfill Intrusion and Construction	110 pCi/g	Ash/Soil	1 Ci/5.1E+5 kg ash x.59 (Cover/Ash) x E+9 pCi/g /Ci/m3 x 0.1 (b)
11	Landfill Intrusion and Residence	80 pCi/g	Ash/Soil	1 Ci/5.1E+5 kg ash x.59 (Cover/Ash) x .67 (c) x E+9 pCi/g /Ci/m3x0.1(b)

(a) The conversion factor 240 kg/m2 soil is for a 15 cm depth, with a density of 1600 kg/m3.
(b) The 0.1 dilution factor accounts for a non-dedicated landfill; 10 % of the contents is Incinerator ash.
(c) Dilution of 0.67 is fraction of contaminated soil in the surface layer. Assume 2000 m2 surface, .15m (15 cm) deep, = 300 m3; 600 m3 contaminated soil from excavation is mixed with this soil: 600/600+300 = 0.67, fraction of contaminated surface soil.

Table A.18 Radionuclide source terms for case history dose calculations

Case	Radio-nuclide	Scenario 1	2	3	4	5	6	7	8	9	10	11
Tonawanda			Ci/m3		Ci/m3	Ci	Ci/m3			Ci/kg	Ci/m3	Ci/m3
	AM241	-	5.4E-04	-	8.0E-04	4.3E-03	7.2E-04	-	-	4.5E-08	8.0E-05	8.0E-05
Grand Island			Ci/m3							Ci/kg[(a)]	Ci/m3[(a)]	Ci/m3[(a)]
	AM241	-	3.6E-05	-						9.0E-09	1.6E-05	1.6E-05
Royersford		Ci/m3	Ci/m3	-	Ci/m3	-	Ci/m3	Ci/m2	Ci/m2	Ci/m3[(b)]	Ci/m3[(b)]	Ci/m3[(b)]
	MN54	2.2E-06	1.6E-06		1.7E-05		1.6E-05	4.9E-09	3.2E-08	1.6E-05	1.7E-05	1.7E-05
	CO58	1.6E-06	5.4E-07		6.0E-06		5.4E-06	1.7E-09	1.1E-08	5.4E-06	6.0E-06	6.0E-06
	CO60	3.6E-05	1.4E-05		1.6E-04		1.4E-04	4.5E-08	3.0E-07	1.4E-04	1.6E-04	1.6E-04
	ZN65	1.5E-05	6.0E-06		6.7E-05		6.0E-05	1.9E-08	1.3E-07	6.0E-05	6.7E-05	6.7E-05
	SR89	4.3E-07	1.6E-07		1.8E-06		1.6E-06	5.0E-10	3.3E-09	1.6E-06	1.8E-06	1.8E-06
	SR90	6.0E-07	3.3E-07		3.7E-06		3.3E-06	1.0E-09	6.9E-09	3.3E-06	3.7E-06	3.7E-06
	CS134	2.9E-06	2.6E-07		2.9E-06		2.6E-06	8.1E-10	5.4E-09	2.6E-06	2.9E-06	2.9E-06
	CS137	1.6E-05	3.8E-06		4.3E-05		3.8E-05	1.2E-08	8.0E-08	3.8E-05	4.3E-05	4.3E-05
	U 233	2.6E-08	1.4E-07		1.6E-06		1.4E-06	4.5E-10	3.0E-09	1.4E-06	1.6E-06	1.6E-06
	U 235	3.3E-09	5.6E-09		6.2E-08		5.6E-08	1.7E-11	1.2E-10	5.6E-08	6.2E-08	6.2E-08
	U 238	7.6E-09	4.6E-08		5.1E-07		4.6E-07	1.4E-10	9.6E-10	4.6E-07	5.1E-07	5.1E-07
	PU238	5.0E-10	3.4E-09		3.8E-08		3.4E-08	1.1E-11	7.1E-11	3.4E-08	3.8E-08	3.8E-08
	PU239	1.1E-09	2.4E-09		2.7E-08		2.4E-08	7.5E-12	5.0E-11	2.4E-08	2.7E-08	2.7E-08
Oak Ridge		Ci/m3	Ci/m3					Ci/m2	Ci/m2			
	60Co	4.5E-06	3.2E-05					1.4E-07	9.1E-07			

Table A.18 (Continued)

Case	Radio-nuclide	Scenario 1	2	3	4	5	6	7	8	9	10	11
Blue Plains (NIH 1984)		Ci/m3	Ci/m3	Ci				Ci/m2	Ci/m2			
	H 3	2.2E-06	2.0E-05	4.6E+00				6.6E-08	4.2E-07			
	C 14	3.0E-07	2.7E-06	6.2E-01				8.4E-09	5.7E-08			
	NA22	4.6E-12	4.2E-11	9.6E-06				1.3E-13	8.8E-13			
	P 32	5.8E-08	5.3E-07	1.2E-01				1.7E-09	1.1E-08			
	P 33	1.1E-11	1.1E-10	2.4E-05				3.4E-13	2.2E-12			
	CA45	2.3E-11	2.1E-10	4.8E-05				6.6E-13	4.4E-12			
	SC46	1.2E-12	1.1E-11	2.4E-06				3.3E-14	2.2E-13			
	CR51	8.7E-08	7.9E-07	1.8E-01				2.5E-09	1.7E-08			
	CO57	3.0E-11	2.7E-10	6.1E-05				8.4E-13	5.6E-12			
	CO58	2.9E-11	2.6E-10	6.0E-05				8.4E-13	5.5E-12			
	FE59	7.3E-10	6.6E-09	1.5E-03				2.6E-11	1.4E-10			
	SE75	1.2E-12	1.1E-11	2.5E-06				3.4E-14	2.3E-13			
	RB86	6.8E-12	6.2E-11					1.9E-13	1.3E-12			
	TC99	6.8E-13	6.2E-12	1.4E-06				1.9E-14	1.3E-13			
	IN111	2.0E-12	1.8E-11	4.1E-06				5.6E-14	3.8E-13			
	I 131	5.8E-09	1.9E-07	4.3E-02				5.9E-10	3.9E-09			
	I 125	2.1E-08	5.3E-08	1.2E-02				1.7E-10	1.1E-09			
	CE141	4.8E-13	4.4E-12	1.0E-06				1.4E-14	9.2E-14			
	U 238	9.2E-11	8.4E-10	1.9E-04				2.6E-12	1.7E-11			
Blue Plains (NIH 1985)		Ci/m3	Ci/m3	Ci				Ci/m2	Ci/m2			
	H 3	2.6E-10	2.4E-05	5.4E+00				7.2E-08	4.9E-07			
	C 14	6.3E-07	5.8E-06	1.3E+00				1.8E-08	1.2E-07			
	NA22	9.8E-10	8.9E-09	2.0E-03				2.8E-11	1.9E-10			
	P 32	1.5E-07	1.3E-06	3.0E-01				4.2E-09	2.8E-08			
	CL36	6.3E-11	5.8E-10					1.8E-12	1.2E-11			
	CA45	9.6E-12	8.8E-11	2.0E-05				2.8E-13	1.8E-12			
	CR51	1.1E-07	1.0E-06	2.3E-01				3.2E-09	2.1E-08			
	CO57	8.0E-12	7.3E-11	1.7E-05				2.3E-13	1.5E-12			
	CO58	5.4E-12	4.9E-11	1.1E-05				1.6E-13	1.0E-12			
	CO60		6.1E-08	4.1E-03				1.9E-10	1.3E-09			
	SE75	1.3E-09	1.1E-08	2.6E-03				3.6E-11	2.4E-10			
	TC99	1.1E-11	1.1E-10	2.3E-05				3.2E-13	2.1E-12			
	I 125	4.3E-08	3.9E-07	8.9E-02				3.2E-09	8.2E-09			
	I 131	1.6E-08	1.4E-07	3.3E-02				1.2E-10	3.0E-09			
	CS137		8.0E-09	5.5E-04				2.5E-11	1.7E-10			
	PB212		7.3E-07	5.0E-02				2.3E-09	1.5E-08			
	TH228	1.6E-11	1.4E-10	3.2E-05				4.4E-13	3.0E-12			
	U 238	1.8E-09	1.7E-10	3.8E-05				5.2E-13	3.5E-12			

(a) Doses for Grand Island calculated as a fraction (1/5) of the dose for Tonawanda
(b) Apply 1:10 dilution to doses to accout for non-dedicated landfill

Table A.19 Source term for deterministic calculations of dose based on theoretical discharges for each scenario

Radio-	Scenario numbers									
nuclide	1 Ci/m^3	2 Ci/m^3	3 Ci/m^3	4 Ci/m^3	5 Ci/m^3	6 Ci/m^3	8 Ci/m^3	9 Ci/m^3	10 Ci/m^3	11 Ci/m^3
H 3	1.0E-03	2.1E-04	5.0E+00	9.8E-07	4.5E+00	1.4E-03	2.9E-05	8.8E-08	1.6E-04	1.6E-04
C 14	3.0E-05	2.1E-04	1.0E+00	4.9E-07	7.5E-01	6.8E-04	5.8E-06	4.4E-08	7.8E-05	7.8E-05
NA22	6.0E-06	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
NA24	5.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
P 32	9.0E-06	2.1E-04	1.0E+00	2.0E-06	1.0E-01	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
P 33	8.0E-05	2.1E-04	1.0E+00	2.0E-06	1.0E-01	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
S 35	1.0E-04	2.1E-04	1.0E+00	2.0E-06	1.0E-01	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
CL36	2.0E-05	2.1E-04	1.0E+00	2.0E-06	1.0E-02	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
CA45	2.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
SC46	1.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
CR51	5.0E-04	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
MN54	3.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
FE55	1.0E-04	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
FE59	1.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
CO57	6.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
CO58	2.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
CO60	3.0E-06	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
NI59	3.0E-04	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
NI63	1.0E-04	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
ZN65	5.0E-06	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
SE75	7.0E-06	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
SR89	8.0E-06	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
RB86	7.0E-06	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
SR90	5.0E-07	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
Y 90	7.0E-06	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
ZR95	2.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
NB95	3.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
TC99M	1.0E-03	2.1E-04	1.0E+00	2.0E-06	1.0E-02	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
TC99	6.0E-05	2.1E-04	1.0E+00	2.0E-06	1.0E-02	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
RU106	3.0E-06	2.1E-04	1.0E+00	2.0E-06	1.0E-02	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
IN111	6.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
I 125	2.0E-06	2.1E-04	1.0E+00	2.0E-06	1.0E-01	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
SB125	3.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
I 129	2.0E-07	2.1E-04	1.0E+00	2.0E-06	1.0E-01	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
I 131	1.0E-06	2.1E-04	1.0E+00	2.0E-06	1.0E-01	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
CS134	9.0E-07	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
CS135	1.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
CS137	1.0E-06	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
BA140	8.0E-06	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
LA140	9.0E-06	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
CE141	3.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
CE144	3.0E-06	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
PR144	6.0E-04	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
SM151	2.0E-04	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
EU152	1.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04

Table A.19 (Continued)

Radionuclide	Scenario numbers									
	1 Ci/m^3	2 Ci/m^3	3 Ci/m^3	4 Ci/m^3	5 Ci/m^3	6 Ci/m^3	8 Ci/m^3	9 Ci/m^3	10 Ci/m^3	11 Ci/m^3
EU154	7.0E-06	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
IR192	1.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
RA226	6.0E-08	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
RN222	0.0E+00	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
PB210	1.0E-08	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
BI210	1.0E-05	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
PO210	4.0E-08	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
TH228	2.0E-07	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
PB212	2.0E-06	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
U 234	3.0E-07	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
U 235	3.0E-07	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
NP237	2.0E-08	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
U 233	3.0E-07	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
U 238	3.0E-07	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
PU238	2.0E-08	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
PU240	2.0E-08	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
AM241	2.0E-08	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04
PU239	2.0E-08	2.1E-04	1.0E+00	2.0E-06	5.0E-03	2.8E-03	5.8E-06	1.8E-07	3.1E-04	3.1E-04

Table A.20 Geometry for cases requiring customized external dose factors

Scenario parameter	Selected value	Comments
No. 1 - 1 STP Sewer System Inspector		
Source geometry		Rectangular slab
Source volume	6000000 cc	
Source length	600 cm	
Source height	200 cm	
Source thickness	50 cm	
Shield 1 water thickness	50 cm	Shield 1=source
Air shield thickness	100 cm	
Operator distance	100 cm	1 m from source
No. 2 - STP Sludge Process Operator		
Source geometry		Infinite slab
Source dimension	100 cm	
Concrete shield thickness	100 cm	
Air shield thickness	200 cm	
Operator distance	200 cm front[(a)]	2 m from source
No. 6 - Incinerator Ash Disposal Truck Driver		
Source geometry		Rectangular slab
Source volume	6000000 cc	5-ton truck[(b)]
Source length	200	
Source height	100 cm	
Source thickness	300 cm	
Shield 1 concrete thickness	300 cm	
Shield 2 iron thickness	0.5 cm	
Shield 3 air thickness	5 cm	
Shield 4 iron thickness	0.5 cm	
Shield 5 air thickness	94 cm	
Operator distance	100 cm	1 m from source front[(c)]

(a) With a 1 m source thickness, operator distance is 2 m from source front and 3 m from farthest surface of source.
(b) From NUREG/CR-3585, p.3-10 (NRC, 1984).
(c) With a 3 m source thickness, operator distance is 1 m from front surface of source and 4 m from farthest surface of the source.

Table A.21 Modified dose factor library used in Scenarios No. 1, 2, and 6 (Sewer Inspector, STP Worker, and Ash Truck Transport Driver)

MODIFIED External Dose Factors for GENII Sv/yr per Bq/m3 (8-Aug-90)

	Air Submersion m3	Water Surface L	Soil Surface "m3"	STP WKR 0.15 m[a] m3	ASH TRANS 0.5 m[b] m3	SEWER MAINT 1.0m [c] m3
H 3	1.95E-16	2.86E-16	1.04E-20	6.56E-21	0.00E+00	1.18E-19
BE7	1.01E-07	1.39E-07	5.39E-11	5.77E-11	1.87E-12	1.24E-11
BE10	4.21E-10	5.88E-10	1.30E-13	1.27E-13	1.29E-15	5.99E-14
C 14	1.41E-11	2.02E-11	2.23E-15	2.10E-15	3.32E-19	2.70E-15
N 13	1.93E-06	2.66E-06	1.03E-09	1.11E-09	3.58E-11	2.37E-10
F 18	1.87E-06	2.58E-06	1.00E-09	1.07E-09	3.47E-11	2.30E-10
NA22	3.89E-06	4.99E-06	2.11E-09	2.34E-09	1.20E-10	6.75E-10
NA24	8.08E-06	1.00E-05	4.07E-09	5.06E-09	4.07E-10	1.95E-09
SI31	6.17E-09	8.26E-09	2.89E-12	3.05E-12	1.10E-13	9.38E-13
P 32	6.32E-09	8.71E-09	2.89E-12	2.98E-12	7.59E-14	8.49E-13
P 33	4.90E-11	6.96E-11	1.01E-14	9.64E-15	2.18E-17	8.63E-15
S 35	1.63E-11	2.34E-11	2.67E-15	2.53E-15	5.49E-19	3.05E-15
CL36	7.52E-10	1.05E-09	2.57E-13	2.55E-13	3.35E-15	1.01E-13
K 40	2.86E-07	3.87E-07	1.53E-10	1.79E-10	1.27E-11	7.10E-11
AR39	4.22E-10	5.89E-10	1.31E-13	1.28E-13	1.32E-15	5.98E-14
AR41	2.14E-06	2.58E-06	1.17E-09	1.34E-09	8.71E-11	4.58E-10
CA41	2.65E-10	3.89E-10	1.41E-14	8.92E-15	0.00E+00	1.60E-13
CA45	5.11E-11	7.26E-11	1.07E-14	1.02E-14	2.52E-17	8.98E-15
SC46	3.62E-06	4.42E-06	1.96E-09	2.20E-09	1.33E-10	7.30E-10
CR51	6.43E-08	8.84E-08	3.47E-11	3.63E-11	1.07E-12	8.14E-12
MN54	1.46E-06	1.82E-06	7.85E-10	8.60E-10	4.56E-11	2.70E-10
MN56	3.22E-06	3.93E-06	1.69E-09	1.98E-09	1.33E-10	6.65E-10
FE55	6.07E-10	8.90E-10	3.23E-14	2.04E-14	0.00E+00	3.67E-13
FE59	1.92E-06	2.32E-06	1.08E-09	1.23E-09	7.51E-11	3.98E-10
CO57	1.79E-07	2.45E-07	7.48E-11	7.34E-11	9.52E-13	2.28E-11
CO58	1.77E-06	2.25E-06	9.50E-10	1.04E-09	5.18E-11	3.10E-10
CO60	4.31E-06	5.19E-06	2.35E-09	2.69E-09	1.75E-10	9.22E-10
NI59	7.37E-10	1.08E-09	3.92E-14	2.48E-14	0.00E+00	4.46E-13
NI63	6.50E-13	9.47E-13	5.65E-17	4.96E-17	1.66E-25	1.94E-16
NI65	1.02E-06	1.32E-06	5.46E-10	6.32E-10	4.29E-11	2.36E-10
CU64	3.57E-07	4.91E-07	1.91E-10	2.05E-10	6.84E-12	4.50E-11
ZN65	1.12E-06	1.36E-06	6.12E-10	6.98E-10	4.50E-11	2.38E-10
ZN69M	9.18E-07	1.27E-06	4.91E-10	5.25E-10	1.70E-11	1.13E-10
ZN69	1.34E-09	1.86E-09	4.98E-13	4.98E-13	8.15E-15	1.80E-13
GA72	5.10E-06	6.31E-06	2.67E-09	3.14E-09	2.15E-10	1.08E-09
AS76	8.60E-07	1.21E-06	4.83E-10	5.29E-10	2.62E-11	1.61E-10
SE75	6.05E-07	8.29E-07	2.90E-10	2.94E-10	6.54E-12	7.50E-11
SE79	1.05E-11	1.50E-11	1.59E-15	1.50E-15	1.86E-19	2.06E-15
BR82	4.81E-06	6.39E-06	2.67E-09	2.95E-09	1.56E-10	9.27E-10
BR83	1.49E-08	2.06E-08	7.77E-12	8.28E-12	2.60E-13	1.85E-12

Table A.21 (Continued)

MODIFIED External Dose Factors for GENII Sv/yr per Bq/m3 (8-Aug-90)

	Air Submersion m3	Water Surface L	Soil Surface "m3"	STP WKR 0.15 m[a] m3	ASH TRANS 0.5 m[b] m3	SEWER MAINT 1.0m [c] m3
KR83M	5.16E-10	7.57E-10	2.90E-14	1.91E-14	2.29E-36	3.05E-13
BR84	3.30E-06	3.97E-06	1.71E-09	2.11E-09	1.55E-10	7.19E-10
KR85M	2.30E-07	3.15E-07	1.08E-10	1.09E-10	2.23E-12	2.84E-11
KR85	4.84E-09	6.69E-09	2.46E-12	2.61E-12	8.06E-14	6.05E-13
KR87	1.66E-06	2.08E-06	8.53E-10	1.01E-09	6.49E-11	3.23E-10
RB87	5.51E-11	7.81E-11	1.19E-14	1.14E-14	3.32E-17	9.57E-15
KR88	3.63E-06	4.43E-06	1.86E-09	2.27E-09	1.73E-10	8.24E-10
RB88	1.32E-06	1.61E-06	6.86E-10	8.30E-10	6.00E-11	2.86E-10
KR89	3.45E-06	4.34E-06	1.82E-09	2.17E-09	1.48E-10	7.35E-10
RB89	3.73E-06	4.53E-06	2.02E-09	2.38E-09	1.62E-10	8.04E-10
SR89	4.77E-09	6.55E-09	2.09E-12	2.15E-12	5.51E-14	6.61E-13
KR90	2.38E-06	3.04E-06	1.27E-09	1.45E-09	8.89E-11	4.84E-10
RB90M	6.06E-06	7.33E-06	3.12E-09	3.84E-09	2.83E-10	1.33E-09
RB90	3.61E-06	4.22E-06	1.83E-09	2.37E-09	1.88E-10	8.07E-10
SR90	3.51E-10	4.90E-10	1.06E-13	1.04E-13	1.01E-15	5.03E-14
Y 90	1.27E-08	1.74E-08	5.92E-12	6.16E-12	1.83E-13	1.80E-12
SR87M	5.34E-07	7.34E-07	2.90E-10	3.03E-10	8.92E-12	6.58E-11
RB86	1.59E-07	1.93E-07	9.13E-11	1.03E-10	5.84E-12	3.15E-11
SR85	9.62E-07	1.33E-06	5.14E-10	5.50E-10	1.78E-11	1.19E-10
SR91	1.17E-06	1.53E-06	6.67E-10	7.42E-10	3.89E-11	2.24E-10
Y 91M	1.10E-06	1.63E-06	6.29E-10	6.74E-10	2.86E-11	1.93E-10
Y 91	1.13E-08	1.45E-08	5.64E-12	6.19E-12	3.14E-13	2.04E-12
SR92	2.57E-06	3.45E-06	1.38E-09	1.61E-09	1.12E-10	6.28E-10
Y 92	5.09E-07	6.51E-07	2.83E-10	3.21E-10	1.88E-11	1.04E-10
Y 93	1.82E-07	2.33E-07	9.59E-11	1.10E-10	6.57E-12	3.60E-11
MO93	1.42E-09	2.08E-09	7.54E-14	4.77E-14	0.00E+00	8.57E-13
ZR93	4.83E-13	7.06E-13	3.97E-17	3.43E-17	3.06E-26	1.53E-16
NB93M	2.94E-10	4.31E-10	1.56E-14	9.89E-15	0.00E+00	1.78E-13
ZR95	1.31E-06	1.76E-06	7.23E-10	7.86E-10	3.84E-11	2.38E-10
NB95M	1.01E-07	1.39E-07	4.91E-11	4.94E-11	1.07E-12	1.29E-11
NB95	1.46E-06	1.82E-06	7.84E-10	8.59E-10	4.55E-11	2.69E-10
ZR97	3.41E-07	4.42E-07	1.84E-10	2.06E-10	1.14E-11	6.44E-11
NB97M	1.13E-06	1.68E-06	6.48E-10	6.94E-10	2.95E-11	1.99E-10
NB97	1.17E-06	1.72E-06	6.69E-10	7.18E-10	3.08E-11	2.06E-10
NB94	2.62E-06	3.54E-06	1.45E-09	1.57E-09	7.57E-11	4.73E-10
MO99	2.48E-07	3.49E-07	1.36E-10	1.46E-10	6.30E-12	4.27E-11
TC99M	1.63E-07	2.22E-07	6.81E-11	6.68E-11	8.33E-13	2.02E-11
TC99	6.61E-11	9.35E-11	1.50E-14	1.44E-14	4.94E-17	1.12E-14
TC101	6.97E-07	9.62E-07	3.78E-10	3.96E-10	1.20E-11	8.80E-11
RU103	9.40E-07	1.30E-06	5.05E-10	5.41E-10	1.80E-11	1.19E-10
PD103	1.12E-08	1.64E-08	9.37E-13	8.71E-13	3.34E-15	2.01E-12
RH103M	1.32E-09	1.93E-09	9.91E-14	8.96E-14	3.18E-36	2.69E-13
RU105	1.40E-06	2.00E-06	7.75E-10	8.29E-10	3.30E-11	2.25E-10
RH105	1.59E-07	2.19E-07	8.63E-11	9.02E-11	2.65E-12	1.96E-11
RU106	4.15E-07	5.77E-07	2.27E-10	2.45E-10	1.00E-11	6.44E-11

Table A.21 (Continued)

MODIFIED External Dose Factors for GENII Sv/yr per Bq/m3 (8-Aug-90)

	Air Submersion m3	Water Surface L	Soil Surface "m3"	STP WKR 0.15 m[a] m3	ASH TRANS 0.5 m[b] m3	SEWER MAINT 1.0m[c] m3
PD107	2.20E-14	3.23E-14	1.24E-18	8.44E-19	0.00E+00	1.21E-17
PD109	1.14E-08	1.64E-08	2.89E-12	2.87E-12	3.75E-14	1.79E-12
AG110M	4.91E-06	6.60E-06	2.71E-09	3.01E-09	1.63E-10	9.70E-10
AG111	5.07E-08	6.97E-08	2.70E-11	2.81E-11	8.05E-13	6.28E-12
CD109	1.04E-08	1.52E-08	7.81E-13	7.14E-13	0.00E+00	1.89E-12
CD113M	4.10E-10	5.72E-10	1.28E-13	1.26E-13	1.33E-15	5.79E-14
CD115M	4.47E-08	5.51E-08	2.47E-11	2.77E-11	1.55E-12	8.65E-12
CD115	3.78E-07	5.22E-07	2.01E-10	2.15E-10	6.89E-12	4.65E-11
IN115M	3.09E-07	4.25E-07	1.65E-10	1.73E-10	5.07E-12	3.83E-11
IN111	5.53E-07	7.57E-07	2.53E-10	2.53E-10	4.83E-12	6.87E-11
IN114M	2.07E-07	3.01E-07	1.10E-10	1.17E-10	4.58E-12	3.47E-11
SN113	1.93E-08	2.75E-08	4.63E-12	4.59E-12	8.23E-14	3.06E-12
IN113M	4.25E-07	5.85E-07	2.29E-10	2.40E-10	7.04E-12	5.25E-11
SN117M	1.72E-07	2.36E-07	6.85E-11	6.71E-11	8.28E-13	2.18E-11
SN119M	7.15E-09	1.05E-08	5.36E-13	4.88E-13	6.19E-20	1.37E-12
SN121M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SN121	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SN123	1.48E-08	1.85E-08	7.98E-12	8.88E-12	4.52E-13	2.72E-12
SN125	5.49E-07	6.72E-07	3.05E-10	3.49E-10	2.08E-11	1.10E-10
SB125	8.41E-07	1.20E-06	4.60E-10	4.92E-10	1.83E-11	1.26E-10
TE125M	2.39E-08	3.46E-08	2.62E-12	2.45E-12	2.65E-15	4.00E-12
SN126	4.62E-08	6.54E-08	1.55E-11	1.50E-11	1.28E-14	6.31E-12
SB126M	2.90E-06	4.20E-06	1.63E-09	1.75E-09	7.03E-11	4.69E-10
SB126	4.88E-06	7.02E-06	2.75E-09	2.96E-09	1.25E-10	8.23E-10
SB122	8.97E-07	1.32E-06	5.12E-10	5.51E-10	2.38E-11	1.59E-10
SB124	3.58E-06	4.73E-06	1.92E-09	2.19E-09	1.33E-10	7.28E-10
SB127	1.20E-06	1.68E-06	6.62E-10	7.12E-10	2.93E-11	1.93E-10
TE127M	7.52E-09	1.09E-08	8.46E-13	7.99E-13	3.47E-15	1.30E-12
TE127	1.13E-08	1.56E-08	5.89E-12	6.27E-12	1.96E-13	1.40E-12
SB129	2.59E-06	3.26E-06	1.42E-09	1.59E-09	8.84E-11	4.93E-10
TE129M	5.88E-08	8.69E-08	3.10E-11	3.31E-11	1.37E-12	1.03E-11
TE129	1.11E-07	1.52E-07	5.82E-11	6.25E-11	2.24E-12	1.53E-11
I 129	1.55E-08	2.25E-08	1.65E-12	1.55E-12	2.07E-19	2.57E-12
TE123M	1.63E-07	2.23E-07	6.52E-11	6.40E-11	7.86E-13	2.05E-11
TE131M	2.61E-06	3.29E-06	1.41E-09	1.56E-09	8.62E-11	4.93E-10
TE131	7.33E-07	9.73E-07	3.87E-10	4.20E-10	1.80E-11	1.18E-10
I 131	6.68E-07	9.31E-07	3.64E-10	3.82E-10	1.20E-11	8.79E-11
XE131M	1.39E-08	1.99E-08	2.51E-12	2.41E-12	1.83E-14	2.21E-12
TE132	3.75E-07	5.15E-07	1.76E-10	1.77E-10	3.77E-12	4.67E-11
I 132	4.16E-06	5.59E-06	2.30E-09	2.54E-09	1.29E-10	7.75E-10

Table A.21 (Continued)

MODIFIED External Dose Factors for GENII Sv/yr per Bq/m3 (8-Aug-90)

	Air Submersion m3	Water Surface L	Soil Surface "m3"	STP WKR 0.15 m[(a)] m3	ASH TRANS 0.5 m[(b)] m3	SEWER MAINT 1.0m [(c)] m3
TE133M	4.08E-06	5.14E-06	2.27E-09	2.56E-09	1.43E-10	7.91E-10
TE133	1.79E-06	2.33E-06	9.74E-10	1.08E-09	5.29E-11	3.05E-10
I 133	1.09E-06	1.48E-06	5.88E-10	6.34E-10	2.39E-11	1.51E-10
XE133M	5.17E-08	7.17E-08	2.11E-11	2.11E-11	4.37E-13	6.87E-12
XE133	4.28E-08	6.06E-08	1.31E-11	1.26E-11	1.09E-14	5.68E-12
TE134	1.58E-06	2.16E-06	8.45E-10	9.04E-10	3.69E-11	2.51E-10
I 134	4.67E-06	5.91E-06	2.52E-09	2.81E-09	1.55E-10	8.84E-10
XE122	1.96E-06	2.72E-06	1.05E-09	1.13E-09	4.04E-11	2.66E-10
XE125	3.56E-07	4.80E-07	1.65E-10	1.71E-10	5.00E-12	4.93E-11
I 125	2.78E-08	4.05E-08	2.84E-12	2.65E-12	1.44E-33	4.68E-12
CS134M	3.37E-08	4.66E-08	1.14E-11	1.11E-11	1.21E-13	4.46E-12
CS134	2.93E-06	3.99E-06	1.62E-09	1.77E-09	8.56E-11	5.34E-10
I 130	3.74E-06	5.33E-06	2.09E-09	2.25E-09	9.22E-11	6.00E-10
I 135	2.89E-06	3.56E-06	1.55E-09	1.79E-09	1.18E-10	6.16E-10
XE135M	7.86E-07	1.09E-06	4.19E-10	4.49E-10	1.45E-11	9.67E-11
XE135	4.02E-07	5.55E-07	1.99E-10	2.02E-10	4.85E-12	5.14E-11
CS135	2.36E-11	3.36E-11	4.32E-15	4.11E-15	3.49E-18	4.19E-15
XE137	4.34E-07	5.87E-07	2.29E-10	2.51E-10	1.04E-11	6.42E-11
CS137	9.84E-07	1.46E-06	5.63E-10	6.04E-10	2.56E-11	1.73E-10
XE138	2.21E-06	2.73E-06	1.13E-09	1.34E-09	9.04E-11	4.50E-10
CS138	4.49E-06	5.78E-06	2.38E-09	2.80E-09	1.91E-10	1.00E-09
CS139	5.98E-07	7.48E-07	3.15E-10	3.71E-10	2.57E-11	1.32E-10
BA139	5.45E-08	7.39E-08	2.42E-11	2.50E-11	7.58E-13	8.09E-12
BA140	3.45E-07	4.76E-07	1.82E-10	1.94E-10	6.11E-12	4.27E-11
LA140	4.05E-06	5.37E-06	2.17E-09	2.49E-09	1.58E-10	8.87E-10
CS136	3.72E-06	4.62E-06	2.05E-09	2.27E-09	1.21E-10	6.93E-10
BA141	1.55E-06	2.06E-06	8.26E-10	9.06E-10	4.34E-11	2.67E-10
LA141	9.77E-08	1.30E-07	5.10E-11	5.89E-11	3.94E-12	2.24E-11
CE141	9.44E-08	1.29E-07	3.80E-11	3.72E-11	4.53E-13	1.17E-11
BA142	1.58E-06	1.98E-06	8.65E-10	9.67E-10	5.32E-11	3.02E-10
LA142	5.20E-06	6.40E-06	2.69E-09	3.30E-09	2.45E-10	1.15E-09
CE143	4.05E-07	5.68E-07	2.04E-10	2.12E-10	6.90E-12	5.88E-11
PR143	1.34E-09	1.86E-09	5.01E-13	5.01E-13	8.21E-15	1.80E-13
CE144	2.42E-08	3.32E-08	9.24E-12	9.05E-12	1.01E-13	3.04E-12
PR144M	1.03E-08	1.46E-08	1.59E-12	1.51E-12	3.65E-21	1.51E-12
PR144	8.01E-08	1.06E-07	4.16E-11	4.77E-11	2.83E-12	1.58E-11
PR142	1.08E-07	1.47E-07	5.74E-11	6.64E-11	4.53E-12	2.59E-11
ND147	2.19E-07	3.04E-07	1.09E-10	1.14E-10	3.35E-12	2.79E-11
PM147	3.67E-11	5.19E-11	8.15E-15	7.83E-15	3.45E-17	6.29E-15
SM147	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PM148M	3.75E-06	5.35E-06	2.14E-09	2.31E-09	1.02E-10	6.57E-10
PM148	1.09E-06	1.48E-06	6.03E-10	6.85E-10	4.18E-11	2.40E-10
PM149	1.92E-08	2.65E-08	9.53E-12	9.79E-12	2.81E-13	2.66E-12
PM151	5.84E-07	8.07E-07	3.05E-10	3.21E-10	1.06E-11	8.14E-11
SM151	8.04E-12	1.18E-11	5.78E-16	4.93E-16	8.17E-24	2.51E-15

Table A.21 (Continued)

MODIFIED External Dose Factors for GENII Sv/yr per Bq/m3 (8-Aug-90)

	Air Submersion m3	Water Surface L	Soil Surface "m3"	STP WKR 0.15 m[a] m3	ASH TRANS 0.5 m[b] m3	SEWER MAINT 1.0m [c] m3
SM153	8.38E-08	1.16E-07	2.88E-11	2.83E-11	3.18E-13	1.06E-11
EU152M	5.53E-07	6.89E-07	3.01E-10	3.35E-10	1.82E-11	1.05E-10
EU152	2.07E-06	2.66E-06	1.12E-09	1.26E-09	7.24E-11	4.16E-10
EU154	2.12E-06	2.69E-06	1.16E-09	1.30E-09	7.36E-11	4.18E-10
EU155	7.19E-08	9.96E-08	2.68E-11	2.62E-11	2.02E-13	9.13E-12
EU156	2.48E-06	3.05E-06	1.33E-09	1.56E-09	1.04E-10	5.27E-10
GD153	1.22E-07	1.70E-07	3.82E-11	3.72E-11	2.35E-13	1.58E-11
GD159	6.62E-08	9.13E-08	3.32E-11	3.45E-11	9.67E-13	8.24E-12
TB160	1.84E-06	2.27E-06	1.01E-09	1.13E-09	6.35E-11	3.57E-10
TB161	2.01E-08	2.84E-08	4.43E-12	4.26E-12	1.12E-15	2.75E-12
DY165	4.08E-08	5.87E-08	2.06E-11	2.16E-11	7.40E-13	6.27E-12
HO166M	2.69E-06	3.62E-06	1.45E-09	1.56E-09	7.00E-11	4.57E-10
HO166	5.08E-08	6.85E-08	2.43E-11	2.75E-11	1.65E-12	1.07E-11
ER169	1.04E-10	1.47E-10	2.54E-14	2.44E-14	1.25E-16	1.82E-14
ER171	6.63E-07	9.08E-07	3.39E-10	3.52E-10	9.79E-12	8.38E-11
TA182	2.28E-06	2.78E-06	1.23E-09	1.39E-09	8.72E-11	4.74E-10
W 181	3.30E-08	4.61E-08	8.23E-12	7.92E-12	1.36E-15	4.47E-12
W 185	2.14E-10	3.00E-10	6.37E-14	6.20E-14	5.21E-16	3.16E-14
W 187	8.43E-07	1.20E-06	4.62E-10	4.95E-10	1.96E-11	1.34E-10
RE187	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
OS185	1.20E-06	1.74E-06	6.69E-10	7.18E-10	3.11E-11	2.11E-10
OS191	7.98E-08	1.10E-07	2.94E-11	2.87E-11	2.43E-13	1.04E-11
IR192	1.60E-06	2.22E-06	8.60E-10	9.06E-10	2.87E-11	2.08E-10
HG203	3.19E-07	4.37E-07	1.54E-10	1.55E-10	3.28E-12	3.94E-11
TH230	5.11E-10	7.22E-10	1.22E-13	1.15E-13	6.46E-16	1.51E-13
RA226	6.55E-09	8.94E-09	2.72E-12	2.67E-12	3.16E-14	8.15E-13
RN222	3.28E-06	4.23E-06	1.75E-09	2.00E-09	1.22E-10	6.63E-10
PB210	2.16E-09	3.08E-09	3.10E-13	2.89E-13	9.37E-24	5.31E-13
BI210	2.13E-09	2.95E-09	8.49E-13	8.57E-13	1.65E-14	2.85E-13
PO210	1.55E-11	1.93E-11	8.31E-15	9.11E-15	4.83E-16	2.85E-15
U 232	4.89E-10	6.96E-10	9.26E-14	8.56E-14	6.81E-16	1.85E-13
TH232	3.49E-10	4.97E-10	6.35E-14	5.86E-14	3.93E-16	1.30E-13
RA228	5.40E-14	7.92E-14	3.23E-18	2.38E-18	0.00E+00	2.60E-17
AC228	1.70E-06	2.13E-06	9.50E-10	1.07E-09	5.96E-11	3.32E-10
TH228	2.51E-09	3.49E-09	1.01E-12	9.98E-13	1.27E-14	4.12E-13
RA224	1.72E-08	2.36E-08	8.41E-12	8.51E-12	1.89E-13	2.12E-12
PB212	2.26E-07	3.10E-07	1.08E-10	1.09E-10	2.27E-12	2.81E-11
BI212	2.79E-06	3.48E-06	1.42E-09	1.73E-09	1.28E-10	6.12E-10
U 234	3.56E-10	5.11E-10	5.62E-14	5.07E-14	3.75E-16	1.53E-13
U 236	2.75E-10	3.99E-10	2.92E-14	2.43E-14	3.44E-19	1.38E-13
U 235	1.67E-07	2.28E-07	7.12E-11	7.01E-11	9.52E-13	2.09E-11
TH231	1.43E-08	2.02E-08	4.37E-12	4.22E-12	1.64E-14	2.66E-12
PA231	5.54E-08	7.63E-08	2.78E-11	2.88E-11	7.75E-13	7.34E-12
AC227	2.05E-10	2.82E-10	7.65E-14	7.45E-14	9.18E-16	3.76E-14
TH227	1.68E-07	2.30E-07	8.18E-11	8.32E-11	1.91E-12	2.11E-11

Table A.21 (Continued)

MODIFIED External Dose Factors for GENII Sv/yr per Bq/m3 (8-Aug-90)

	Air Submersion m3	Water Surface L	Soil Surface "m3"	STP WKR 0.15 m[(a)] m3	ASH TRANS 0.5 m[(b)] m3	SEWER MAINT 1.0m [(c)] m3
FR223	6.96E-08	9.55E-08	2.91E-11	2.98E-11	6.81E-13	9.40E-12
RA223	4.88E-07	6.65E-07	2.48E-10	2.58E-10	7.55E-12	6.40E-11
U 237	2.08E-07	2.85E-07	9.08E-11	9.04E-11	1.51E-12	2.65E-11
NP237	2.45E-08	3.44E-08	8.75E-12	8.50E-12	4.54E-14	3.81E-12
PA233	3.98E-07	5.47E-07	2.10E-10	2.18E-10	6.01E-12	4.95E-11
U 233	4.17E-10	5.77E-10	1.44E-13	1.39E-13	1.70E-15	9.19E-14
TH229	1.01E-07	1.39E-07	4.10E-11	4.02E-11	4.03E-13	1.34E-11
RA225	1.30E-08	1.83E-08	2.20E-12	2.11E-12	9.12E-17	1.86E-12
AC225	4.49E-07	6.15E-07	2.34E-10	2.52E-10	9.34E-12	6.43E-11
U 238	2.43E-10	3.53E-10	2.56E-14	2.14E-14	3.00E-19	1.22E-13
TH234	3.87E-08	5.01E-08	1.94E-11	2.10E-11	8.84E-13	6.57E-12
PA234	3.44E-06	4.45E-06	1.89E-09	2.09E-09	1.10E-10	6.49E-10
PU236	3.25E-10	4.74E-10	2.81E-14	2.21E-14	2.54E-19	1.75E-13
PU237	6.98E-08	9.55E-08	2.85E-11	2.79E-11	2.94E-13	9.17E-12
AM242M	1.03E-09	1.48E-09	1.74E-13	1.59E-13	1.54E-15	4.42E-13
AM242	2.03E-08	2.78E-08	8.18E-12	8.00E-12	8.55E-14	2.84E-12
CM242	2.67E-10	3.90E-10	1.76E-14	1.26E-14	1.72E-21	1.53E-13
PU242	2.18E-10	3.18E-10	1.55E-14	1.15E-14	1.97E-21	1.22E-13
NP238	9.55E-07	1.15E-06	5.52E-10	6.27E-10	3.58E-11	1.91E-10
PU238	2.72E-10	3.97E-10	1.87E-14	1.36E-14	2.10E-21	1.53E-13
CM244	2.35E-10	3.44E-10	1.51E-14	1.06E-14	1.26E-21	1.36E-13
PU244	1.82E-10	2.66E-10	1.10E-14	7.63E-15	6.53E-26	1.05E-13
U 240	6.45E-07	9.10E-07	3.62E-10	3.95E-10	1.89E-11	1.20E-10
PU240	2.62E-10	3.83E-10	1.86E-14	1.38E-14	2.33E-21	1.46E-13
CM245	9.58E-08	1.31E-07	3.95E-11	3.87E-11	4.31E-13	1.25E-11
PU241	6.50E-16	9.54E-16	3.46E-20	2.19E-20	0.00E+00	3.93E-19
AM241	1.87E-08	2.63E-08	4.24E-12	4.06E-12	2.15E-18	2.86E-12
CM246	2.09E-10	3.05E-10	1.24E-14	8.49E-15	6.38E-26	1.21E-13
CM247	7.37E-07	1.02E-06	3.92E-10	4.19E-10	1.34E-11	9.07E-11
CM243	1.92E-07	2.62E-07	8.75E-11	8.73E-11	1.55E-12	2.42E-11
PU243	2.40E-08	3.36E-08	9.85E-12	9.74E-12	8.74E-14	3.17E-12
AM243	4.72E-08	6.55E-08	1.56E-11	1.51E-11	9.23E-15	6.37E-12
NP239	2.62E-07	3.58E-07	1.20E-10	1.20E-10	2.19E-12	3.29E-11
PU239	1.82E-10	2.58E-10	4.14E-14	3.89E-14	4.45E-16	6.81E-14
CM248	1.69E-10	2.47E-10	1.13E-14	8.16E-15	1.17E-21	9.62E-14
CF252	1.71E-10	2.50E-10	1.26E-14	9.41E-15	8.31E-20	9.66E-14

(a) Dose factors for Scenario 2, STP Sludge Process Operator, are given under the heading of 0.15 m burial depth.
(b) Dose factors for Scenario 6, Incinerator Ash Disposal Truck Driver, are given under the heading of 0.5 m burial depth.
(c) Dose factors for Scenario 1, Sewer System Inspector, are given under the heading of 1.0 m burial depth.

References

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Appendix B

Results of Deterministic Dose Calculations

This appendix presents detailed results of the calculations described in Appendix A. Potential doses from the case histories described in Section 2 are given in Tables B.1 through B.5. Potential doses from theoretical discharges of radionuclides are presented for each scenario in Tables B.6 through B.16. Decay of the source term, from the time contaminants enter the sewer system until exposure occurs, is calculated and applied in a post-processing step and is shown in Tables B.6 through B.16 under the heading of "Fraction Remaining." Blank spaces indicate that either no data are available or the pathway did not apply to the given scenario.

A list of the tables and their page locations is provided so the reader can turn directly to the table(s) of interest.

Tables

Tables (Continued)

Table B.1 Potential doses from contamination at Tonawanda

Scenario	Radio-nuclide	Fraction remaining	Dose to individual, mrem Inhalation	Ingestion	External	Total
2 - STP Sludge Process Operator	AM241	1.00	4.8E+01		1.4E+00	4.9E+01
4 - Sludge Incinerator Operator	AM241	1.00	9.2E+01		1.5E-01	9.3E+01
5 - Sludge Incinerator Effluent	AM241	1.00	2.3E-01	3.9E-03		2.4E-01
6 - Incinerator Ash Truck Driver	AM241	1.00	4.2E+00		6.5E-07	4.2E+00
9 - Landfill Equipment Operator	AM241	1.00	8.4E-01		3.2E-02	8.7E-01
10 - Landfill Intrusion and Construction	AM241	1.00	6.6E-01		3.5E-02	6.9E-01
11 - Landfill Intrusion and Residence	AM241	1.00	5.3E-01	1.3E+00	1.2E-01	1.9E+00

Table B.2 Potential doses from contamination at Grand Island

Scenario	Radio-nuclide	Fraction Remaining	Dose to individual, mrem Inhalation	Ingestion	External	Total
2 - STP Sludge Process Operator[a]	AM241	1.00	3.2E+00		9.3E-02	3.3E+00
9 - Landfill Equipment Operator[b]	AM241	1.00	1.7E-01		6.4E-03	1.7E-01
10 - Landfill Intrusion and Construction[b]	AM241	1.00	1.3E-01		7.0E-03	1.4E-01
11 - Landfill Intrusion and Residence[b]	AM241	1.00	1.1E-01	2.6E-01	2.4E-02	3.8E-01

(a) Dose calculated as 1/15 of dose from Tonawanda.
(b) Dose calculated as 1/5 of dose from Tonawanda.

Table B.3 Potential doses from contamination at Royersford

Scenario	Radio-nuclide	Fraction remaining	Dose to Individual, mrem Inhalation	Ingestion	External	Subtotal
1 - STP Sewer Inspector	CO60	1.00	9.3E-07		1.4E-01	1.4E-01
	ZN65	1.00	3.4E-08		1.5E-02	1.5E-02
	CS137	1.00	5.7E-08		1.2E-02	1.2E-02
	CS134	1.00	1.5E-08		6.5E-03	6.5E-03
	MN54	1.00			2.5E-03	2.5E-03
	CO58	1.00			2.1E-03	2.1E-03
	SR89	1.00			1.2E-06	1.2E-06
	U 233	1.00	4.6E-07		1.0E-08	4.7E-07
	U 235	1.00	5.4E-08		2.9E-07	3.4E-07
	SR90	1.00	1.6E-08		1.3E-07	1.5E-07
	U 238	1.00	1.2E-07			1.2E-07
	PU239	1.00	4.3E-08			4.4E-08
	PU238	1.00	1.8E-08			1.8E-08
					TOTAL	1.8E-01
2 - STP Sludge Process Operator	CO60	1.00	5.4E-04		2.4E+01	2.4E+01
	ZN65	0.99	2.1E-05		2.6E+00	2.6E+00
	CS137	1.00	2.0E-05		1.5E+00	1.5E+00
	MN54	0.99	2.0E-06		8.5E-01	8.5E-01
	CO58	0.97	1.2E-06		3.4E-01	3.4E-01
	CS134	1.00	2.1E-06		2.9E-01	2.9E-01
	U 234	1.00	3.6E-03		4.5E-06	3.6E-03
	U 238	1.00	1.1E-03		6.3E-07	1.1E-03
	U 235	1.00	1.4E-04		2.5E-04	3.9E-04
	SR89	0.96	1.6E-07		2.0E-04	2.0E-04
	PU238	1.00	1.9E-04			1.9E-04
	PU239	1.00	1.4E-04			1.4E-04
	SR90	1.00	1.3E-05		2.2E-05	3.5E-05
					TOTAL	3.0E+01
4 - STP Sludge Incinerator	CO60	1.00	8.4E-03		1.6E+01	1.6E+01
	ZN65	0.99	3.0E-04		1.7E+00	1.7E+00
	CS137	1.00	3.0E-04		1.0E+00	1.0E+00
	MN54	0.99	2.8E-05		5.8E-01	5.8E-01
	CO58	0.97	1.7E-05		2.2E-01	2.2E-01
	CS134	1.00	3.2E-05		2.0E-01	2.0E-01
	U 234	1.00	5.6E-02		3.7E-06	5.6E-02
	U 238	1.00	1.5E-02		5.6E-07	1.5E-02
	PU238	1.00	2.8E-03			2.8E-03
	U 235	1.00	2.0E-03		1.9E-04	2.2E-03
	PU239	1.00	2.2E-03			2.2E-03
	SR90	1.00	2.0E-04		1.7E-05	2.1E-04
	SR89	0.96	2.5E-06		1.5E-04	1.5E-04
					TOTAL	2.0E+01

Table B.3 (Continued)

Scenario	Radio-nuclide	Fraction Remaining	Dose to Individual, mrem: Inhalation	Ingestion	External	Subtotal
6 - Incinerator Ash Truck Driver	CO60	1.00	3.6E-04		1.0E+01	1.0E+01
	ZN65	0.99	1.4E-05		1.1E+00	1.1E+00
	CS137	1.00	1.3E-05		4.1E-01	4.1E-01
	MN54	0.99	1.3E-06		3.0E-01	3.0E-01
	CO58	0.97	7.1E-07		1.2E-01	1.2E-01
	CS134	1.00	1.4E-06		9.5E-02	9.5E-02
	U 233	1.00	2.4E-03		1.0E-06	2.4E-03
	U 238	1.00	7.1E-04			7.1E-04
	PU238	1.00	1.3E-04			1.3E-04
	U 235	1.00	9.0E-05		2.3E-05	1.1E-04
	PU239	1.00	9.4E-05			9.4E-05
	SR89	0.95	1.0E-07		3.5E-05	3.5E-05
	SR90	1.00	8.5E-06		1.4E-06	9.9E-06
					TOTAL	1.2E+01
7 - Sludge Application to Agricultural Soil	CO60	1.00	1.6E-06	3.2E-03	1.5E-01	1.5E-01
	ZN65	0.97		3.8E-02	1.6E-02	5.4E-02
	SR90	1.00		1.9E-02	1.5E-07	1.9E-02
	CS137	1.00		8.7E-04	9.4E-03	1.0E-02
	MN54	0.97		6.6E-04	5.2E-03	5.9E-03
	CO58	0.89		2.7E-05	2.0E-03	2.1E-03
	CS134	0.99		8.3E-05	1.8E-03	1.9E-03
	SR89	0.85		4.3E-04	1.2E-06	4.3E-04
	U 233	1.00	1.1E-05	3.4E-06		1.4E-05
	U 238	1.00	2.8E-06	1.2E-06		4.0E-06
	U 235	1.00	3.6E-07	1.4E-07	1.7E-06	2.2E-06
	PU238	1.00	5.4E-07	1.4E-07		6.8E-07
	PU239	1.00	3.9E-07	1.0E-07		4.9E-07
					TOTAL	2.5E-01
8 - Sludge Application to non-Agricultural Soil	CO60	1.00	2.6E-06		9.9E-01	9.9E-01
	ZN65	0.97			1.1E-01	1.1E-01
	CS137	1.00			6.4E-02	6.4E-02
	MN54	0.97			3.4E-02	3.4E-02
	CO58	0.89			1.3E-02	1.3E-02
	CS134	0.99			1.2E-02	1.2E-02
	U 233	1.00	1.8E-05		6.0E-07	1.9E-05
	U 235	1.00	6.4E-07		1.2E-05	1.3E-05
	SR89	0.85			8.3E-06	8.3E-06
	U 238	1.00	5.0E-06			5.0E-06
	SR90	1.00			1.0E-06	1.1E-06
	PU238	1.00	8.9E-07			8.9E-07
	PU239	1.00	6.7E-07			6.7E-07
					TOTAL	1.2E+00

Table B.3 (Continued)

Scenario	Radio-nuclide	Fraction Remaining	Dose to Individual, mrem Inhalation	Ingestion	External	Subtotal
9 - Landfill Equipment Operator	CO60	1.00	7.2E-05		3.5E+00	3.5E+00
	ZN65	1.00	2.8E-06		3.9E-01	3.9E-01
	CS137	1.00	2.7E-06		2.2E-01	2.2E-01
	MN54	1.00	2.7E-07		1.3E-01	1.3E-01
	CO58	1.00	1.5E-07		5.4E-02	5.4E-02
	CS134	1.00	2.8E-07		4.4E-02	4.4E-02
	U 233	1.00	4.9E-04		2.1E-06	4.9E-04
	U 238	1.00	1.4E-04		1.3E-07	1.4E-04
	U 235	1.00	1.9E-05		4.2E-05	6.1E-05
	SR89	1.00	2.3E-08		3.5E-05	3.5E-05
	PU238	1.00	2.5E-05			2.5E-05
	PU239	1.00	1.9E-05		1.0E-08	1.9E-05
	SR90	1.00	1.7E-06		3.7E-06	5.4E-06
					TOTAL	4.3E+00
10 - Landfill Intrusion and Construction	CO60	1.00	3.2E-05		3.6E+00	3.6E+00
	CS137	1.00	2.0E-06		3.8E-01	3.8E-01
	CS134	1.00	4.6E-08		1.5E-02	1.5E-02
	ZN65	1.00	1.3E-08		4.3E-03	4.3E-03
	MN54	1.00			4.2E-03	4.2E-03
	U 233	1.00	4.2E-04		7.4E-06	4.3E-04
	SR90	1.00	1.4E-06		3.4E-04	3.4E-04
	U 238	1.00	1.2E-04		2.1E-04	3.3E-04
	U 235	1.00	1.5E-05		7.9E-05	9.4E-05
	PU238	1.00	2.0E-05			2.0E-05
	PU239	1.00	1.6E-05		1.8E-08	1.6E-05
	CO58	1.00				1.8E-09
	SR89	1.00				8.9E-16
					TOTAL	4.0E+00
11 - Landfill Intrusion and Residence	CO60	1.00	2.4E-05	1.7E-02	9.1E+00	9.1E+00
	CS137	1.00	1.6E-06	8.4E-03	9.0E-01	9.1E-01
	SR90	1.00	1.1E-06	1.8E-01	7.8E-04	1.8E-01
	CS134	1.00	3.4E-08	1.7E-04	3.8E-02	3.8E-02
	ZN65	1.00	1.0E-08	2.2E-03	1.1E-02	1.3E-02
	MN54	1.00		1.2E-04	1.0E-02	1.0E-02
	U 238	1.00	9.3E-05	1.6E-05	5.0E-04	6.1E-04
	U 233	1.00	3.4E-04	4.1E-05	1.6E-05	4.0E-04
	U 235	1.00	1.2E-05	2.2E-06	1.6E-04	1.7E-04
	PU238	1.00	1.6E-05	1.3E-06	2.3E-08	1.7E-05
	PU239	1.00	1.3E-05	1.1E-06	3.9E-08	1.4E-05
	CO58	1.00				4.3E-09
	SR89	1.00				7.6E-14
					TOTAL	10.3E+00

Table B.4 Potential doses from contamination at Oak Ridge

Scenario	Radio-nuclide	Fraction Remaining	Dose to Individual, mrem Inhalation	Ingestion	External	Subtotal
2 - STP Sludge Process Operator	C060	1.00	1.2E-03		5.5E+01	5.5E+01
7 - Sludge Application to Agricultural Soil	C060	1.00	4.8E-06	9.9E-03	4.6E-01	4.7E-01
8 - Sludge Application to Non-Agricultural Soil	C060	1.00	7.8E-06		3.0E+00	3.0E+00

Table B.5a Potential doses from contamination at Blue Plains[(a)]

Scenario	Radio-nuclide	Fraction Remaining	Dose to Individual, mrem Inhalation	Ingestion	External	Subtotal
1 - STP Sewer Inspector	CO57	1.00			3.0E-05	3.0E-05
	CR51	1.00			3.0E-05	3.0E-05
	I 131	1.00			2.1E-05	2.1E-05
	FE59	1.00			1.2E-05	1.2E-05
	I 125	1.00			4.2E-06	4.2E-06
	P 32	1.00			2.1E-06	2.1E-06
	CO58	1.00			3.8E-07	3.8E-07
	NA22	1.00			1.3E-07	1.3E-07
	SC46	1.00				3.8E-08
	C 14	1.00				3.5E-08
	U 238	1.00				1.4E-08
	RB86	1.00				9.1E-09
	IN111	1.00				5.8E-09
	SE75	1.00				3.9E-09
	H 3	1.00				2.6E-10
	CE141	1.00				2.4E-10
	CA45	1.00				8.8E-12
	P 33	1.00				4.2E-12
	TC99	1.00				3.3E-13
					TOTAL	1.0E-04
2 - STP Sludge Process Operator	CO57	0.99			1.9E-02	1.9E-02
	CR51	0.93			1.8E-02	1.8E-02
	I 131	0.77	2.4E-07		1.0E-02	1.0E-02
	FE59	0.95			4.8E-03	4.8E-03
	P 32	0.86	4.9E-07		8.6E-04	8.7E-04
	I 125	0.97	8.2E-07		3.0E-04	3.0E-04
	CO58	0.97			1.7E-04	1.7E-04
	NA22	1.00			6.2E-05	6.2E-05
	U 238	1.00	2.0E-05			2.0E-05
	SC46	0.98			1.5E-05	1.5E-05
	C 14	1.00	1.0E-06		3.6E-06	4.6E-06
	RB86	0.89			3.8E-06	3.8E-06
	SE75	0.98			2.1E-06	2.1E-06
	IN111	0.48			1.4E-06	1.4E-06
	H 3	1.00	3.3E-07			3.3E-07
	CE141	0.94			9.4E-08	9.4E-08
	CA45	0.99				1.7E-09
	P 33	0.92				6.4E-10
	TC99	1.00				7.0E-11
					TOTAL	5.3E-03

Table B.5a (Continued)

Scenario	Radio-nuclide	Fraction Remaining	Dose to Individual, mrem			
			Inhalation	Ingestion	External	Subtotal
3- STP Liquid Effluent	P 32	0.99		1.5E-01		1.5E-01
	C 14	1.00		2.4E-02		2.4E-02
	I 125	1.00		4.5E-04		4.5E-04
	I 131	0.98		9.8E-05	2.0E-07	9.8E-05
	FE59	1.00		4.3E-05	3.8E-07	4.4E-05
	H 3	1.00		1.3E-05		1.3E-05
	P 33	0.99		3.0E-06		3.0E-06
	CR51	0.99		1.9E-06	9.3E-07	2.9E-06
	U 238	1.00		9.9E-07		1.0E-06
	NA22	1.00		4.1E-07		4.3E-07
	SE75	1.00		3.0E-07		3.0E-07
	CO58	1.00		1.5E-07		1.7E-07
	CA45	1.00				9.4E-08
	CO57	1.00				5.4E-08
	IN111	0.93				8.6E-09
	SC46	1.00				6.4E-09
	CE141	0.99				3.3E-09
	TC99	1.00				3.2E-09
					TOTAL	1.7E-01
7 - Sludge Application to Agricultural Soil	P 32	0.56		1.2E-03	3.9E-06	1.2E-03
	I 125	0.87		4.5E-04	2.1E-06	4.5E-04
	CR51	0.74		5.3E-07	8.9E-05	8.9E-05
	I 131	0.36		2.6E-05	3.1E-05	5.7E-05
	FE59	0.83		1.6E-07	3.3E-05	3.3E-05
	NA22	0.99		1.5E-06	3.9E-07	1.9E-06
	CO58	0.89			9.8E-07	9.8E-07
	CA45	0.95		2.9E-07		2.9E-07
	TC99	1.00		2.1E-07		2.1E-07
	CO57	0.97				9.0E-08
	SC46	0.91				8.3E-08
	U 238	1.00				7.5E-08
	P 33	0.72				4.1E-08
	RB86	0.64				3.0E-08
	C 14	1.00				2.9E-08
	SE75	0.93				2.1E-08
	IN111	0.05				1.0E-09
	H 3	1.00				9.3E-10
	CE141	0.77				6.4E-10
					TOTAL	1.9E-04

Table B.5a (Continued)

Scenario	Radio-nuclide	Fraction Remaining	Dose to Individual, mrem Inhalation	Ingestion	External	Subtotal
8 - Sludge Application to non-Agricultural Soil	CR51	0.74			6.1E-04	6.1E-04
	I 131	0.36			2.0E-04	2.0E-04
	FE59	0.83			1.7E-04	1.7E-04
	P 32	0.56			2.5E-05	2.5E-05
	I 125	0.87			1.3E-05	1.3E-05
	CO58	0.89			6.5E-06	6.5E-06
	NA22	0.99			2.6E-06	2.6E-06
	CO57	0.97			5.7E-07	5.7E-07
	SC46	0.91			5.7E-07	5.7E-07
	C 14	1.00			1.8E-07	1.8E-07
	RB86	0.64			1.1E-07	1.1E-07
	U 238	1.00				8.8E-08
	SE75	0.93				8.7E-08
	IN111	0.05			7.2E-09	7.2E-09
	CE141	0.77				3.8E-09
	H 3	1.00				1.5E-09
	CA45	0.95				6.4E-11
	P 33	0.72				2.3E-11
	TC99	1.00				2.8E-12
					TOTAL	1.0E-03

(a) Date based on a 1984 unpublished study by the National Institute of Health.

Table B.5b Potential doses from contamination at Blue Plains[(a)]

Scenario	Radio-nuclide	Fraction Remaining	Dose to Individual, mrem: Inhalation	Ingestion	External	Subtotal
1 - STP Sewer Inspector	I 131	1.00			5.9E-05	5.9E-05
	CO57	1.00			3.9E-05	3.9E-05
	CR51	1.00			3.9E-05	3.9E-05
	NA22	1.00			2.7E-05	2.7E-05
	I 125	1.00			8.5E-06	8.5E-06
	P 32	1.00			5.3E-06	5.3E-06
	SE75	1.00			4.2E-06	4.2E-06
	U 238	1.00	2.7E-07			2.8E-07
	C 14	1.00				7.4E-08
	CO58	1.00				7.1E-08
	TH228	1.00				7.1E-09
	CL36	1.00				2.7E-10
	TC99	1.00				5.5E-12
	CA45	1.00				3.8E-12
	H 3	1.00				3.0E-14
					TOTAL	2.0E-04
2 - STP Sludge Process Operator	CO60	1.00	2.4E-06		1.0E-01	1.0E-01
	I 131	0.77	6.4E-07		2.6E-02	2.6E-02
	CO57	0.99			2.3E-02	2.3E-02
	CR51	0.93			2.1E-02	2.1E-02
	NA22	1.00			1.3E-02	1.3E-02
	CS137	1.00			3.1E-03	3.1E-03
	P 32	0.86	1.3E-06		2.1E-03	2.1E-03
	SE75	0.98			2.1E-03	2.1E-03
	I 125	0.97	1.6E-06		6.4E-04	6.4E-04
	PB212	0.01	2.1E-07		4.4E-04	4.4E-04
	CO58	0.97			3.1E-05	3.1E-05
	C 14	1.00	2.2E-06		7.7E-06	9.9E-06
	TH228	1.00	8.7E-06			8.8E-06
	U 238	1.00	4.0E-06			4.0E-06
	H 3	1.00	4.0E-07			4.0E-07
	CL36	1.00				9.3E-08
	TC99	1.00				1.2E-09
	CA45	0.99				6.7E-10
					TOTAL	1.9E-01

Table B.5b (Continued)

Scenario	Radio-nuclide	Fraction Remaining	Dose to Individual, mrem: Inhalation	Ingestion	External	Subtotal
3- STP Liquid Effluent	P 32	0.99		3.5E-01		3.5E-01
	C 14	1.00		5.3E-02		5.3E-02
	PB212	0.63		1.5E-03	3.2E-07	1.5E-03
	I 125	1.00		9.5E-04		9.5E-04
	CS137	1.00		8.5E-04	4.0E-07	8.5E-04
	SE75	1.00		3.2E-04	4.1E-07	3.3E-04
	I 131	0.98		2.7E-04	5.8E-07	2.7E-04
	NA22	1.00		8.4E-05	3.9E-06	8.7E-05
	CO60	1.00		5.1E-05	1.2E-05	6.3E-05
	H 3	1.00		1.5E-05		1.5E-05
	TH228	1.00		5.7E-06		5.7E-06
	CR51	0.99		2.5E-06	1.2E-06	3.6E-06
	U 238	1.00		2.0E-07		2.0E-07
	TC99	1.00				5.4E-08
	CA45	1.00				3.9E-08
	CO58	1.00				3.2E-08
	CO57	1.00				1.5E-08
					TOTAL	4.1E-01
7 - Sludge Application to Agricultural Soil	P 32	0.56		2.9E-03	9.5E-06	2.9E-03
	I 125	0.87		2.4E-03	1.1E-05	2.4E-03
	CO60	1.00		1.3E-05	6.4E-04	6.5E-04
	NA22	0.99		3.3E-04	8.2E-05	4.1E-04
	CR51	0.74		6.8E-07	1.1E-04	1.1E-04
	I 131	0.36		1.9E-05	2.2E-05	3.9E-05
	SE75	0.93		9.3E-06	1.4E-05	2.3E-05
	CS137	1.00		1.8E-06	1.9E-05	2.1E-05
	CL36	1.00		1.8E-05		1.8E-05
	TC99	1.00		3.6E-06		3.6E-06
	CO58	0.89			1.9E-07	2.0E-07
	CA45	0.95		1.2E-07		1.2E-07
	TH228	0.99				9.6E-08
	C 14	1.00				6.1E-08
	CO57	0.97				2.4E-08
	U 238	1.00				1.5E-08
	H 3	1.00				1.0E-09
	PB212	0.00		3.9E-14	2.5E-12	2.5E-12
					TOTAL	6.6E-03

Table B.5b (Continued)

Scenario	Radio-nuclide	Fraction Remaining	Dose to Individual, mrem: Inhalation	Ingestion	External	Subtotal
8 - Sludge Application to Non-Agricultural Soil	CO60	1.00			4.3E-03	4.3E-03
	CR51	0.74			7.4E-04	7.4E-04
	NA22	0.99			5.7E-04	5.7E-04
	I 131	0.36			5.3E-04	5.3E-04
	CS137	1.00			1.3E-04	1.3E-04
	SE75	0.93			9.3E-05	9.3E-05
	P 32	0.56			6.1E-05	6.1E-05
	I 125	0.87			2.9E-05	2.9E-05
	CO58	0.89			1.2E-06	1.2E-06
	C 14	1.00			3.7E-07	3.8E-07
	CO57	0.97			1.6E-07	1.6E-07
	TH228	0.99				4.5E-08
	U 238	1.00				1.8E-08
	CL36	1.00				4.3E-09
	H 3	1.00				1.8E-09
	TC99	1.00				4.5E-11
	CA45	0.95				2.6E-11
	PB212	0.00	7.7E-16		1.6E-11	1.6E-11
					TOTAL	6.4E-03

(a) Data based on a 1985 unpublished study by the National Institute of Health.

Table B.6 Deterministic doses calculated for theoretical discharges for Scenario No. 1 - STP Sewer System Inspector (with a decay time of 0.2 hours and a reporting cutoff of 1.0 E-10 rem/yr)[a]

Radio-	Fraction	---Annual dose to individual, rem/yr---			
nuclide	Remaining	Inhalation	Ingestion	External	TEDE
NA24	0.99			4.1E-03	4.1E-03
TC99M	0.98			8.0E-04	8.0E-04
MN54	1.00	2.5E-10		3.4E-04	3.4E-04
NB95	1.00	2.2E-10		3.4E-04	3.4E-04
LA140	1.00			3.3E-04	3.3E-04
SC46	1.00	3.7E-10		3.0E-04	3.0E-04
CO58	1.00	2.7E-10		2.6E-04	2.6E-04
PR144	0.62			2.5E-04	2.5E-04
ZR95	1.00	3.9E-10		2.0E-04	2.0E-04
NA22	1.00			1.7E-04	1.7E-04
CR51	1.00	2.1E-10		1.7E-04	1.7E-04
IN111	1.00			1.7E-04	1.7E-04
EU152	1.00	2.7E-09		1.7E-04	1.7E-04
FE59	1.00	1.6E-10		1.6E-04	1.6E-04
SB125	1.00	4.8E-10		1.6E-04	1.6E-04
CO60	1.00	7.8E-10		1.2E-04	1.2E-04
EU154	1.00	2.6E-09		1.2E-04	1.2E-04
IR192	1.00	3.7E-10		8.5E-05	8.5E-05
CO57	1.00	6.7E-10		5.7E-05	5.7E-05
ZN65	1.00	1.2E-10		5.0E-05	5.0E-05
SE75	1.00			2.2E-05	2.2E-05
CS134	1.00			2.0E-05	2.0E-05
CE141	1.00	3.4E-10		1.5E-05	1.5E-05
BA140	1.00			1.4E-05	1.4E-05
RB86	1.00			9.3E-06	9.3E-06
RU106	1.00	1.8E-09		8.1E-06	8.1E-06
CS137	1.00			7.0E-06	7.0E-06
NI59	1.00	3.4E-10		5.6E-06	5.6E-06
I 131	1.00			3.6E-06	3.6E-06
PB212	0.99	4.5E-10		2.4E-06	2.4E-06
FE55	1.00	1.7E-10		1.5E-06	1.5E-06
Y 90	1.00			5.3E-07	5.3E-07
I 125	1.00			4.0E-07	4.0E-07
CE144	1.00	1.4E-09		3.8E-07	3.8E-07
P 32	1.00			3.1E-07	3.1E-07
U 235	1.00	4.8E-08		2.6E-07	3.1E-07
SR89	1.00			2.2E-07	2.2E-07
BI210	1.00	2.6E-09		1.2E-07	1.2E-07
TH228	1.00	8.9E-08		3.5E-09	9.2E-08
CL36	1.00			8.6E-08	8.6E-08
U 234	1.00	5.2E-08		1.9E-09	5.4E-08
U 233	1.00	5.3E-08		1.2E-09	5.4E-08

Table B.6 (Continued)

Radio- nuclide	Fraction Remaining	---Annual dose to individual, rem/yr--- Inhalation	Ingestion	External	TEDE
U 238	1.00	4.6E-08		1.5E-09	4.7E-08
P 33	1.00			2.9E-08	2.9E-08
TC99	1.00	6.7E-10		2.8E-08	2.9E-08
SM151	1.00	7.8E-09		2.1E-08	2.9E-08
I 129	1.00			2.2E-08	2.2E-08
NP237	1.00	1.7E-08		3.2E-09	2.0E-08
AM241	1.00	1.2E-08		2.4E-09	1.4E-08
S 35	1.00	3.2E-10		1.2E-08	1.2E-08
PU240	1.00	7.9E-09		1.2E-10	8.0E-09
PU239	1.00	7.9E-09			8.0E-09
CA45	1.00	1.7E-10		7.6E-09	7.8E-09
PU238	1.00	7.5E-09		1.3E-10	7.6E-09
C 14	1.00			3.4E-09	3.5E-09
RA226	1.00	6.3E-10		2.1E-09	2.7E-09
CS135	1.00			1.7E-09	1.8E-09
SR90	1.00	1.3E-10		1.1E-09	1.2E-09
NI63	1.00	2.9E-10		7.9E-10	1.1E-09
PO210	1.00	4.5E-10			4.5E-10
PB210	1.00	1.8E-10		2.2E-10	4.0E-10
H 3	1.00	1.2E-10			1.2E-10

(a) Dose less than 1.0E-10 rem/year not shown

Table B.7 Deterministic doses calculated for theoretical discharges for Scenario No. 2 - STP Operator (with a decay time of 3 days and a reporting cutoff of 1.0 E-10 rem/yr)

Radio-Nuclide	Fraction Remaining	---Annual dose to individual, rem/yr --- Inhalation	Ingestion[a]	External	TEDE
CO60	1.00	8.1E-06		3.6E-01	3.6E-01
NA22	1.00	3.6E-07		3.1E-01	3.1E-01
SC46	0.98	1.1E-06		2.8E-01	2.8E-01
CS134	1.00	1.6E-06		2.4E-01	2.4E-01
EU154	1.00	1.1E-05		1.7E-01	1.7E-01
EU152	1.00	8.4E-06		1.7E-01	1.7E-01
RN222	0.58			1.6E-01	1.6E-01
FE59	0.95	4.7E-07		1.5E-01	1.5E-01
CO58	0.97	4.1E-07		1.4E-01	1.4E-01
IR192	0.97	1.0E-06		1.2E-01	1.2E-01
MN54	0.99	2.5E-07		1.1E-01	1.1E-01
NB95	0.94	2.1E-07		1.0E-01	1.0E-01
ZR95	0.97	6.0E-07		9.7E-02	9.7E-02
LA140	0.29	4.1E-08		9.6E-02	9.6E-02
ZN65	0.99	7.1E-07		9.2E-02	9.2E-02
CS137	1.00	1.1E-06		8.0E-02	8.0E-02
SB125	1.00	5.0E-07		6.6E-02	6.6E-02
I 131	0.77	9.6E-07		3.9E-02	3.9E-02
SE75	0.98	3.1E-07		3.8E-02	3.8E-02
RU106	0.99	1.9E-05		3.3E-02	3.3E-02
NP237	1.00	2.6E-02		1.1E-03	2.7E-02
NA24	0.04	1.7E-09		2.4E-02	2.4E-02
BA140	0.85	1.0E-07		2.2E-02	2.2E-02
AM241	1.00	1.8E-02		5.4E-04	1.9E-02
IN111	0.48	1.1E-08		1.6E-02	1.6E-02
U 235	1.00	5.0E-03		9.3E-03	1.4E-02
TH228	1.00	1.3E-02		1.3E-04	1.3E-02
RB86	0.89	2.1E-07		1.2E-02	1.2E-02
PU239	1.00	1.2E-02		5.2E-06	1.2E-02
PU240	1.00	1.2E-02		1.8E-06	1.2E-02
PU238	1.00	1.2E-02		1.8E-06	1.2E-02
CO57	0.99	3.4E-07		9.7E-03	9.7E-03
U 233	1.00	5.4E-03		1.9E-05	5.4E-03
U 234	1.00	5.4E-03		6.8E-06	5.4E-03
U 238	1.00	4.8E-03		2.9E-06	4.8E-03
CE141	0.94	3.2E-07		4.7E-03	4.7E-03
CR51	0.93	1.2E-08		4.5E-03	4.5E-03
CE144	0.99	1.5E-05		1.2E-03	1.2E-03
RA226	1.00	3.3E-04		3.6E-04	6.9E-04
PB210	1.00	5.4E-04		3.8E-05	5.8E-04
Y 90	0.46	1.7E-07		3.8E-04	3.8E-04
P 32	0.86	1.9E-07		3.4E-04	3.4E-04
PO210	0.99	3.4E-04		1.2E-06	3.4E-04
I 125	0.97	8.9E-07		3.4E-04	3.4E-04

Table B.7 (Continued)

Radio-Nuclide	Fraction Remaining	---Annual dose to individual, rem/yr --- Inhalation	Ingestion[a]	External	TEDE
SR89	0.96	2.2E-07		2.8E-04	2.8E-04
I 129	1.00	6.1E-06		2.1E-04	2.2E-04
PB212	0.01	6.2E-08		1.4E-04	1.4E-04
BI210	0.66	5.2E-06		7.3E-05	7.8E-05
CL36	1.00	7.6E-08		3.4E-05	3.4E-05
SR90	1.00	8.3E-06		1.4E-05	2.2E-05
NI59	1.00	3.3E-08		3.3E-06	3.3E-06
FE55	1.00	4.9E-08		2.7E-06	2.7E-06
TC99	1.00	3.8E-07		1.9E-06	2.3E-06
TC99M	0.00			2.2E-06	2.2E-06
CA45	0.99	2.7E-07		1.4E-06	1.7E-06
SM151	1.00	1.2E-06		6.6E-08	1.3E-06
P 33	0.92	2.1E-08		1.2E-06	1.2E-06
CS135	1.00	1.5E-07		5.5E-07	7.0E-07
S 35	0.98	9.7E-08		3.3E-07	4.3E-07
C 14	1.00	2.1E-08		7.1E-08	9.2E-08
NI63	1.00	8.1E-08		6.6E-09	8.8E-08
H 3	1.00	1.8E-09			1.8E-09

(a) Ingestion does not apply for this scenario.

Table B.8 Deterministic doses calculated for theoretical discharges for Scenario No. 3 - STP Liquid Effluent (with a decay time of 7 hours and a reporting cutoff of 1.0 E-10 rem/yr)

Radio- Nuclide	Fraction Remaining	---Annual dose to individual, rem/yr --- Inhalation	Ingestion	External	TEDE
NP237	1.00	2.4E-08	2.9E-02	2.5E-07	2.9E-02
PB210	1.00	6.8E-10	2.4E-02	1.5E-09	2.4E-02
CS134	1.00		2.3E-03	1.8E-06	2.3E-03
CS137	1.00		1.6E-03	7.3E-07	1.6E-03
P 32	0.99		1.2E-03	2.3E-10	1.2E-03
AM241	1.00	1.7E-08	9.6E-04	5.5E-09	9.6E-04
PO210	1.00	1.5E-10	3.9E-04		3.9E-04
CS135	1.00		2.2E-04		2.2E-04
PU239	1.00	1.2E-08	2.2E-04		2.2E-04
PU240	1.00	1.2E-08	2.2E-04		2.2E-04
PU238	1.00	1.1E-08	2.0E-04		2.0E-04
RA226	1.00	3.2E-10	1.8E-04	2.2E-06	1.8E-04
TH228	1.00	1.0E-08	1.8E-04	1.7E-06	1.8E-04
SE75	1.00		1.2E-04	1.6E-07	1.2E-04
P 33	0.99		1.2E-04		1.2E-04
ZN65	1.00		9.5E-05	5.0E-07	9.6E-05
I 129	1.00		9.5E-05	1.6E-09	9.5E-05
NA22	1.00		4.2E-05	2.0E-06	4.4E-05
C 14	1.00		4.1E-05		4.1E-05
RB86	0.99		3.9E-05	9.4E-09	3.9E-05
SR90	1.00		3.0E-05	7.6E-09	3.0E-05
PB212	0.63		2.9E-05	6.3E-09	2.9E-05
FE59	1.00		2.9E-05	2.5E-07	2.9E-05
CE144	1.00		2.5E-05	4.4E-08	2.5E-05
CO60	1.00		1.2E-05	2.9E-06	1.5E-05
I 125	1.00		1.1E-05	8.7E-10	1.1E-05
CL36	1.00		9.2E-06	2.4E-10	9.2E-06
EU154	1.00		7.8E-06	1.5E-06	9.2E-06
I 131	0.98		8.5E-06	1.7E-08	8.5E-06
RU106	1.00		8.0E-06	2.2E-07	8.2E-06
BI210	0.96		7.5E-06		7.5E-06
EU152	1.00		5.3E-06	1.4E-06	6.7E-06
U 238	1.00	4.5E-09	5.3E-06	2.6E-08	5.3E-06
BA140	0.98		5.0E-06	1.6E-07	5.2E-06
U 235	1.00	4.7E-09	4.6E-06	1.0E-07	4.7E-06
U 233	1.00	5.1E-09	4.4E-06	2.0E-10	4.4E-06
U 234	1.00	5.0E-09	4.3E-06		4.3E-06
MN54	1.00		2.6E-06	7.1E-07	3.3E-06
CE141	0.99		3.3E-06	6.8E-09	3.3E-06
CO58	1.00		2.6E-06	3.3E-07	2.9E-06
FE55	1.00		2.8E-06		2.8E-06
SC46	1.00		1.9E-06	8.4E-07	2.7E-06
TC99	1.00		2.3E-06		2.3E-06

Table B.8 (Continued)

Radio-nuclide	Fraction remaining	Inhalation	Ingestion	External	TEDE
		---Annual dose to individual, rem/yr ---			
ZR95	1.00		1.8E-06	4.8E-07	2.3E-06
SB125	1.00		1.6E-06	5.2E-07	2.1E-06
IN111	0.93		2.0E-06	5.8E-09	2.0E-06
CA45	1.00		2.0E-06		2.0E-06
S 35	1.00		1.5E-06		1.5E-06
SR89	1.00		1.4E-06	5.6E-10	1.4E-06
IR192	1.00		9.0E-07	3.2E-07	1.2E-06
CO57	1.00		8.2E-07	6.4E-08	8.9E-07
NB95	0.99		5.9E-07	1.5E-07	7.4E-07
Y 90	0.93		4.3E-07	1.3E-10	4.3E-07
SM151	1.00		3.1E-07		3.1E-07
LA140	0.89		2.7E-07	3.3E-08	3.0E-07
RN222	0.95		2.3E-07	4.6E-08	2.8E-07
NI63	1.00		1.7E-07		1.7E-07
NA24	0.72		5.3E-08	3.3E-08	8.7E-08
NI59	1.00		6.2E-08		6.2E-08
CR51	0.99		1.1E-08	5.2E-09	1.6E-08
H 3	1.00		1.4E-08		1.4E-08
TC99M	0.45			3.3E-10	4.1E-10

Table B.9 Deterministic doses calculated for theoretical discharges for Scenario No. 4 - Sludge Incinerator Operator (with a decay time of 3 days and a reporting cutoff of 1.0 E-10 rem/yr)

Radio-nuclide	Fraction remaining	---Annual dose to individual, rem/yr --- Inhalation	Ingestion[a]	External	TEDE
NP237	1.00	4.9E-01		1.1E-03	5.0E-01
AM241	1.00	3.4E-01		5.3E-04	3.4E-01
CO60	1.00	1.6E-04		3.0E-01	3.0E-01
NA22	1.00	7.0E-06		2.7E-01	2.7E-01
TH228	1.00	2.5E-01		1.3E-04	2.5E-01
SC46	0.98	2.1E-05		2.4E-01	2.4E-01
PU239	1.00	2.4E-01		5.2E-06	2.4E-01
PU240	1.00	2.4E-01		2.3E-06	2.4E-01
PU238	1.00	2.2E-01		2.4E-06	2.2E-01
CS134	1.00	3.2E-05		2.0E-01	2.0E-01
EU154	1.00	2.1E-04		1.5E-01	1.5E-01
EU152	1.00	1.6E-04		1.4E-01	1.4E-01
FE59	0.95	9.0E-06		1.3E-01	1.3E-01
RN222	0.58			1.3E-01	1.3E-01
CO58	0.97	8.0E-06		1.2E-01	1.2E-01
U 235	1.00	9.6E-02		9.0E-03	1.1E-01
U 233	1.00	1.1E-01		1.8E-05	1.1E-01
IR192	0.97	2.0E-05		1.1E-01	1.1E-01
U 234	1.00	1.0E-01		7.1E-06	1.0E-01
MN54	0.99	4.9E-06		9.8E-02	9.8E-02
NB95	0.94	4.1E-06		9.3E-02	9.3E-02
U 238	1.00	9.2E-02		3.2E-06	9.2E-02
ZR95	0.97	1.2E-05		8.8E-02	8.8E-02
LA140	0.29	7.8E-07		7.8E-02	7.8E-02
ZN65	0.99	1.4E-05		7.6E-02	7.6E-02
CS137	1.00	2.1E-05		7.1E-02	7.1E-02
SB125	1.00	9.6E-06		5.8E-02	5.8E-02
I 131	0.77	1.9E-05		3.6E-02	3.6E-02
SE75	0.98	6.0E-06		3.5E-02	3.5E-02
RU106	0.99	3.6E-04		2.9E-02	2.9E-02
BA140	0.85	2.0E-06		2.0E-02	2.0E-02
NA24	0.04	3.2E-08		1.8E-02	1.8E-02
IN111	0.48	2.1E-07		1.5E-02	1.5E-02
PB210	1.00	1.1E-02		3.9E-05	1.1E-02
RB86	0.89	4.1E-06		9.8E-03	9.8E-03
CO57	0.99	6.6E-06		9.3E-03	9.3E-03
RA226	1.00	6.3E-03		3.4E-04	6.7E-03
PO210	0.99	6.6E-03		9.9E-07	6.6E-03
CE141	0.94	6.3E-06		4.5E-03	4.5E-03
CR51	0.93	2.3E-07		4.1E-03	4.1E-03
CE144	0.99	2.9E-04		1.2E-03	1.5E-03

Table B.9 (Continued)

Radio-nuclide	Fraction remaining	---Annual dose to individual, rem/yr --- Inhalation	Ingestion[a]	External	TEDE
I 125	0.97	1.7E-05		3.5E-04	3.6E-04
Y 90	0.46	3.1E-06		3.4E-04	3.4E-04
I 129	1.00	1.2E-04		2.1E-04	3.3E-04
P 32	0.86	3.8E-06		3.1E-04	3.2E-04
SR89	0.96	4.0E-06		2.5E-04	2.6E-04
BI210	0.66	9.9E-05		7.3E-05	1.7E-04
SR90	1.00	1.6E-04		1.3E-05	1.7E-04
PB212	0.01	1.2E-06		1.3E-04	1.3E-04
CL36	1.00	1.5E-06		3.2E-05	3.4E-05
SM151	1.00	2.3E-05		7.3E-08	2.3E-05
TC99	1.00	7.1E-06		1.9E-06	9.0E-06
CA45	0.99	5.0E-06		1.3E-06	6.4E-06
NI59	1.00	6.3E-07		4.9E-06	5.6E-06
FE55	1.00	9.6E-07		4.1E-06	5.0E-06
CS135	1.00	2.9E-06		5.4E-07	3.4E-06
S 35	0.98	1.9E-06		3.3E-07	2.2E-06
TC99M	0.00			2.2E-06	2.2E-06
NI63	1.00	1.6E-06		7.1E-09	1.6E-06
P 33	0.92	4.1E-07		1.2E-06	1.6E-06
C 14	1.00	3.7E-07		7.2E-08	4.4E-07
H 3	1.00	3.2E-08			3.2E-08

(a) Ingestion does not apply for this scenario.

Table B.10 Deterministic doses calculated for theoretical discharges for Scenario No. 5 - Sludge Incinerator Effluent (with a decay time of 3 days and a reporting cutoff of 1.0 E-10 rem/yr)

Radio-nuclide	Fraction remaining	---Annual dose to individual, rem/yr --- Inhalation	Ingestion	External	TEDE
NP237	1.00	3.9E-04	9.9E-06	5.0E-09	4.0E-04
AM241	1.00	2.7E-04	4.5E-06	1.1E-10	2.7E-04
I 129	1.00	1.8E-06	2.2E-04	5.7E-09	2.2E-04
TH228	1.00	2.0E-04	1.4E-06	3.2E-08	2.0E-04
PU239	1.00	1.8E-04	4.6E-07		1.9E-04
PU240	1.00	1.8E-04	4.6E-07		1.9E-04
PU238	1.00	1.7E-04	4.2E-07		1.8E-04
U 233	1.00	8.2E-05	3.7E-08		8.2E-05
U 234	1.00	8.1E-05	3.7E-08		8.1E-05
U 235	1.00	7.5E-05	3.9E-08	1.9E-09	7.5E-05
U 238	1.00	7.2E-05	5.4E-08	5.2E-10	7.2E-05
I 125	0.97	2.6E-07	2.0E-05	2.8E-09	2.0E-05
PB210	1.00	8.2E-06	9.2E-06		1.7E-05
C 14	1.00	1.8E-07	8.6E-06		8.8E-06
I 131	0.77	2.9E-07	8.5E-06	4.6E-08	8.5E-06
PO210	0.99	5.2E-06	3.1E-06		8.2E-06
RA226	1.00	5.0E-06	1.6E-06	4.3E-08	6.6E-06
SE75	0.98	4.7E-09	1.1E-06	3.0E-09	1.1E-06
CS134	1.00	2.5E-08	6.5E-07	3.5E-08	7.1E-07
RU106	0.99	5.6E-07	8.3E-08	8.5E-09	6.5E-07
NA22	1.00	5.4E-09	5.1E-07	3.8E-08	5.5E-07
CS137	1.00	1.7E-08	4.9E-07	1.4E-08	5.2E-07
SR90	1.00	1.2E-07	3.2E-07	1.5E-10	4.4E-07
P 32	0.86	5.9E-08	2.9E-07		3.5E-07
ZN65	0.99	1.1E-08	3.0E-07	9.7E-09	3.2E-07
CE144	0.99	2.3E-07	3.2E-08	8.5E-10	2.6E-07
CL36	1.00	2.3E-09	2.5E-07		2.5E-07
CO60	1.00	1.2E-07	6.5E-08	5.6E-08	2.4E-07
EU154	1.00	1.7E-07	2.6E-08	2.9E-08	2.2E-07
S 35	0.98	2.9E-08	1.8E-07		2.1E-07
EU152	1.00	1.3E-07	1.8E-08	2.8E-08	1.7E-07
H 3	1.00	4.7E-08	1.1E-07		1.6E-07
BI210	0.66	7.9E-08	7.3E-08		1.5E-07
TC99	1.00	1.1E-08	9.0E-08		1.0E-07
CS135	1.00	2.3E-09	7.0E-08		7.2E-08
P 33	0.92	6.4E-09	4.8E-08		5.4E-08
SC46	0.98	1.7E-08	8.2E-09	1.6E-08	4.0E-08
IR192	0.97	1.6E-08	5.3E-09	6.1E-09	2.7E-08
SB125	1.00	7.5E-09	6.7E-09	1.0E-08	2.4E-08
ZR95	0.97	8.9E-09	3.7E-09	9.2E-09	2.2E-08

Table B.10 (Continued)

Radio- nuclide	Fraction remaining	---Annual dose to individual, rem/yr --- Inhalation	Ingestion	External	TEDE
MN54	0.99	3.9E-09	4.0E-09	1.4E-08	2.2E-08
FE59	0.95	7.1E-09	8.3E-09	4.8E-09	2.0E-08
CO58	0.97	6.2E-09	6.2E-09	6.6E-09	1.9E-08
SM151	1.00	1.8E-08	1.0E-09		1.9E-08
RB86	0.89	3.2E-09	1.3E-08	1.7E-10	1.7E-08
CA45	0.99	3.9E-09	9.9E-09		1.4E-08
SR89	0.96	3.2E-09	8.7E-09		1.2E-08
CO57	0.99	5.2E-09	3.7E-09	1.2E-09	9.9E-09
BA140	0.85	1.6E-09	5.0E-09	2.6E-09	9.4E-09
NB95	0.94	3.3E-09	1.4E-09	2.7E-09	7.4E-09
CE141	0.94	5.0E-09	1.6E-09	1.2E-10	6.7E-09
FE55	1.00	7.5E-10	3.6E-09		4.3E-09
Y 90	0.46	2.4E-09	2.0E-10		2.7E-09
NI63	1.00	1.2E-09	1.0E-09		2.3E-09
LA140	0.29	6.1E-10		2.5E-10	9.3E-10
PB212	0.01	9.2E-10			9.2E-10
NI59	1.00	4.9E-10	3.8E-10		8.8E-10
CR51	0.93	1.9E-10			3.6E-10
IN111	0.48	1.6E-10			2.5E-10
RN222	0.58			2.3E-10	2.3E-10
NA24	0.04				7.2E-11
TC99M	0.00				2.0E-14

Table B.11 Deterministic doses calculated for theoretical discharges for Scenario No. 6 - Incinerator Ash Disposal Truck Driver (with a decay time of 3.5 days and a reporting cutoff of 1.0 E-10 rem/yr)

Radio-nuclide	Fraction Remaining	---Annual dose to individual, rem/yr --- Inhalation	Ingestion[a]	External	TEDE
CO60	1.00	7.2E-06		2.1E-01	2.1E-01
SC46	0.98	1.0E-06		1.6E-01	1.6E-01
NA22	1.00	3.1E-07		1.4E-01	1.4E-01
CS134	1.00	1.5E-06		1.0E-01	1.0E-01
EU154	1.00	9.9E-06		8.7E-02	8.7E-02
EU152	1.00	7.5E-06		8.6E-02	8.6E-02
FE59	0.95	4.1E-07		8.5E-02	8.5E-02
RN222	0.58			8.1E-02	8.1E-02
CO58	0.97	3.6E-07		5.9E-02	5.9E-02
LA140	0.29	3.7E-08		5.5E-02	5.5E-02
MN54	0.99	2.2E-07		5.3E-02	5.3E-02
ZN65	0.99	6.2E-07		5.2E-02	5.2E-02
NB95	0.94	2.0E-07		5.1E-02	5.1E-02
ZR95	0.97	5.2E-07		4.4E-02	4.4E-02
IR192	0.97	9.3E-07		3.3E-02	3.3E-02
CS137	1.00	9.9E-07		3.0E-02	3.0E-02
NP237	1.00	2.2E-02		5.4E-05	2.3E-02
SB125	1.00	4.4E-07		2.2E-02	2.2E-02
NA24	0.04	1.5E-09		1.7E-02	1.7E-02
AM241	1.00	1.7E-02		2.5E-09	1.7E-02
RU106	0.99	1.6E-05		1.2E-02	1.2E-02
TH228	1.00	1.2E-02		1.5E-05	1.2E-02
PU239	1.00	1.1E-02		5.3E-07	1.1E-02
PU240	1.00	1.1E-02			1.1E-02
I 131	0.77	8.5E-07		1.1E-02	1.1E-02
PU238	1.00	1.0E-02			1.0E-02
SE75	0.98	2.8E-07		7.5E-03	7.5E-03
RB86	0.89	1.9E-07		6.1E-03	6.1E-03
BA140	0.85	9.3E-08		6.1E-03	6.1E-03
U 235	1.00	4.5E-03		1.1E-03	5.6E-03
U 233	1.00	4.8E-03		2.0E-06	4.8E-03
U 234	1.00	4.8E-03		4.4E-07	4.8E-03
U 238	1.00	4.2E-03		3.6E-10	4.2E-03
IN111	0.48	9.4E-09		2.7E-03	2.7E-03
CR51	0.93	1.1E-08		1.2E-03	1.2E-03
CO57	0.99	3.1E-07		1.1E-03	1.1E-03
CE141	0.94	3.0E-07		5.1E-04	5.1E-04
PB210	1.00	4.8E-04			4.8E-04
RA226	1.00	3.0E-04		3.7E-05	3.4E-04
PO210	0.99	3.1E-04		5.6E-07	3.1E-04

Table B.11 (Continued)

Radio-nuclide	Fraction remaining	---Annual dose to individual, rem/yr --- Inhalation	Ingestion[a]	External	TEDE
CE144	0.99	1.3E-05		1.2E-04	1.3E-04
Y 90	0.46	1.4E-07		1.0E-04	1.0E-04
P 32	0.86	1.8E-07		7.7E-05	7.8E-05
SR89	0.96	1.9E-07		6.2E-05	6.3E-05
PB212	0.01	5.5E-08		2.5E-05	2.5E-05
BI210	0.66	4.7E-06		1.3E-05	1.8E-05
SR90	1.00	7.3E-06		1.2E-06	8.5E-06
I 129	1.00	5.4E-06		2.5E-10	5.4E-06
CL36	1.00	6.7E-08		4.0E-06	4.1E-06
SM151	1.00	1.1E-06			1.1E-06
I 125	0.97	7.9E-07			7.9E-07
TC99	1.00	3.3E-07		5.8E-08	3.9E-07
CA45	0.99	2.4E-07		3.0E-08	2.7E-07
TC99M	0.00			2.5E-07	2.5E-07
CS135	1.00	1.3E-07		4.1E-09	1.4E-07
S 35	0.98	8.7E-08		6.4E-10	8.7E-08
NI63	1.00	7.2E-08			7.2E-08
FE55	1.00	4.3E-08			4.3E-08
P 33	0.92	1.9E-08		2.4E-08	4.3E-08
NI59	1.00	2.9E-08			2.9E-08
C 14	1.00	1.8E-08			1.8E-08
H 3	1.00	1.5E-09			1.5E-09

(a) Ingestion does not apply for this scenario.

Table B.12 Deterministic doses calculated for theoretical discharges for Scenario No. 7 - Sludge Agricultural Soil Application (with a decay time of 12 days and a reporting cutoff of 1.0 E-10 rem/yr)

Radio- nuclide	Fraction remaining	---Annual Dose to Individual, rem/yr --- Inhalation	Ingestion	External	TEDE
NP237	1.00	9.5E-05	3.3E-01	1.1E-05	3.3E-01
PB210	1.00	2.0E-06	3.5E-02	3.8E-07	3.5E-02
SR90	1.00	3.0E-08	1.7E-02	1.3E-07	1.7E-02
NA22	0.99	1.3E-09	1.1E-02	2.6E-03	1.3E-02
TC99	1.00	1.4E-09	9.8E-03	1.8E-08	9.8E-03
CL36	1.00	2.8E-10	8.5E-03	3.2E-07	8.5E-03
I 129	1.00	2.3E-08	7.8E-03	2.0E-06	7.8E-03
RA226	1.00	1.2E-06	6.1E-03	3.4E-06	6.1E-03
CO60	1.00	3.0E-08	6.2E-05	2.9E-03	3.0E-03
ZN65	0.97	2.6E-09	1.7E-03	7.2E-04	2.4E-03
SC46	0.91	3.9E-09	3.3E-06	2.2E-03	2.2E-03
CS134	0.99	6.1E-09	9.1E-05	2.0E-03	2.1E-03
EU152	1.00	3.1E-08	4.1E-06	1.4E-03	1.4E-03
EU154	1.00	4.1E-08	6.0E-06	1.4E-03	1.4E-03
FE59	0.83	1.5E-09	5.5E-06	1.1E-03	1.1E-03
MN54	0.97	9.3E-10	1.2E-04	9.4E-04	1.1E-03
CO58	0.89	1.4E-09	1.4E-05	1.1E-03	1.1E-03
PO210	0.94	1.2E-06	1.0E-03	9.4E-09	1.0E-03
IR192	0.89	3.6E-09	2.8E-05	9.8E-04	9.8E-04
ZR95	0.88	2.0E-09	8.8E-06	7.8E-04	7.9E-04
NB95	0.79	6.7E-10	3.9E-06	7.7E-04	7.7E-04
SR89	0.85	7.0E-10	7.6E-04	2.2E-06	7.6E-04
CS137	1.00	4.1E-09	6.5E-05	6.9E-04	7.6E-04
I 125	0.87	3.0E-09	6.8E-04	3.0E-06	6.8E-04
RU106	0.98	6.8E-08	3.7E-04	2.7E-04	6.5E-04
P 32	0.56	4.8E-10	6.1E-04	2.0E-06	6.1E-04
SE75	0.93	1.1E-09	2.4E-04	3.4E-04	5.8E-04
SB125	0.99	1.8E-09	1.2E-05	5.7E-04	5.8E-04
AM241	1.00	6.6E-05	4.8E-04	5.2E-06	5.5E-04
BI210	0.19	5.7E-09	4.6E-04	1.9E-07	4.6E-04
CA45	0.95	9.3E-10	3.9E-04	1.2E-08	3.9E-04
I 131	0.36	1.6E-09	1.4E-04	1.6E-04	3.0E-04
RN222	0.11		2.0E-09	2.5E-04	2.5E-04
TH228	0.99	4.8E-05	1.4E-04	1.2E-06	1.9E-04
RB86	0.64	5.7E-10	6.4E-05	7.1E-05	1.4E-04
BA140	0.52	2.4E-10	1.1E-05	1.1E-04	1.3E-04
U 235	1.00	1.9E-05	7.0E-06	8.8E-05	1.1E-04
P 33	0.72		1.1E-04	8.6E-09	1.1E-04
CO57	0.97	1.3E-09	4.3E-06	8.9E-05	9.4E-05
CE144	0.97	5.4E-08	5.0E-05	1.1E-05	6.0E-05

Table B.12 (Continued)

Radio-nuclide	Fraction remaining	---Annual Dose to Individual, rem/yr --- Inhalation	Ingestion	External	TEDE
PU239	1.00	4.5E-05	1.2E-05	5.1E-08	5.7E-05
PU240	1.00	4.5E-05	1.2E-05	2.3E-08	5.7E-05
PU238	1.00	4.3E-05	1.1E-05	2.3E-08	5.4E-05
S 35	0.91	3.4E-10	4.4E-05	3.0E-09	4.4E-05
CE141	0.77	1.0E-09	4.1E-06	3.6E-05	4.0E-05
CR51	0.74		1.9E-07	3.2E-05	3.2E-05
U 234	1.00	2.0E-05	6.6E-06	6.9E-08	2.7E-05
U 233	1.00	2.0E-05	6.7E-06	1.8E-07	2.7E-05
U 238	1.00	1.8E-05	7.2E-06	3.2E-08	2.5E-05
LA140	0.01		8.5E-10	1.9E-05	1.9E-05
IN111	0.05		2.3E-09	1.6E-05	1.6E-05
CS135	1.00	5.5E-10	9.1E-06	5.3E-09	9.1E-06
NI63	1.00	3.0E-10	3.6E-06		3.6E-06
NI59	1.00	1.2E-10	1.3E-06	4.8E-08	1.4E-06
FE55	0.99	1.8E-10	7.4E-07	4.0E-08	7.8E-07
Y 90	0.04		1.5E-08	3.2E-07	3.4E-07
SM151	1.00	4.5E-09	2.5E-07	7.1E-10	2.5E-07
NA24	0.00			8.3E-09	8.3E-09
C 14	1.00	2.9E-10		2.8E-09	3.0E-09

Table B.13 Deterministic doses calculated for theoretical discharges for Scenario No. 8 - Sludge Non-Agricultural Soil Application (with a decay time of 12 days and a reporting cutoff of 1.0 E-10 rem/yr)

Radio-	Fraction	---Annual dose to individual, rem/yr ---			
nuclide	Remaining	Inhalation	Ingestion[a]	External	TEDE
CO60	1.00	5.0E-08		1.9E-02	1.9E-02
NA22	0.99	2.2E-09		1.7E-02	1.7E-02
SC46	0.91	6.4E-09		1.4E-02	1.4E-02
CS134	0.99	9.9E-09		1.3E-02	1.3E-02
EU154	1.00	6.8E-08		9.4E-03	9.4E-03
EU152	1.00	5.2E-08		9.1E-03	9.1E-03
FE59	0.83	2.5E-09		7.3E-03	7.3E-03
CO58	0.89	2.3E-09		6.8E-03	6.8E-03
IR192	0.89	6.0E-09		6.3E-03	6.3E-03
MN54	0.97	1.6E-09		6.2E-03	6.2E-03
ZR95	0.88	3.3E-09		5.2E-03	5.2E-03
NB95	0.79	1.1E-09		5.0E-03	5.0E-03
ZN65	0.97	4.3E-09		4.8E-03	4.8E-03
CS137	1.00	6.8E-09		4.6E-03	4.6E-03
SB125	0.99	3.1E-09		3.7E-03	3.7E-03
SE75	0.93	1.9E-09		2.2E-03	2.2E-03
RU106	0.98	1.2E-07		1.8E-03	1.8E-03
RN222	0.11			1.6E-03	1.6E-03
I 131	0.36	2.7E-09		1.1E-03	1.1E-03
BA140	0.52	4.0E-10		7.8E-04	7.8E-04
U 235	1.00	3.1E-05		5.8E-04	6.1E-04
CO57	0.97	2.0E-09		5.9E-04	5.9E-04
RB86	0.64	9.6E-10		4.7E-04	4.7E-04
CE141	0.77	1.7E-09		2.4E-04	2.4E-04
NP237	1.00	1.6E-04		7.1E-05	2.3E-04
CR51	0.74			2.1E-04	2.1E-04
AM241	1.00	1.1E-04		3.5E-05	1.4E-04
LA140	0.01			1.3E-04	1.3E-04
IN111	0.05			1.1E-04	1.1E-04
TH228	0.99	8.0E-05		8.1E-06	8.8E-05
PU239	1.00	7.6E-05		3.4E-07	7.6E-05
PU240	1.00	7.6E-05		1.5E-07	7.6E-05
CE144	0.97	9.0E-08		7.3E-05	7.3E-05
PU238	1.00	7.2E-05		1.5E-07	7.2E-05
U 233	1.00	3.4E-05		1.2E-06	3.5E-05
U 234	1.00	3.3E-05		4.6E-07	3.4E-05
U 238	1.00	2.9E-05		2.1E-07	3.0E-05
RA226	1.00	2.0E-06		2.2E-05	2.4E-05
I 125	0.87	4.9E-09		2.0E-05	2.0E-05
SR89	0.85	1.2E-09		1.4E-05	1.4E-05

Table B.13 (Continued)

Radio- nuclide	Fraction remaining	---Annual dose to individual, rem/yr --- Inhalation	Ingestion[a]	External	TEDE
P 32	0.56	7.8E-10		1.3E-05	1.3E-05
I 129	1.00	3.8E-08		1.3E-05	1.3E-05
PB210	1.00	3.4E-06		2.5E-06	5.9E-06
Y 90	0.04			2.1E-06	2.1E-06
CL36	1.00	4.7E-10		2.1E-06	2.1E-06
PO210	0.94	2.1E-06		6.4E-08	2.1E-06
BI210	0.19	9.3E-09		1.3E-06	1.3E-06
SR90	1.00	5.1E-08		8.6E-07	9.1E-07
NI59	1.00	2.0E-10		3.2E-07	3.2E-07
FE55	0.99	3.1E-10		2.6E-07	2.6E-07
TC99	1.00	2.3E-09		1.2E-07	1.2E-07
CA45	0.95	1.5E-09		8.3E-08	8.5E-08
P 33	0.72	1.0E-10		5.9E-08	5.9E-08
NA24	0.00			5.5E-08	5.5E-08
CS135	1.00	9.2E-10		3.5E-08	3.6E-08
S 35	0.91	5.6E-10		2.0E-08	2.0E-08
C 14	1.00	4.9E-10		1.8E-08	1.9E-08
SM151	1.00	7.5E-09		4.7E-09	1.2E-08
NI63	1.00	5.0E-10		4.6E-10	9.6E-10
H 3	1.00	1.1E-10			1.1E-10

(a) Ingestion does not apply for this scenario.

Table B.14 Deterministic doses calculated for theoretical discharges for Scenario No. 9 - Landfill Operator (with a decay time of 3.5 days and a reporting cutoff of 1.0 E-10 rem/yr)

Radio- nuclide	Fraction remaining	---Annual Dose to individual, rem/yr --- Inhalation	Ingestion[a]	External	TEDE
CO60	1.00	1.4E-06		6.4E-02	6.4E-02
NA22	1.00	6.2E-08		5.7E-02	5.7E-02
SC46	0.97	1.9E-07		5.1E-02	5.1E-02
CS134	1.00	2.9E-07		4.4E-02	4.4E-02
EU154	1.00	1.9E-06		3.1E-02	3.1E-02
EU152	1.00	1.4E-06		3.0E-02	3.0E-02
FE59	0.95	8.0E-08		2.7E-02	2.7E-02
CO58	0.97	7.0E-08		2.5E-02	2.5E-02
RN222	0.53			2.5E-02	2.5E-02
IR192	0.97	1.7E-07		2.2E-02	2.2E-02
MN54	0.99	4.4E-08		2.1E-02	2.1E-02
NB95	0.93	3.6E-08		2.0E-02	2.0E-02
ZR95	0.96	9.6E-08		1.9E-02	1.9E-02
ZN65	0.99	1.2E-07		1.7E-02	1.7E-02
CS137	1.00	1.9E-07		1.5E-02	1.5E-02
LA140	0.24	5.7E-09		1.4E-02	1.4E-02
SB125	1.00	8.5E-08		1.2E-02	1.2E-02
SE75	0.98	5.3E-08		7.7E-03	7.7E-03
I 131	0.74	1.6E-07		7.3E-03	7.3E-03
RU106	0.99	3.2E-06		6.2E-03	6.2E-03
NP237	1.00	4.4E-03		2.4E-04	4.6E-03
BA140	0.83	1.7E-08		4.1E-03	4.1E-03
AM241	1.00	3.0E-03		1.2E-04	3.2E-03
IN111	0.42	1.6E-09		2.9E-03	2.9E-03
U 235	1.00	8.5E-04		1.9E-03	2.8E-03
TH228	1.00	2.2E-03		2.7E-05	2.3E-03
NA24	0.02	1.6E-10		2.3E-03	2.3E-03
RB86	0.88	3.6E-08		2.2E-03	2.2E-03
PU239	1.00	2.1E-03		1.1E-06	2.1E-03
PU240	1.00	2.1E-03		5.0E-07	2.1E-03
PU238	1.00	2.0E-03		5.1E-07	2.0E-03
CO57	0.99	5.8E-08		2.0E-03	2.0E-03
U 233	1.00	9.3E-04		3.9E-06	9.3E-04
CE141	0.93	5.6E-08		9.3E-04	9.3E-04
U 234	1.00	9.2E-04		1.5E-06	9.2E-04
CR51	0.92	2.0E-09		8.6E-04	8.6E-04
U 238	1.00	8.1E-04		6.9E-07	8.1E-04
CE144	0.99	2.6E-06		2.5E-04	2.5E-04
RA226	1.00	5.6E-05		7.4E-05	1.3E-04
PB210	1.00	9.3E-05		8.4E-06	1.0E-04
I 125	0.96	1.5E-07		7.4E-05	7.4E-05
P 32	0.84	3.3E-08		6.6E-05	6.6E-05

Table B.14 (Continued)

Radio-nuclide	Fraction remaining	---Annual dose to individual, rem/yr --- Inhalation	Ingestion[a]	External	TEDE
Y 90	0.40	2.4E-08		6.4E-05	6.4E-05
PO210	0.98	5.9E-05		2.3E-07	5.9E-05
SR89	0.95	3.6E-08		5.4E-05	5.4E-05
I 129	1.00	1.0E-06		4.5E-05	4.6E-05
BI210	0.62	8.6E-07		1.4E-05	1.5E-05
PB212	0.00	4.6E-09		1.2E-05	1.2E-05
CL36	1.00	1.3E-08		7.0E-06	7.0E-06
SR90	1.00	1.4E-06		2.9E-06	4.3E-06
NI59	1.00	5.6E-09		1.1E-06	1.1E-06
FE55	1.00	8.5E-09		8.8E-07	8.8E-07
TC99	1.00	6.3E-08		4.1E-07	4.7E-07
CA45	0.99	4.4E-08		2.9E-07	3.3E-07
P 33	0.91	3.5E-09		2.5E-07	2.5E-07
SM151	1.00	2.1E-07		1.6E-08	2.2E-07
CS135	1.00	2.6E-08		1.2E-07	1.4E-07
TC99M	0.00			1.1E-07	1.1E-07
S 35	0.97	1.7E-08		7.0E-08	8.7E-08
C 14	1.00	3.3E-09		1.5E-08	1.9E-08
NI63	1.00	1.4E-08		1.5E-09	1.5E-08
H 3	1.00	3.0E-10			3.0E-10

(a) Ingestion does not apply for this scenario.

Table B.15 Deterministic doses calculated for theoretical discharges for Scenario No. 10 - Landfill Intrusion and Construction (with a prior decay time of 5 years and a reporting cutoff of 1.0 E-10 rem/yr)

Radio-nuclide	---Annual Dose to individual, rem/yr --- Inhalation	Ingestion[a]	External	TEDE
RA226	6.7E-05		7.1E-02	7.1E-02
CO60	6.0E-07		4.7E-02	4.7E-02
EU152	9.8E-07		3.4E-02	3.4E-02
EU154	1.1E-06		3.0E-02	3.0E-02
CS137	1.5E-07		1.8E-02	1.8E-02
NA22	8.6E-09		1.4E-02	1.4E-02
NP237	3.8E-03		7.7E-03	1.2E-02
CS134	4.6E-08		1.1E-02	1.1E-02
TH228	3.2E-04		1.1E-02	1.1E-02
SB125	2.3E-08		4.6E-03	4.6E-03
U 235	7.4E-04		2.5E-03	3.2E-03
AM241	2.6E-03		1.4E-04	2.8E-03
PU240	1.8E-03		6.0E-07	1.8E-03
PU239	1.8E-03		1.3E-06	1.8E-03
PU238	1.7E-03		5.5E-07	1.7E-03
U 238	7.1E-04		8.4E-04	1.6E-03
U 233	8.1E-04		9.3E-06	8.2E-04
U 234	8.0E-04		1.8E-06	8.0E-04
MN54	7.0E-10		5.1E-04	5.1E-04
RU106	8.9E-08		2.7E-04	2.7E-04
SR90	1.1E-06		1.8E-04	1.8E-04
PB210	1.2E-04		3.3E-05	1.5E-04
ZN65	5.8E-10		1.3E-04	1.3E-04
I 129	4.1E-07		2.3E-05	2.4E-05
CO57	4.7E-10		2.3E-05	2.3E-05
CE144	2.6E-08		2.3E-05	2.3E-05
CL36	5.1E-09		3.9E-06	3.9E-06
NI59	4.9E-09		1.3E-06	1.3E-06
FE55	2.0E-09		2.8E-07	2.8E-07
SE75			2.5E-07	2.5E-07
TC99	2.5E-08		2.1E-07	2.4E-07
SM151	1.7E-07		1.7E-08	1.9E-07
CS135	2.2E-08		1.4E-07	1.6E-07
RN222	5.4E-08		1.5E-08	7.0E-08
SC46			2.1E-08	2.1E-08
NI63	1.2E-08		1.7E-09	1.3E-08
C 14	1.3E-09		7.7E-09	9.0E-09
PO210	5.5E-09		5.6E-09	
IR192			1.1E-09	1.1E-09
CO58			6.2E-10	6.2E-10
ZR95			2.4E-10	2.4E-10

Table B.15 (Continued)

Radio-nuclide	---Annual Dose to individual, rem/yr --- Inhalation	Ingestion[a]	External	TEDE
BI210	2.1E-10		2.1E-10	
CA45			1.5E-10	1.6E-10
H 3				9.3E-11

(a) Ingestion does not apply for this scenario.

Table B.16 Deterministic doses calculated for theoretical discharges for Scenario 11 - Landfill Intrusion and Residence (with a prior decay time of 5 years and a reporting cutoff of 1.0 E-10 rem/yr)

Radio-nuclide	---Annual dose to individual, rem/yr --- Inhalation	Ingestion	External	TEDE
NP237	3.0E-03	3.4E+00	2.6E-02	3.4E+00
RA226	5.4E-05	1.2E-01	2.6E-01	3.8E-01
PB210	9.2E-05	3.4E-01	1.1E-04	3.4E-01
CO60	4.8E-07	3.2E-04	1.7E-01	1.7E-01
SR90	8.9E-07	1.5E-01	6.4E-04	1.5E-01
EU152	7.7E-07	3.3E-05	1.2E-01	1.2E-01
EU154	8.7E-07	4.1E-05	1.1E-01	1.1E-01
NA22	6.9E-09	1.7E-02	5.5E-02	7.2E-02
CS137	1.2E-07	5.9E-04	6.5E-02	6.6E-02
TC99	2.0E-08	4.6E-02	7.2E-07	4.6E-02
TH228	2.5E-04	4.2E-04	4.2E-02	4.2E-02
CS134	3.7E-08	1.8E-04	4.0E-02	4.0E-02
CL36	4.1E-09	3.9E-02	1.3E-05	3.9E-02
I 129	3.3E-07	3.7E-02	7.7E-05	3.7E-02
SB125	1.8E-08	6.0E-04	1.7E-02	1.8E-02
U 235	5.9E-04	1.1E-04	8.1E-03	8.8E-03
AM241	2.1E-03	5.0E-03	4.4E-04	7.5E-03
U 238	5.7E-04	9.9E-05	3.0E-03	3.6E-03
MN54	5.3E-10	2.2E-05	1.9E-03	1.9E-03
PU240	1.5E-03	1.2E-04	1.9E-06	1.6E-03
PU239	1.5E-03	1.3E-04	4.4E-06	1.6E-03
PU238	1.3E-03	1.1E-04	1.9E-06	1.4E-03
RU106	7.0E-08	1.3E-04	9.8E-04	1.1E-03
U 233	6.5E-04	8.0E-05	3.2E-05	7.6E-04
U 234	6.4E-04	6.9E-05	5.9E-06	7.1E-04
ZN65	4.6E-10	1.0E-04	4.9E-04	5.9E-04
RN222	4.3E-08	1.6E-04	5.2E-08	1.6E-04
CS135	1.8E-08	9.3E-05	4.5E-07	9.4E-05
CE144	2.1E-08	6.2E-06	8.3E-05	8.9E-05
CO57	3.8E-10	4.3E-07	7.4E-05	7.4E-05
NI63	9.2E-09	3.6E-05	5.7E-09	3.6E-05
NI59	3.9E-09	1.3E-05	4.1E-06	1.8E-05
FE55	1.6E-09	2.1E-06	9.6E-07	3.1E-06
SM151	1.4E-07	2.5E-06	5.8E-08	2.7E-06
CA45		1.9E-06	4.8E-10	1.9E-06
PO210	4.4E-09	1.2E-06	1.2E-10	1.2E-06

Table B.16 (Continued)

Radio- nuclide	---Annual dose to individual, rem/yr --- Inhalation	Ingestion	External	TEDE
SE75		6.8E-08	8.7E-07	9.4E-07
SC46			7.9E-08	7.9E-08
BI210	1.6E-10	4.6E-08		4.6E-08
C 14	1.1E-09		2.6E-08	2.8E-08
IR192			4.1E-09	4.1E-09
CO58			2.2E-09	2.2E-09
ZR95			8.8E-10	8.8E-10
S 35			2.5E-10	2.5E-10
TC99M			1.5E-10	1.5E-10

Appendix C

Results of Stochastic Uncertainty and Sensitivity Analysis

This appendix contains detailed information on the results of the stochastic uncertainty and sensitivity analysis conducted for the reference exposure scenarios. Tables C.1 through C.11 present the input parameter distributions for each scenario. Table C.12 lists the statistical results of the uncertainty analysis. Tables C.13 through C.30 summarize the sensitivity analysis results, which include partial rank correlation coefficients (PRCCs) and the ranks of the PRCCs for each scenario by isotope. Table C.31 provides the sensitivity ranking for input parameters by scenario and isotope. Finally, Figures C.1 through C.29 are graphs depicting the dose distribution data for each scenario, also by individual isotope analyzed.

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Tables

Tables (Continued)

Figures

Figures (Continued)

Figures (Continued)

Table C.1 Input parameter distributions for Scenario No. 1 - Sewer System Inspector (^{60}Co, ^{192}Ir)

Parameter (Units)	Distribution	Minimum	Maximum	Determ. value
Inventory(Ci/m^3)	Loguniform	3.0E-07	3.0E-06	3.0E-06 (^{60}Co)
		1.0E-06	1.0E-04	1.0E-05 (^{192}Ir)
External(Hrs)	Loguniform	40	240	100
Inhalation(Hrs)	Loguniform	8	48	20
Dust Loading(g/m^3)	Loguniform	5.0E-5	5.0E-3	1E-4

Table C.2 Input parameter distributions for Scenario No. 2 - STP Sludge Process Operator (^{60}Co, ^{137}Cs, ^{192}Ir)

Parameter (Units)	Distribution	Minimum	Maximum	Determ. value
Inventory(Ci/m^3)	Loguniform	1.1E-5	1.1E-3	2.1E-4
External(Hrs)	Loguniform	500	1750	1500
Inhalation(Hrs)	Loguniform	100	350	300
Dust Loading(g/m^3)	Loguniform	1.0E-4	5.0E-2	1.0E-3

Table C.3 Input parameter distributions for Scenario No. 3 - STP Liquid Effluent (^{60}Co, ^{90}Sr, ^{137}Cs, ^{241}Am)

Parameter (Units)	Distribution	Minimum	Maximum	Determ. value
External(Hrs/Yr)	Loguniform	100	4400	1800
Dust Loading(g/m^3)	Loguniform	1.0E-5	5.0E-4	1.0E-4
Leafy Veg.(kg/Yr)	Uniform	0	9.8	4.9
Other Veg.(kg/Yr)	Uniform	0	91	45.5
Fruit(kg/Yr)	Uniform	0	42	21.0
Grain(kg/Yr)	Uniform	0	47	23.5
Beef(kg/Yr)	Uniform	0	95	47.5
Milk(L/Yr)	Uniform	0	110	55.0
Milk-Feed Fraction	Uniform	0.5	1.0	0.75
Flow(m^3/sec)	Loguniform	80	3000	100.0
Fish(kg/yr)	Uniform Step			
	5%	0	0	6.9
	10%	0	1.3	
	20%	1.3	3.3	
	30%	3.3	6.1	
	20%	6.1	9.4	
	8%	9.4	15.4	
	6%	15.4	21.0	
	1%	21.0	35.0	
Irrigation(in./yr)	Uniform Step	0	40	30

Table C.3 (Continued)

Parameter (Units)	Distribution	Minimum	Maximum	Determ. value
Swimming(Hrs/yr)	Uniform Step			
	40%	0	0	10
	15%	0	1.0	
	10%	1.0	2.4	
	10%	2.4	3.6	
	10%	3.6	5.0	
	10%	5.0	28.4	
	5%	28.4	40.0	
Boating(Hrs/yr)	Uniform Step			
	40%	0	0	5
	15%	0	1.0	
	10%	1.0	2.4	
	10%	2.4	3.6	
	10%	3.6	5.0	
	10%	5.0	28.4	
	5%	28.4	40.0	
Shoreline(Hrs/yr)	Uniform Step			
	40%	0	0	17
	15%	0	1.0	
	10%	1.0	2.4	
	10%	2.4	3.6	
	10%	3.6	5.0	
	10%	5.0	28.4	
	5%	28.4	40.0	

Table C.4 Input parameter distributions for Scenario No. 4 - STP Incinerator Operator (^{60}Co, ^{192}Ir, ^{241}Am)

Parameter (Units)	Distribution	Minimum	Maximum	Determ. value
Inventory(Ci/kg)	Loguniform	9.8E-8	9.8E-6	2.0E-6
External(Hrs)	Loguniform	10	200	100
Inhalation(Hrs)	Loguniform	20	400	400
Dust Loading(g/m^3)	Loguniform	1.0E-4	1.0E-3	1.0E-3

Table C.5 Input parameter distributions for Scenario No. 5 - Sludge Incinerator Effluent (^{137}Cs, ^{241}Am)

Parameter	Distribution	Minimum	Maximum	Determ. value
Inventory(Ci/yr)	Uniform	1.0E-3	5.0E-2	5.0E-2
External(Hrs)	Loguniform	100	4400	1800
Inhalation(Hrs)	Uniform	2200	6600	3990
Leafy Veg.(kg/Yr)	Uniform	0	9.8	4.9
Other Veg.(kg/Yr)	Uniform	0	91	45.5
Fruit(kg/Yr)	Uniform	0	42	21.0
Grain(kg/Yr)	Uniform	0	47	23.5
Beef(kg/Yr)	Uniform	0	95	47.5
Milk(l/Yr)	Uniform	0	110	55.0
Milk-Feed Fraction	Uniform	0.5	1.0	0.75
CHI/Q(sec/m^3)	Loguniform	1.0E-8	1.0E-6	1.0E-7

Table C.6 Input parameter distributions for Scenario No. 6 - Incinerator Ash Disposal Truck Driver (^{60}Co, ^{192}Ir)

Parameter	Distribution	Minimum	Maximum	Determ. value
Inventory(Ci/m^3)	Loguniform	1.6E-4	1.6E-2	2.8E-3
External(Hrs)	Loguniform	100	1000	1000
Inhalation(Hrs)	Loguniform	20	200	200
Dust Loading(g/m^3)	Loguniform	5.0E-5	5.0E-3	1.0E-4

Table C.7 Input parameter distributions for Scenario No. 7 - Sludge Application to Agricultural Soil (^{90}Sr)

Parameter	Distribution	Minimum	Maximum	Determ. value
Inventory(Ci/m^2)	Loguniform	5.8E-9	7.3E-6	8.8E-7
External(Hrs)	Uniform	125	500	500
Inhalation(Hrs)	Uniform	100	400	400
Dust Loading(g/m^3)	Loguniform	1.0E-4	1.0E-3	1.0E-4
Leafy Veg.(kg/Yr)	Uniform	1	9.8	4.9
Other Veg.(kg/Yr)	Loguniform	9.1	91	45.5
Fruit(kg/Yr)	Loguniform	4.2	42	21.0
Grain(kg/Yr)	Uniform	4.7	47	23.5
Holdup Leafy Veg. (day)	Loguniform	1	10	1.0

Table C.8 Input parameter distributions for Scenario No. 8 - Sludge Application to Non-Agricultural Soil (^{60}Co, ^{137}Cs, ^{192}Ir)

Parameter	Distribution	Minimum	Maximum	Determ. value
Inventory(Ci/m^3)	Loguniform	2.9E-8	5.9E-5	5.8E-6
External(Hrs)	Loguniform	100	2000	500
Inhalation(Hrs)	Loguniform	20	400	100
Dust Loading(g/m^3)	Loguniform	5.0E-5	5.0E-3	1.0E-4

Table C.9 Input parameter distributions for Scenario No.9 - Landfill Equipment Operator (^{60}Co, ^{137}Cs, ^{192}Ir, ^{241}Am)

Parameter	Distribution	Minimum	Maximum	Determ. value
Inventory(Ci/kg)	Loguniform	8.8E-9	8.8E-7	1.8E-7
External(Hrs)	Loguniform	20	400	250
Inhalation(Hrs)	Loguniform	20	400	100
Dust Loading(g/m^3)	Loguniform	1.0E-4	1.0E-3	4.0E-4

Table C.10 Input parameter distributions for Scenario No. 10 - Landfill Intrusion and Construction (^{60}Co, ^{137}Cs)

Parameter	Distribution	Minimum	Maximum	Determ. value
Inventory(Ci/m^3)	Loguniform	1.6E-5	2.6E-3	3.1E-4
Decay Time(Yr)	Uniform	1	50	5
Manual Redistribution(m)	Loguniform	1.5E-3	1.2E-1	9.0E-2
External(Hrs)	Loguniform	20	400	250
Inhalation(Hrs)	Loguniform	20	400	100
Dust Loading(g/m^3)	Loguniform	1.0E-4	1.0E-3	5.0E-4

Table C.11 Input parameter distributions for Scenario No. 11 - Landfill Intrusion and Residence (^{60}Co, ^{90}Sr, ^{137}Cs)

Parameter	Distribution	Minimum	Maximum	Determ. value
Inventory(Ci/m^3)	Loguniform	1.6E-5	1.6E-3	3.1E-4
Decay Time(Yr)	Uniform	0	50	5
Manual Redistribution(m)	Loguniform	9.0E-4	9.0E-2	5.9E-2
External(Hrs)	Loguniform	977	3350	2030
Inhalation(Hrs)	Loguniform	294	928	605
Dust Loading(g/m^3)	Loguniform	1.0E-5	1.0E-3	1.0E-4
Leafy Veg.(kg/Yr)	Uniform	0	9.8	2.5
Other Veg.(kg/Yr)	Uniform	0	91	22.8
Fruit(kg/Yr)	Uniform	0	42	10.5
Grain(kg/Yr)	Uniform	0	47	11.8
Holdup Leafy Veg. (day)	Loguniform	1	10	1.0

Table C.12 Statistical results of the uncertainty analysis for the 11 reference scenarios

Scenario	Nuclide	Dose Type	Total Dose (rem) Mean[a]	SD	Min	5%	Median	95%	99%	Max
1	Co-60	INHALATION	1.7E-08	3.0E-08	5.6E-11	1.9E-10	3.6E-09	7.6E-08	1.4E-07	1.4E-07
		EXTERNAL	2.8E-04	3.7E-04	7.2E-06	1.2E-05	1.0E-04	1.1E-03	1.5E-03	1.8E-03
		TOTAL	2.8E-04	3.7E-04	7.2E-06	1.2E-05	1.0E-04	1.1E-03	1.5E-03	1.8E-03
1	Ir-192	INHALATION	7.9E-09	1.4E-08	2.7E-11	8.8E-11	1.7E-09	3.7E-08	6.2E-08	6.5E-08
		EXTERNAL	2.1E-04	2.9E-04	5.5E-06	8.5E-06	7.6E-05	7.7E-04	1.2E-03	1.4E-03
		TOTAL	2.1E-04	2.9E-04	5.5E-06	8.5E-06	7.6E-05	7.7E-04	1.2E-02	1.4E-03
2	Co-60	INHALATION	7.6E-05	1.3E-04	3.6E-07	8.2E-07	1.8E-05	3.4E-04	5.4E-04	7.4E-04
		EXTERNAL	2.7E-01	3.4E-01	8.9E-03	1.4E-02	1.1E-01	1.0E+00	1.3E+00	1.5E+00
		TOTAL	2.7E-01	3.4E-01	8.9E-03	1.4E-02	1.1E-01	1.0E+00	1.3E+00	1.5E+00
2	Cs-137	INHALATION	1.0E-05	1.8E-05	4.9E-08	1.1E-07	2.5E-06	4.6E-05	7.4E-05	1.0E-04
		EXTERNAL	6.1E-02	7.6E-02	2.0E-03	3.1E-03	2.5E-02	2.2E-01	2.9E-01	3.4E-01
		TOTAL	6.1E-02	7.6E-02	2.0E-03	3.1E-03	2.5E-02	2.2E-01	2.9E-01	3.4E-01
2	Ir-192	INHALATION	1.0E-05	1.8E-05	4.8E-08	1.1E-07	2.4E-06	4.5E-05	7.2E-05	9.9E-05
		EXTERNAL	9.0E-02	1.1E-01	3.0E-03	4.7E-03	3.7E-02	3.4E-01	4.4E-01	5.0E-01
		TOTAL	9.0E-02	1.1E-01	3.0E-03	4.7E-03	3.7E-02	3.4E-01	4.4E-01	5.0E-01
3	Co-60	INHALATION	1.1E-12	2.5E-11	0.0E+00	4.8E-15	1.8E-13	3.8E-12	1.2E-11	1.8E-11
		INGESTION	3.7E-06	4.3E-05	6.2E-08	3.1E-07	1.9E-06	1.2E-05	1.7E-05	2.4E-05
		EXTERNAL	3.7E-07	7.2E-07	3.4E-09	6.4E-09	1.3E-07	1.6E-06	3.8E-06	4.9E-06
		TOTAL	4.0E-06	4.6E-06	1.1E-07	4.0E-07	2.0E-06	1.3E-05	1.9E-05	2.5E-05
3	Sr-90	INHALATION	1.2E-12	2.8E-12	0.0E+00	5.5E-15	2.0E-13	4.2E-12	1.4E-11	2.0E-11
		INGESTION	9.3E-06	9.5E-06	4.8E-07	8.6E-07	5.3E-06	2.9E-05	3.6E-05	4.4E-05
		EXTERNAL	1.0E-09	1.9E-09	8.4E-12	1.3E-11	3.4E-10	4.3E-09	1.0E-08	1.3E-08
		TOTAL	9.3E-06	9.5E-06	4.8E-07	8.6E-07	5.3E-06	2.9E-05	3.6E-05	4.4E-05

Table C.12 (Continued)

Scenario	Nuclide	Dose Type	Total Dose (rem) Mean[a]	SD	Min	5%	Median	95%	99%	Max
3	Cs-137	INHALATION	1.5E-13	3.6E-13	0.0E+00	7.1E-16	2.6E-14	5.5E-13	1.7E-12	2.6E-12
		INGESTION	4.2E-04	6.0E-04	5.1E-07	9.9E-06	1.9E-04	1.5E-03	2.7E-03	3.9E-03
		EXTERNAL	9.6E-08	1.9E-07	8.8E-10	1.6E-09	3.3E-08	4.0E-07	9.8E-07	1.3E-06
		TOTAL	4.2E-04	6.0E-04	5.2E-07	9.9E-06	1.9E-04	1.5E-03	2.7E-03	3.9E-03
3	Am-241	INHALATION	2.5E-09	5.9E-09	0.0E+00	1.1E-11	4.2E-10	8.8E-09	2.8E-08	4.3E-08
		INGESTION	2.7E-04	3.4E-04	5.9E-06	1.2E-05	1.3E-04	9.1E-04	1.5E-03	2.1E-03
		EXTERNAL	7.4E-10	1.4E-09	6.9E-12	1.3E-11	2.5E-10	3.0E-09	7.6E-09	9.6E-09
		TOTAL	2.7E-04	3.4E-04	5.9E-06	1.2E-05	1.3E-04	9.1E-04	1.5E-03	2.1E-03
4	Co-60	INHALATION	5.9E-05	1.1E-04	1.2E-07	5.8E-07	1.5E-05	2.6E-04	5.4E-04	5.6E-04
		EXTERNAL	1.8E-01	2.6E-01	1.9E-03	4.6E-03	7.5E-02	5.8E-01	1.4E+00	1.6E+00
		TOTAL	1.8E-01	2.6E-01	1.9E-03	4.6E-03	7.5E-02	5.8E-01	1.4E+00	1.6E+00
4	Ir-192	INHALATION	7.9E-06	1.5E-05	1.6E-08	7.7E-08	2.0E-06	3.5E-05	7.2E-05	7.5E-05
		EXTERNAL	6.4E-02	9.7E-02	6.8E-04	1.7E-03	2.8E-02	2.1E-01	5.3E-05	5.9E-01
		TOTAL	6.4E-02	9.7E-02	6.8E-04	1.7E-03	2.8E-02	2.1E-01	5.3E-05	5.9E-01
4	Am-241	INHALATION	1.3E-01	2.4E-01	2.7E-04	1.3E-03	3.3E-02	5.7E-01	1.2E+00	1.2E+00
		EXTERNAL	3.2E-04	4.8E-04	3.3E-06	8.4E-06	1.4E-04	1.0E-03	2.6E-03	2.9E-03
		TOTAL	1.3E-01	2.4E-01	3.4E-04	1.4E-03	3.4E-02	5.7E-01	1.2E+00	1.2E+00
5	Cs-137	INHALATION	1.5E-08	2.3E-08	1.2E-10	2.5E-10	4.6E-09	6.3E-08	1.0E-07	1.2E-07
		INGESTION	3.8E-07	5.5E-07	1.9E-09	4.0E-09	8.8E-08	1.6E-06	2.2E-06	2.3E-06
		EXTERNAL	8.1E-09	2.2E-08	1.1E-11	5.6E-11	1.2E-09	3.4E-08	9.6E-08	1.5E-07
		TOTAL	4.0E-07	5.9E-07	2.2E-09	4.2E-09	9.4E-08	1.7E-06	2.4E-06	2.5E-06
5	Am-241	INHALATION	2.4E-04	3.8E-04	2.0E-06	4.0E-06	7.5E-05	1.0E-03	1.7E-03	2.0E-03
		INGESTION	3.7E-06	6.0E-06	2.4E-08	4.8E-08	8.8E-07	1.7E-05	2.3E-05	2.7E-05
		EXTERNAL	6.4E-11	1.7E-10	1.0E-13	4.4E-13	1.4E-11	2.6E-10	7.4E-10	1.2E-09
		TOTAL	2.4E-04	3.8E-04	2.0E-06	4.0E-06	7.7E-05	1.0E-03	1.7E-03	2.0E-03

Table C.12 (Continued)

Scenario	Nuclide	Dose Type	Total Dose (rem)							
			Mean[a]	SD	Min	5%	Median	95%	99%	Max
6	Co-60	INHALATION	2.0E-04	3.7E-03	5.2E-07	2.2E-06	4.0E-05	9.2E-04	1.7E-03	1.7E-03
		EXTERNAL	1.0E-01	1.4E-01	2.0E-03	3.2E-03	3.0E-02	3.9E-01	6.3E-01	7.1E-01
		TOTAL	1.0E-01	1.4E-01	2.0E-03	3.2E-03	3.0E-02	3.9E-01	6.3E-01	7.1E-01
6	Ir-192	INHALATION	2.7E-05	4.9E-05	6.9E-09	2.9E-07	5.3E-06	1.2E-04	2.3E-04	2.3E-04
		EXTERNAL	1.6E-02	2.4E-02	3.3E-04	5.3E-04	4.9E-03	6.4E-02	1.0E-01	1.2E-01
		TOTAL	1.6E-02	2.4E-02	3.3E-04	5.3E-04	4.9E-03	6.4E-02	1.0E-01	1.2E-01
7	Sr-90	INHALATION	7.8E-08	1.4E-07	2.0E-10	3.0E-10	1.3E-08	3.6E-07	5.9E-07	8.1E-07
		INGESTION	1.5E-02	2.8E-02	5.6E-05	9.6E-05	3.0E-03	6.5E-02	1.4E-01	1.5E-01
		EXTERNAL	9.7E-08	1.7E-07	3.7E-10	6.5E-10	1.5E-08	5.0E-07	6.5E-07	8.6E-07
		TOTAL	1.5E-02	2.8E-02	5.6E-05	9.6E-05	3.0E-03	6.5E-02	1.4E-01	1.5E-01
8	Co-60	INHALATION	6.1E-07	1.2E-06	2.2E-10	9.0E-10	3.8E-08	4.0E-06	4.8E-06	5.0E-06
		EXTERNAL	3.2E-02	6.6E-02	4.1E-05	8.7E-05	3.2E-03	1.6E-01	2.9E-01	3.8E-01
		TOTAL	3.2E-02	6.6E-02	4.1E-05	8.7E-05	3.2E-03	1.6E-01	2.9E-01	3.8E-01
8	Cs-137	INHALATION	8.3E-08	1.7E-07	3.0E-11	1.2E-10	5.2E-09	6.3E-07	6.6E-07	6.8E-07
		EXTERNAL	7.6E-03	1.6E-03	9.9E-06	2.1E-05	7.6E-04	3.7E-02	6.9E-02	9.2E-02
		TOTAL	7.6E-03	1.6E-03	9.9E-06	2.1E-05	7.6E-04	3.7E-02	6.9E-02	9.2E-02
8	Ir-192	INHALATION	2.3E-08	1.5E-07	2.6E-11	1.1E-10	4.6E-09	5.5E-07	5.7E-07	6.0E-07
		EXTERNAL	1.0E-02	2.2E-02	1.3E-05	2.9E-05	1.1E-03	5.1E-02	9.8E-02	1.3E-01
		TOTAL	1.0E-02	2.2E-02	1.3E-05	2.9E-05	1.1E-03	5.1E-02	9.8E-02	1.3E-01
9	Co-60	INHALATION	1.7E-06	2.9E-06	9.0E-09	2.8E-08	4.4E-07	7.2E-06	1.3E-05	1.4E-05
		EXTERNAL	3.2E-02	4.9E-02	3.0E-04	8.7E-04	1.4E-02	1.1E-01	2.7E-01	3.0E-01
		TOTAL	3.2E-02	4.9E-02	3.0E-04	8.7E-04	1.4E-02	1.1E-01	2.7E-01	3.0E-01
9	Cs-137	INHALATION	2.4E-07	4.0E-07	1.2E-09	3.8E-09	6.0E-08	9.8E-07	1.8E-06	1.9E-06
		EXTERNAL	7.6E-03	1.2E-02	7.2E-05	2.1E-04	3.3E-03	2.6E-02	6.4E-02	7.1E-02
		TOTAL	7.6E-03	1.2E-02	7.2E-05	2.1E-04	3.3E-03	2.6E-02	6.4E-02	7.1E-02

Table C.12 (Continued)

Scenario	Nuclide	Dose Type	Total Dose (rem) Mean[a]	SD	Min	5%	Median	95%	99%	Max
9	Ir-192	INHALATION	2.3E-07	3.9E-07	1.2E-09	3.7E-09	5.9E-08	9.6E-07	1.7E-06	1.8E-06
		EXTERNAL	1.2E-02	1.8E-02	1.1E-04	3.2E-04	5.1E-03	4.0E-02	9.8E-02	1.1E-01
		TOTAL	1.2E-02	1.8E-02	1.1E-04	3.2E-04	5.1E-03	4.0E-02	9.8E-02	1.1E-01
9	Am-241	INHALATION	3.9E-03	6.4E-03	2.0E-05	6.2E-05	9.7E-04	1.6E-02	2.9E-02	3.0E-02
		EXTERNAL	5.8E-05	8.8E-05	5.4E-07	1.6E-06	2.5E-05	2.0E-04	4.8E-04	5.3E-04
		TOTAL	3.9E-03	6.4E-03	3.2E-05	7.6E-05	1.2E-03	1.6E-02	2.9E-02	3.0E-02
10	Co-60	INHALATION	8.8E-08	3.7E-07	1.0E-12	6.8E-12	3.0E-09	4.4E-07	1.0E-06	3.4E-06
		EXTERNAL	3.0E-02	9.0E-02	2.5E-05	3.1E-05	3.1E-03	1.2E-01	5.5E-01	6.1E-01
		TOTAL	3.0E-02	9.0E-02	2.5E-05	3.1E-05	3.1E-03	1.2E-01	5.5E-01	6.1E-01
10	Cs-137	INHALATION	4.8E-08	1.3E-07	1.8E-11	1.0E-10	6.0E-09	2.3E-07	6.0E-07	9.3E-07
		EXTERNAL	2.1E-02	3.5E-02	2.5E-04	5.8E-04	7.5E-03	7.7E-02	1.6E-01	2.4E-01
		TOTAL	2.1E-02	3.5E-02	2.5E-04	5.8E-04	7.5E-03	7.7E-02	1.6E-01	2.4E-01
11	Co-60	INHALATION	8.8E-08	3.7E-07	1.0E-12	6.8E-12	3.0E-09	4.4E-07	1.0E-06	3.4E-06
		INGESTION	4.5E-05	1.2E-04	3.5E-09	1.5E-08	3.5E-06	3.0E-04	4.3E-04	9.0E-04
		EXTERNAL	3.0E-02	9.0E-02	2.5E-05	3.2E-05	3.1E-03	1.2E-01	5.5E-01	6.1E-01
		TOTAL	3.0E-02	9.0E-02	2.5E-05	3.2E-05	3.1E-03	1.2E-01	5.5E-01	6.1E-01
11	Sr-90	INHALATION	3.5E-07	9.4E-07	1.3E-10	7.4E-10	4.4E-08	1.7E-06	4.7E-06	6.8E-06
		INGESTION	6.1E-02	1.2E-01	1.5E-04	3.1E-04	1.4E-02	3.0E-01	4.4E-01	8.5E-01
		EXTERNAL	1.9E-04	3.5E-04	2.9E-07	4.0E-06	6.7E-06	7.1E-04	1.6E-03	2.5E-03
		TOTAL	6.1E-02	1.2E-01	1.5E-04	3.1E-04	1.4E-02	3.0E-01	4.4E-01	8.5E-01
11	Cs-137	INHALATION	4.7E-08	1.3E-07	1.8E-11	1.0E-10	6.0E-09	2.3E-07	6.0E-07	9.3E-07
		INGESTION	2.4E-04	4.8E-04	6.3E-07	1.4E-06	5.3E-05	1.3E-03	1.8E-03	3.2E-03
		EXTERNAL	2.1E-02	3.6E-02	2.5E-04	5.8E-04	7.5E-03	7.7E-02	1.6E-01	2.4E-01
		TOTAL	2.1E-02	3.7E-02	2.5E-04	5.8E-04	7.6E-03	7.9E-03	1.7E-01	2.4E-01

(a) Mean = arithmetic mean.

Table C.13 Sensitivity analysis results for ^{60}Co and ^{192}Ir for Scenario No. 1 - Sewer System Inspector

	Dose type		
	Inhalation	**External**	**Total**
^{60}Co			
Partial rank correlation coefficients (PRCC)			
Inventory	0.99	1.00	1.99
External (h)	0.96	0.99	0.98
Dust Loading	0.99	0.07	0.07
R^2	0.99	0.99	0.99
Ranks of PRCC			
Inventory	1	1	1
External (h)	3	2	2
Dust Loading	2	3	3
^{192}Ir			
Partial rank correlation coefficients (PRCC)			
Inventory	0.99	1.00	1.00
External (h)	0.96	0.98	0.98
Dust Loading	0.99	0.10	0.10
R^2	0.99	0.99	0.99
Ranks of PRCC			
Inventory	1	1	1
External (h)	3	2	2
Dust Loading	2	3	3

Table C.14 Sensitivity analysis results for ^{60}Co, ^{137}Cs, and ^{192}Ir for Scenario No. 2 - Sludge Process Operator

	Inhalation	External	Total
^{60}Co			
Partial rank correlation coefficients (PRCC)			
Inventory	0.99	1.09	1.00
External (h)	0.33	0.04	0.04
Inhalation (h)	-0.01	-0.01	-0.01
Dust Loading	0.99	0.06	0.06
R^2	0.99	1.00	1.00
Ranks of PRCC			
Inventory	1	1	1
External (h)	3	3	3
Inhalation (h)	4	4	4
Dust Loading	2	2	2
^{137}Cs			
Partial rank correlation coefficients (PRCC)			
Inventory	0.99	1.00	1.00
External (h)	0.04	0.03	0.03
Inhalation (h)	-0.02	0.00	0.00
Dust Loading	0.99	0.02	0.02
R^2	0.99	1.00	1.00
Ranks of PRCC			
Inventory	1	1	1
External (h)	3	2	2
Inhalation (h)	4	4	4
Dust Loading	2	3	3
^{192}Ir			
Partial rank correlation coefficients (PRCC)			
Inventory	0.99	1.00	1.00
External (h)	0.05	0.01	0.01
Inhalation (h)	-0.03	0.02	0.02
Dust Loading	0.99	0.05	0.05
R^2	0.99	1.00	1.00
Ranks of PRCC			
Inventory	1	1	1
External (h)	3	4	4
Inhalation (h)	4	3	3
Dust Loading	2	2	2

Table C.15 Sensitivity analysis results for ^{60}Co for Scenario No. 3 - STP Liquid Effluent

	Inhalation	Ingestion	External	Total
Partial rank correlation coefficients (PRCC)				
EXTERNAL Hrs	-0.02	0.07	-0.02	0.08
INHALATION Hrs	0.04	-0.07	0.03	-0.07
DUST LOADING	0.94	0.15	-0.06	0.22
LEAFY VEG.	-0.13	0.10	-0.07	0.09
ROOT VEG.	0.01	0.08	0.03	0.15
FRUIT	-0.13	0.30	-0.16	0.24
GRAIN	0.11	-0.15	0.07	-0.14
BEEF	0.26	0.78	0.10	0.82
MILK	-0.16	-0.07	-0.15	-0.18
MILK F.F.	0.00	0.02	0.05	0.07
FLOW	-0.92	-0.98	-0.93	-0.99
FISH	0.02	0.90	0.03	0.90
IRRIGATION	0.87	0.02	0.83	0.35
SWIMMING	-0.03	-0.04	-0.25	-0.04
BOATING	0.01	0.07	-0.01	0.06
SHORELINE	0.07	0.04	0.36	0.15
R^2	0.96	0.97	0.93	0.98
Ranks of PRCC				
EXTERNAL Hrs	12	10	15	12
INHALATION Hrs	10	11	12	13
DUST LOADING	1	6	10	6
LEAFY VEG.	7	7	8	11
ROOT VEG.	14	8	14	8
FRUIT	6	4	5	5
GRAIN	8	5	9	10
BEEF	4	3	7	3
MILK	5	9	6	7
MILK F.F.	16	16	11	14
FLOW	2	1	1	1
FISH	13	2	13	2
IRRIGATION	3	15	2	4
SWIMMING	11	14	4	16
BOATING	15	12	16	15
SHORELINE	9	13	3	9

Table C.16 Sensitivity analysis results for ^{90}Sr for Scenario No. 3 - STP Liquid Effluent

	Inhalation	Ingestion	External	Total
Partial rank correlation coefficients (PRCC)				
EXTERNAL Hrs	-0.03	0.09	-0.03	0.09
INHALATION Hrs	0.04	-0.09	0.04	-0.09
DUST LOADING	0.94	0.15	-0.07	0.15
LEAFY VEG.	-0.13	0.28	-0.06	0.28
ROOT VEG.	0.01	0.76	0.02	0.76
FRUIT	-0.14	0.43	-0.16	0.43
GRAIN	0.12	-0.03	0.08	-0.03
BEEF	0.25	0.41	0.10	0.41
MILK	-0.16	0.26	-0.14	-0.26
MILK F.F.	0.00	0.14	0.04	0.14
FLOW	-0.92	-0.99	-0.92	-0.99
FISH	0.01	0.91	0.02	0.91
IRRIGATION	0.87	0.02	0.83	0.02
SWIMMING	-0.03	0.12	-0.28	0.12
BOATING	0.00	0.14	-0.03	0.14
SHORELINE	0.07	0.08	0.36	0.08
R^2	0.96	0.99	-0.93	0.99
Ranks of PRCC				
EXTERNAL Hrs	12	12	14	12
INHALATION Hrs	10	13	12	13
DUST LOADING	1	8	9	8
LEAFY VEG.	7	6	10	6
ROOT VEG.	14	3	16	3
FRUIT	6	4	5	4
GRAIN	8	15	8	15
BEEF	4	5	7	5
MILK	5	7	6	7
MILK F.F.	15	10	11	10
FLOW	2	1	1	1
FISH	13	2	15	2
IRRIGATION	3	16	2	16
SWIMMING	11	11	4	11
BOATING	16	9	13	9
SHORELINE	9	14	3	14

Table C.17. Sensitivity analysis results for ^{137}Cs for Scenario No. 3 - STP Liquid Effluent

	Inhalation	Ingestion	External	Total
Partial rank correlation coefficients (PRCC)				
EXTERNAL Hrs	-0.02	0.05	-0.03	0.04
INHALATION Hrs	0.04	-0.05	0.05	-0.04
DUST LOADING	0.94	0.08	-0.06	0.08
LEAFY VEG.	-0.14	-0.02	-0.06	-0.02
ROOT VEG.	0.01	-0.14	0.03	-0.14
FRUIT	-0.14	-0.18	-0.16	-0.18
GRAIN	0.12	-0.26	0.08	-0.26
BEEF	0.26	-0.09	0.11	-0.09
MILK	-0.16	-0.03	-0.15	-0.03
MILK F.F.	0.00	-0.13	0.05	-0.13
FLOW	-0.92	-0.95	-0.93	-0.95
FISH	0.02	0.94	0.01	0.94
IRRIGATION	0.87	-0.19	0.84	-0.19
SWIMMING	-0.03	0.08	-0.24	0.08
BOATING	0.01	0.08	-0.01	0.08
SHORELINE	0.06	-0.05	0.35	-0.05
R^2	0.96	0.94	0.93	0.94
Ranks of PRCC				
EXTERNAL Hrs	12	14	13	14
INHALATION Hrs	10	13	12	13
DUST LOADING	1	11	9	11
LEAFY VEG.	6	16	10	16
ROOT VEG.	14	6	14	6
FRUIT	7	5	5	5
GRAIN	8	3	8	3
BEEF	4	8	7	8
MILK	5	15	6	15
MILK F.F.	16	7	11	7
FLOW	2	1	1	1
FISH	13	2	15	2
IRRIGATION	3	4	2	4
SWIMMING	11	10	4	10
BOATING	15	9	16	9
SHORELINE	9	12	3	12

Table C.18 Sensitivity analysis results for ^{241}Am for Scenario No. 3 - STP Liquid Effluent

	Inhalation	Ingestion	External	Total
Partial rank correlation coefficients (PRCC)				
EXTERNAL Hrs	-0.02	0.10	-0.05	0.10
INHALATION Hrs	0.03	-0.10	0.06	-0.10
DUST LOADING	0.94	0.10	-0.03	0.10
LEAFY VEG.	-0.13	0.27	-0.09	0.27
ROOT VEG.	0.01	0.21	0.03	0.21
FRUIT	-0.14	0.02	-0.14	0.02
GRAIN	0.12	-0.20	0.09	-0.20
BEEF	0.26	-0.08	0.12	-0.08
MILK	-0.15	-0.20	-0.16	-0.20
MILK F.F.	0.01	-0.04	0.04	-0.04
FLOW	-0.93	-0.98	-0.93	-0.98
FISH	0.02	0.95	0.01	0.95
IRRIGATION	0.87	-0.13	0.82	-0.13
SWIMMING	-0.02	0.04	-0.17	0.04
BOATING	0.01	0.13	0.02	0.13
SHORELINE	0.07	0.03	0.35	0.03
R^2	0.96	0.97	0.93	0.97
Ranks of PRCC				
EXTERNAL Hrs	13	10	11	10
INHALATION Hrs	10	9	10	9
DUST LOADING	1	11	14	11
LEAFY VEG.	7	3	9	3
ROOT VEG.	14	4	13	4
FRUIT	6	16	6	16
GRAIN	8	6	8	6
BEEF	4	12	7	12
MILK	5	5	5	5
MILK F.F.	16	13	12	13
FLOW	2	1	1	1
FISH	12	2	16	2
IRRIGATION	3	7	2	7
SWIMMING	11	14	4	14
BOATING	15	8	15	8
SHORELINE	9	15	3	15

Table C.19 Sensitivity analysis results for ^{60}Co, ^{192}Ir, and ^{241}Am for Scenario No. 4 - STP Incinerator Operator

^{60}Co	Inhalation	External	Total
Partial rank correlation coefficients (PRCC)			
INVENTORY	0.98	0.99	0.99
EXTERNAL Hrs	0.03	0.96	0.96
INHALATION Hrs	0.96	0.15	0.15
DUST LOADING	0.98	0.11	0.11
R^2	0.98	0.98	0.98
Ranks of PRCC			
INVENTORY	1	1	1
EXTERNAL Hrs	4	2	2
INHALATION Hrs	3	3	3
DUST LOADING	2	4	4
^{192}Ir			
Partial rank correlation coefficients (PRCC)			
INVENTORY	0.98	0.99	0.99
EXTERNAL Hrs	0.04	0.96	0.96
INHALATION Hrs	0.96	0.15	0.15
DUST LOADING	0.98	0.12	0.12
R^2	0.98	0.98	0.98
Ranks of PRCC			
INVENTORY	1	1	1
EXTERNAL Hrs	4	2	2
INHALATION Hrs	3	3	3
DUST LOADING	2	4	4
^{241}Am			
Partial rank correlation coefficients (PRCC)			
INVENTORY	0.98	0.99	0.98
EXTERNAL Hrs	0.03	0.96	0.08
INHALATION Hrs	0.96	0.14	0.96
DUST LOADING	0.98	0.11	0.98
R^2	0.98	0.98	0.98
Ranks of PRCC			
INVENTORY	1	1	1
EXTERNAL Hrs	4	2	4
INHALATION Hrs	3	3	3
DUST LOADING	2	4	2

Table C.20 Sensitivity analysis results for ^{137}Cs for Scenario No. 5 - Sludge Incinerator Effluent

	Inhalation	Ingestion	External	Total
Partial rank correlation coefficients (PRCC)				
EXTERNAL Hrs	-0.14	0.10	0.96	0.21
INHALATION Hrs	0.89	0.03	-0.06	0.13
LEAFY VEG.	0.01	-0.13	-0.05	-0.12
ROOT VEG.	-0.02	-0.12	-0.11	-0.09
FRUIT	-0.01	0.15	-0.17	0.15
GRAIN	-0.03	0.16	0.17	0.13
BEEF	0.12	0.93	0.03	0.93
MILK	0.07	0.43	-0.16	0.48
MILK F.F.	-0.09	0.28	0.03	0.32
CHI/Q	1.00	0.99	0.99	1.00
R^2	0.99	0.99	0.98	0.99
Ranks of PRCC				
EXTERNAL Hrs	3	9	2	5
INHALATION Hrs	2	10	7	8
LEAFY VEG.	10	7	8	9
ROOT VEG.	8	8	6	10
FRUIT	9	6	4	6
GRAIN	7	5	3	7
BEEF	4	2	10	2
MILK	6	3	5	3
MILK F.F.	5	4	9	4
CHI/Q	1	1	1	1

Table C.21 Sensitivity analysis results for ^{241}Am for Scenario No. 5 - Sludge Incinerator Effluent

	Inhalation	Ingestion	External	Total
Partial rank correlation coefficients (PRCC)				
EXTERNAL Hrs	-0.13	-0.06	0.96	-0.15
INHALATION Hrs	0.90	-0.12	-0.05	0.89
LEAFY VEG.	-0.01	0.75	-0.05	0.01
ROOT VEG.	0.00	0.87	-0.12	-0.02
FRUIT	-0.02	0.43	-0.18	-0.01
GRAIN	-0.02	0.74	0.15	0.01
BEEF	0.13	0.02	0.00	0.14
MILK	0.07	0.10	-0.14	0.09
MILK F.F.	-0.10	0.20	0.04	-0.11
CHI/Q	1.00	1.00	0.99	1.00
R^2	0.99	1.00	0.98	0.99
Ranks of PRCC				
EXTERNAL Hrs	3	9	2	3
INHALATION Hrs	2	7	8	2
LEAFY VEG.	9	3	7	10
ROOT VEG.	10	2	6	7
FRUIT	7	5	3	8
GRAIN	8	4	4	9
BEEF	4	10	10	4
MILK	6	8	5	6
MILK F.F.	5	6	9	5
CHI/Q	1	1	1	1

Table C.22 Sensitivity analysis results for ^{60}Co and ^{192}Ir for Scenario No. 6 - Incinerator Ash Disposal Truck Driver

^{60}Co	Inhalation	Ingestion	External	Total
Partial rank correlation coefficients (PRCC)				
INVENTORY	0.99	0.00	1.00	1.00
EXTERNAL Hrs	0.13	0.00	0.02	0.02
INHALATION Hrs	-0.09	0.00	0.03	0.03
DUST LOADING	0.99	0.00	0.22	0.22
R^2	0.99	0.00	0.99	0.99
Ranks of PRCC				
INVENTORY	1	0	1	1
EXTERNAL Hrs	3	0	4	4
INHALATION Hrs	4	0	3	3
DUST LOADING	2	0	2	2
^{192}Ir				
Partial rank correlation coefficients (PRCC)				
INVENTORY	0.99	0.00	1.00	1.00
EXTERNAL Hrs	0.12	0.00	0.01	0.01
INHALATION Hrs	-0.08	0.00	0.04	0.04
DUST LOADING	0.99	0.00	0.22	0.22
R^2	0.99	0.00	0.99	0.99
Ranks of PRCC				
INVENTORY	1	0	1	1
EXTERNAL Hrs	3	0	4	4
INHALATION Hrs	4	0	3	3
DUST LOADING	2	0	2	2

Table C.23 Sensitivity analysis results for ^{90}Sr for Scenario No. 7 - Sludge Application to Agricultural Soil

	Inhalation	Ingestion	External	Total
Partial rank correlation coefficients (PRCC)				
INVENTORY	1.00	1.00	1.00	1.00
EXTERNAL Hrs	-0.08	0.05	0.94	0.05
INHALATION Hrs	0.92	-0.08	0.03	-0.08
DUST LOADING	0.97	-0.07	0.18	-0.07
LEAFY VEGS.	0.01	0.24	0.00	0.24
OTHER VEGS.	-0.01	0.94	-0.03	0.94
FRUIT	0.14	0.72	0.08	0.72
GRAIN	0.01	0.18	-0.12	0.18
HLEAFY VEGS.	-0.05	-0.01	-0.08	-0.01
R^2	1.00	0.99	1.00	0.99
Ranks of PRCC				
INVENTORY	1	1	1	1
EXTERNAL Hrs	5	8	2	8
INHALATION Hrs	3	6	7	6
DUST LOADING	2	7	3	7
LEAFY	8	4	9	4
OTHER VEGS.	7	2	8	2
FRUIT	4	3	6	3
GRAIN	9	5	4	5
HLEAFY VEGS.	6	9	5	9

Table C.24 Sensitivity analysis results for ^{60}Co, ^{137}Cs, and ^{192}Ir for Scenario No. 8 - Sludge Application to Non-Agricultural Soil

	Inhalation	Ingestion	External	Total
^{60}Co				
Partial rank correlation coefficients (PRCC)				
INVENTORY	0.99	0.00	1.00	1.00
EXTERNAL Hrs	0.01	0.00	0.13	0.13
INHALATION Hrs	0.01	0.00	-0.09	-0.09
DUST LOADING	0.98	0.00	0.09	0.09
R^2	0.99	0.00	0.99	0.99
Ranks of PRCC				
INVENTORY	1	0	1	1
EXTERNAL Hrs	4	0	2	2
INHALATION Hrs	3	0	3	3
DUST LOADING	2	0	4	4
^{137}Cs				
Partial rank correlation coefficients (PRCC)				
INVENTORY	0.99	0.00	1.00	1.00
EXTERNAL Hrs	0.02	0.00	0.13	0.13
INHALATION Hrs	0.00	0.00	-0.09	-0.09
DUST LOADING	0.98	0.00	0.08	0.08
R^2	0.99	0.00	0.99	0.99
Ranks of PRCC				
INVENTORY	1	0	1	1
EXTERNAL Hrs	3	0	2	2
INHALATION Hrs	4	0	3	3
DUST LOADING	2	0	4	4
^{192}Ir				
Partial rank correlation coefficients (PRCC)				
INVENTORY	0.99	0.00	1.00	1.00
EXTERNAL Hrs	0.02	0.00	0.14	0.14
INHALATION Hrs	0.01	0.00	-0.10	-0.10
DUST LOADING	0.98	0.00	0.11	0.11
R^2	0.99	0.00	0.99	0.99
Ranks of PRCC				
INVENTORY	1	0	1	1
EXTERNAL Hrs	3	0	2	2
INHALATION Hrs	4	0	4	4
DUST LOADING	2	0	3	3

Table C.25 Sensitivity analysis results for ^{60}Co and ^{192}Ir for Scenario No. 9 - Landfill Equipment Operator

^{60}Co

	Inhalation	External	Total
Partial rank correlation coefficients (PRCC)			
INVENTORY	0.99	0.99	0.99
EXTERNAL Hrs	0.13	0.96	0.96
INHALATION Hrs	0.97	0.16	0.16
DUST LOADING	0.96	0.13	0.13
R^2	0.99	0.98	0.98
Ranks of PRCC			
INVENTORY	1	1	1
EXTERNAL Hrs	4	2	2
INHALATION Hrs	2	3	3
DUST LOADING	3	4	4

^{192}Ir

	Inhalation	External	Total
Partial rank correlation coefficients (PRCC)			
INVENTORY	0.99	0.99	0.99
EXTERNAL Hrs	0.11	0.96	0.96
INHALATION Hrs	0.97	0.14	0.14
DUST LOADING	0.96	0.13	0.13
R^2	0.99	0.98	0.98
Ranks of PRCC			
INVENTORY	1	1	1
EXTERNAL Hrs	4	2	2
INHALATION Hrs	2	3	3
DUST LOADING	3	4	4

Table C.26 Sensitivity analysis results for ^{241}Am and ^{137}Cs for Scenario No. 9 - Landfill Equipment Operator

^{241}Am

	Inhalation	External	Total
Partial rank correlation coefficients (PRCC)			
INVENTORY	0.99	0.99	0.99
EXTERNAL Hrs	0.14	0.96	0.27
INHALATION Hrs	0.97	0.14	0.97
DUST LOADING	0.96	0.13	0.95
R^2	0.99	0.98	0.99
Ranks of PRCC			
INVENTORY	1	1	1
EXTERNAL Hrs	4	2	4
INHALATION Hrs	2	3	3
DUST LOADING	3	4	3

^{137}Cs

	Inhalation	External	Total
Partial rank correlation coefficients (PRCC)			
INVENTORY	0.99	0.99	0.99
EXTERNAL Hrs	0.15	0.96	0.96
INHALATION Hrs	0.97	0.15	0.15
DUST LOADING	0.96	0.13	0.13
R^2	0.99	0.98	0.98
Ranks of PRCC			
INVENTORY	1	1	1
EXTERNAL Hrs	4	2	2
INHALATION Hrs	2	3	3
DUST LOADING	3	4	4

Table C.27 Sensitivity analysis results for ^{60}Co and ^{137}Cs for Scenario No. 10 - Landfill Intrusion and Construction

^{60}Co

	Inhalation	External	Total
Partial rank correlation coefficients (PRCC)			
INVENTORY	0.88	0.94	0.94
DECAY TIME	-0.93	-0.97	-0.97
MANUAL REDIST.	0.87	0.61	0.61
EXTERNAL Hrs	-0.05	0.59	0.59
INHALATION Hrs	0.45	0.15	0.15
DUST LOADING	0.86	-0.17	-0.17
R^2	0.94	0.96	0.96
Ranks of PRCC			
INVENTORY	2	2	2
DECAY TIME	1	1	1
MANUAL REDIST.	3	3	3
EXTERNAL Hrs	6	4	4
INHALATION Hrs	5	6	6
DUST LOADING	4	5	5

^{137}Cs

	Inhalation	External	Total
Partial rank correlation coefficients (PRCC)			
INVENTORY	0.95	0.98	0.98
DECAY TIME	-0.51	-0.79	-0.79
MANUAL REDIST.	0.95	0.89	0.89
EXTERNAL Hrs	-0.08	0.79	0.79
INHALATION Hrs	0.55	-0.08	-0.08
DUST LOADING	0.95	-0.08	-0.08
R^2	0.96	0.97	0.97
Ranks of PRCC			
INVENTORY	3	1	1
DECAY TIME	5	3	3
MANUAL REDIST.	1	2	2
EXTERNAL Hrs	6	4	4
INHALATION Hrs	4	5	5
DUST LOADING	2	6	6

Table C.28 Sensitivity analysis results for ^{60}Co for Scenario No. 11 - Landfill Intrusion and Residence

	Inhalation	Ingestion	External	Total
Partial rank correlation coefficients (PRCC)				
INVENTORY	0.88	0.91	0.94	0.94
DECAY TIME	-0.94	-0.97	-0.97	-0.97
MANUAL REDIST.	0.87	0.93	0.62	0.62
EXTERNAL Hrs	-0.05	-0.05	0.60	0.59
INHALATION Hrs	0.46	-0.01	0.16	0.15
DUST LOADING	0.86	-0.04	-0.17	-0.17
LEAFY VEGS.	-0.01	0.15	-0.02	-0.03
OTHER VEGS.	0.17	0.68	-0.04	-0.04
FRUIT	0.03	0.27	-0.07	-0.07
GRAIN	-0.01	-0.22	-0.02	-0.03
HLEAFY VEGS.	-0.07	-0.06	0.00	0.00
R^2	0.94	0.96	0.96	0.96
Ranks of PRCC				
INVENTORY	2	3	2	2
DECAY TIME	1	1	1	1
MANUAL REDIST.	3	2	3	3
EXTERNAL Hrs	9	9	4	4
INHALATION Hrs	5	11	6	6
DUST LOADING	4	10	5	5
LEAFY VEG.	11	7	9	10
OTHER VEGS.	6	4	8	8
FRUIT	10	5	7	7
GRAIN	7	6	10	9
HLEAFY VEGS.	8	8	11	11

Table C.29 Sensitivity analysis results for ^{90}Sr for Scenario No. 11 - Landfill Intrusion and Residence

	Inhalation	Ingestion	External	Total
Partial rank correlation coefficients (PRCC)				
INVENTORY	0.95	0.96	0.96	0.96
DECAY TIME	-0.54	-0.64	-0.54	-0.64
MANUAL REDIST.	0.95	0.96	0.83	0.96
EXTERNAL Hrs	-0.09	-0.14	0.62	-0.14
INHALATION Hrs	0.56	-0.16	-0.14	-0.16
DUST LOADING	0.95	0.06	-0.08	0.06
LEAFY VEGS.	-0.17	0.07	-0.14	0.07
OTHER VEGS.	0.04	0.77	-0.03	0.77
FRUIT	0.02	0.27	-0.08	0.27
GRAIN	-0.09	0.04	-0.07	0.04
HLEAFY VEGS.	-0.01	0.11	-0.03	0.11
R^2	0.96	0.97	0.94	0.97
Ranks of PRCC				
INVENTORY	2	1	1	1
DECAY TIME	5	4	4	4
MANUAL REDIST.	1	2	2	2
EXTERNAL Hrs	8	7	3	7
INHALATION Hrs	5	6	6	6
DUST LOADING	3	10	7	10
LEAFY VEG.	6	9	5	9
OTHER VEGS.	9	3	11	3
FRUIT	10	5	8	5
GRAIN	7	11	9	11
HLEAFY VEGS.	11	8	10	8

Table C.30 Sensitivity analysis results for ^{241}Am for Scenario No. 11 - Landfill Intrusion and Residence

	Inhalation	Ingestion	External	Total
Partial rank correlation coefficients (PRCC)				
INVENTORY	0.95	0.97	0.98	0.98
DECAY TIME	-0.51	-0.63	-0.80	-0.79
MANUAL REDIST.	0.95	0.97	0.89	0.89
EXTERNAL Hrs	-0.08	-0.12	0.79	0.78
INHALATION Hrs	0.56	-0.08	-0.08	-0.11
DUST LOADING	0.95	0.06	-0.08	-0.07
LEAFY VEGS.	-0.15	0.05	-0.02	0.01
OTHER VEGS.	0.05	0.74	-0.43	-0.02
FRUIT	0.01	0.23	-0.15	-0.02
GRAIN	-0.08	0.20	0.00	0.03
HLEAFY VEGS.	0.00	0.12	-0.07	-0.07
R^2	0.96	0.97	0.97	0.97
Ranks of PRCC				
INVENTORY	2	1	1	1
DECAY TIME	5	4	3	3
MANUAL REDIST.	1	2	2	2
EXTERNAL Hrs	7	7	4	4
INHALATION Hrs	4	9	6	6
DUST LOADING	3	10	7	7
LEAFY VEG.	6	11	10	11
OTHER VEGS.	9	3	9	10
FRUIT	10	5	5	5
GRAIN	8	6	11	9
HLEAFY VEGS.	11	8	8	8

Table C.31 Ranking of sensitivity of input parameters

Scenario	Nuclide	Parameter Ranking[a] Most Sensitive	2nd Most Sensitive	3rd Most Sensitive
1	^{60}Co	INVENTORY	EXTERNAL Hrs	DUST LOADING
1	^{192}Ir	INVENTORY	EXTERNAL Hrs	DUST LOADING
2	^{60}Co	INVENTORY	DUST LOADING	EXTERNAL Hrs
2	^{137}Cs	INVENTORY	EXTERNAL Hrs	DUST LOADING
2	^{192}Ir	INVENTORY	DUST LOADING	INHALATION Hrs
3	^{60}Co	FLOW	FISH	BEEF
3	^{90}Sr	FLOW	FISH	ROOT VEGETableS
3	^{137}Cs	FLOW	FISH	GRAIN
3	^{241}Am	FLOW	FISH	LEAFY VEGETableS
4	^{60}Co	INVENTORY	EXTERNAL Hrs	INHALATION Hrs
4	^{192}Ir	INVENTORY	EXTERNAL Hrs	INHALATION Hrs
4	^{241}Am	INVENTORY	DUST LOADING	INHALATION Hrs
5	^{137}Cs	CHI/Q	BEEF	MILK
5	^{241}Am	CHI/Q	INHALATION Hrs	EXTERNAL Hrs
6	^{60}Co	INVENTORY	DUST LOADING	INHALATION Hrs
6	^{192}Ir	INVENTORY	DUST LOADING	INHALATION Hrs
7	^{90}Sr	INVENTORY	OTHER VEGETableS	FRUIT
8	^{60}Co	INVENTORY	EXTERNAL Hrs	INHALATION Hrs
8	^{137}Cs	INVENTORY	EXTERNAL Hrs	INHALATION Hrs
8	^{192}Ir	INVENTORY	EXTERNAL Hrs	DUST LOADING
9	^{60}Co	INVENTORY	EXTERNAL Hrs	INHALATION Hrs
9	^{137}Cs	INVENTORY	EXTERNAL Hrs	INHALATION Hrs
9	^{192}Ir	INVENTORY	EXTERNAL Hrs	INHALATION Hrs
9	^{241}Am	INVENTORY	INHALATION Hrs	DUST LOADING
10	^{60}Co	DECAY TIME	INVENTORY	MANUAL REDISTRIBUTION
10	^{137}Cs	INVENTORY	MANUAL REDISTR.	DECAY TIME
11	^{60}Co	DECAY TIME	INVENTORY	MANUAL REDISTRIBUTION
11	^{90}Sr	INVENTORY	MANUAL REDISTR.	OTHER VEGETableS
11	^{137}Cs	INVENTORY	MANUAL REDISTR.	DECAY TIME

(a) Ranking applies to total dose calculated by the GENII code using the uncertainty sample sets.

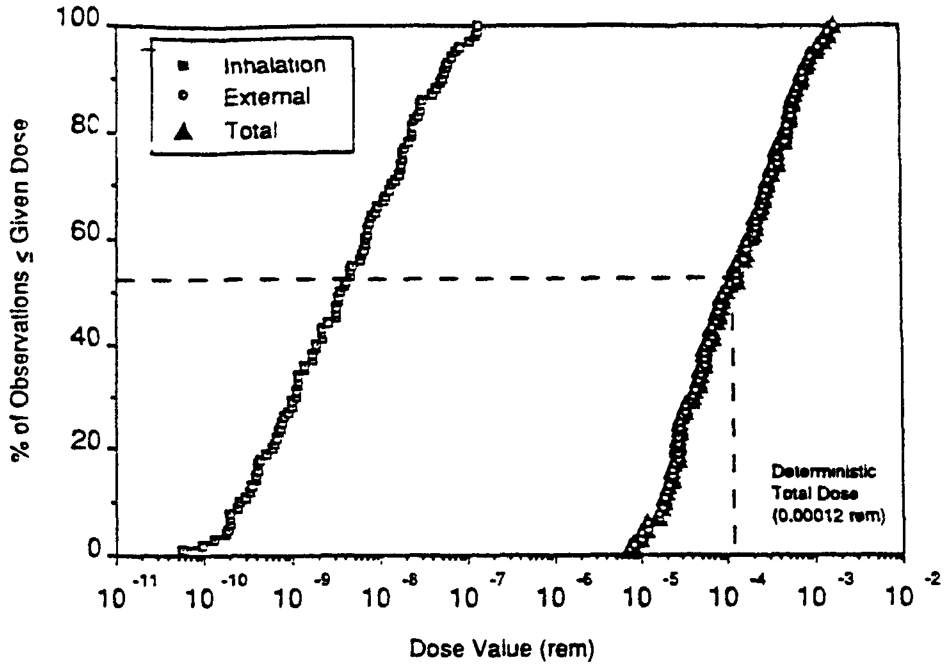

Figure C.1 Frequency distribution of inhalation, external, and total doses ^{60}Co from uncertainty analysis of Scenario No. 1 - Sewer System Inspector

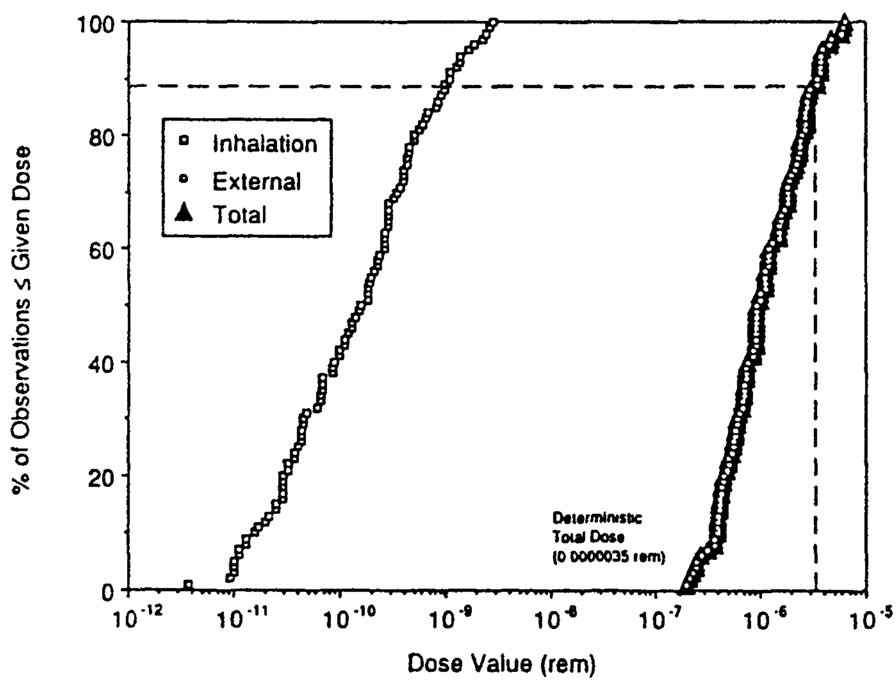

Figure C.2 Frequency distribution of inhalation, ingestion, and total doses from ^{192}Ir from uncertainty analysis of Scenario No. 1 - Sewer System Inspector

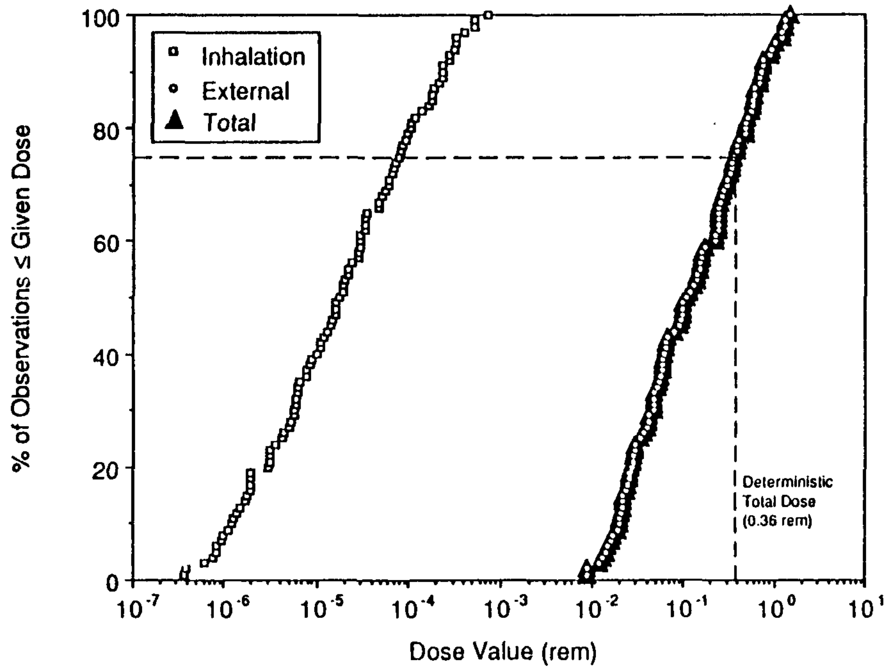

Figure C.3 Frequency distribution of inhalation, external, and total doses from ^{60}Co from uncertainty analysis of Scenario No. 2 - STP Sludge Process Operator

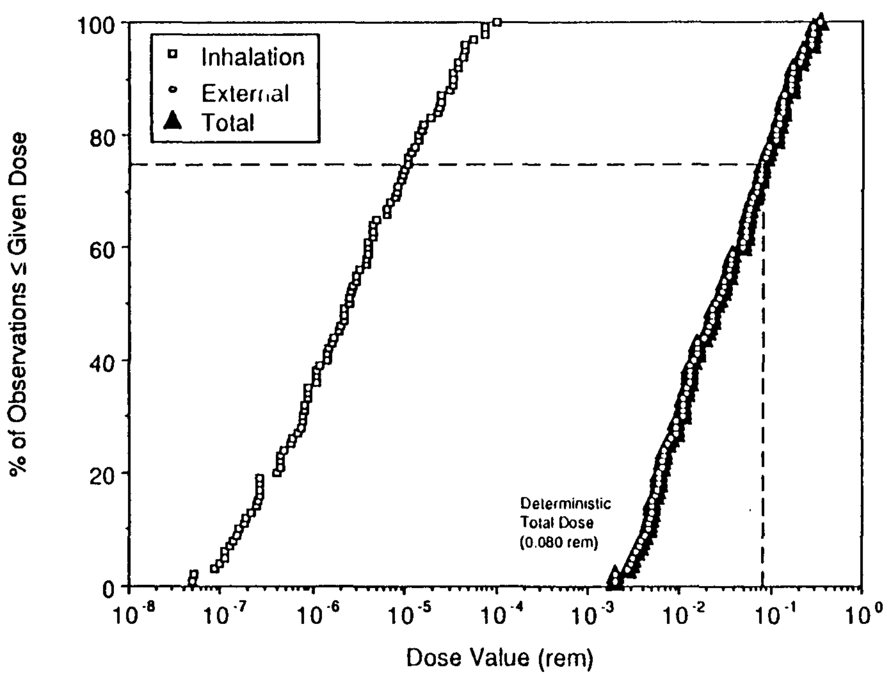

Figure C.4 Frequency distribution of inhalation, external, and total doses from ^{137}Cs from uncertainty analysis of Scenario No. 2 - STP Sludge Process Operator

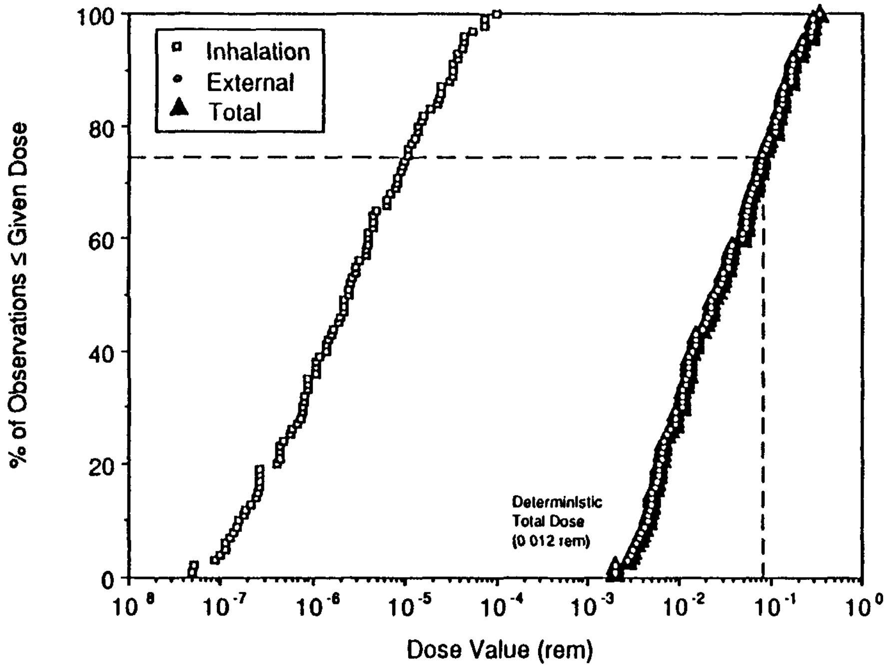

Figure C.5 Frequency distribution of inhalation, external, and total doses from ^{192}Ir from uncertainty analysis of Scenario No. 2 - STP Sludge Process Operator

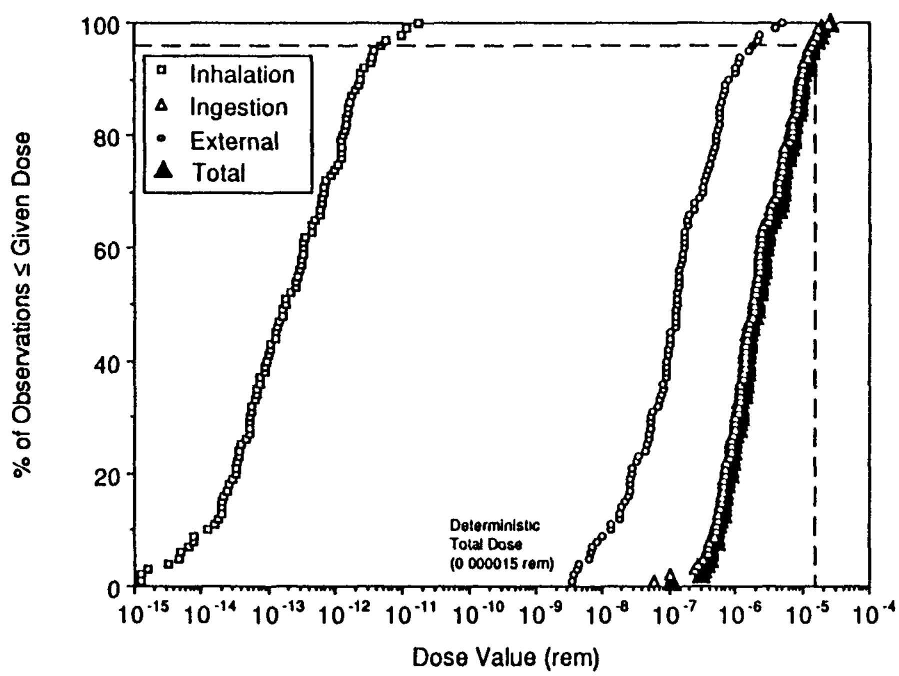

Figure C.6 Frequency distribution of inhalation, ingestion, external, and total doses from ^{60}Co from uncertainty analysis of Scenario No. 3 - STP Liquid Effluent

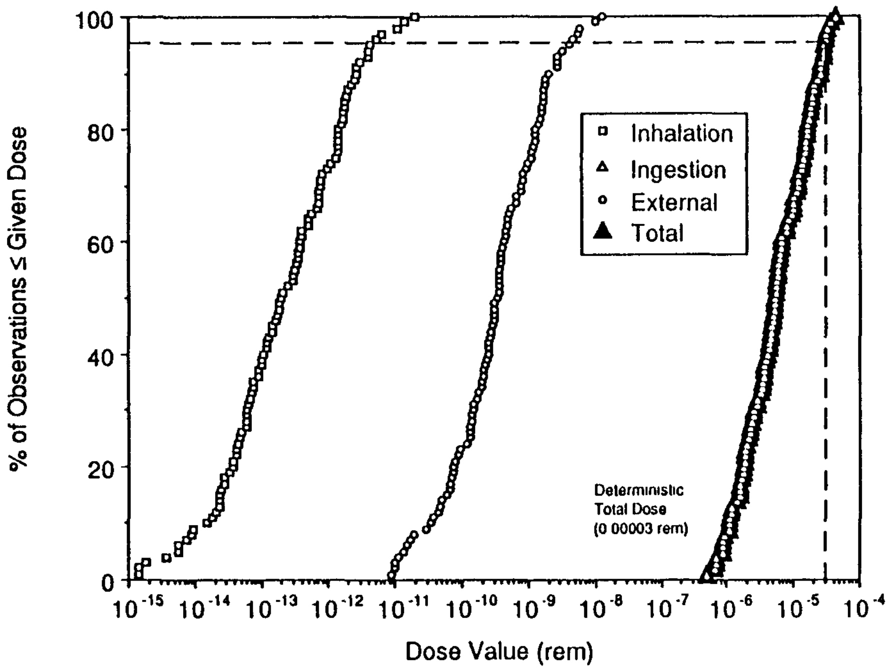

Figure C.7 Frequency distribution of inhalation, ingestion, external, and total doses from ^{90}Sr from uncertainty analysis of Scenario No. 3 - STP Liquid Effluent

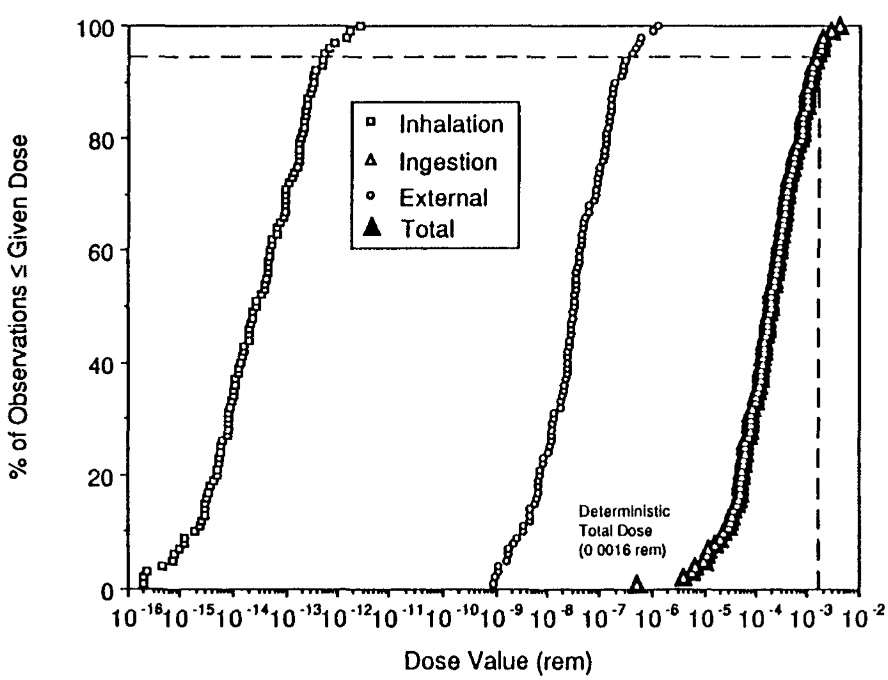

Figure C.8 Frequency distribution of inhalation, ingestion, external, and total doses from ^{137}Cs from uncertainty analysis of Scenario No. 3 - STP Liquid Effluent

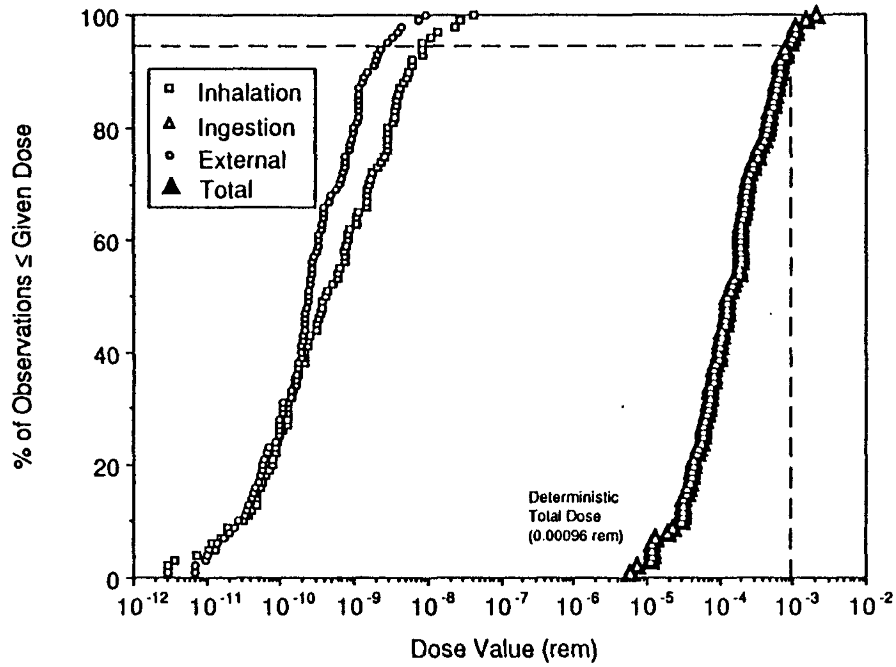

Figure C.9 Frequency distribution of inhalation, ingestion, external, and total doses from ^{241}Am from uncertainty analysis of Scenario No. 3 - STP Liquid Effluent

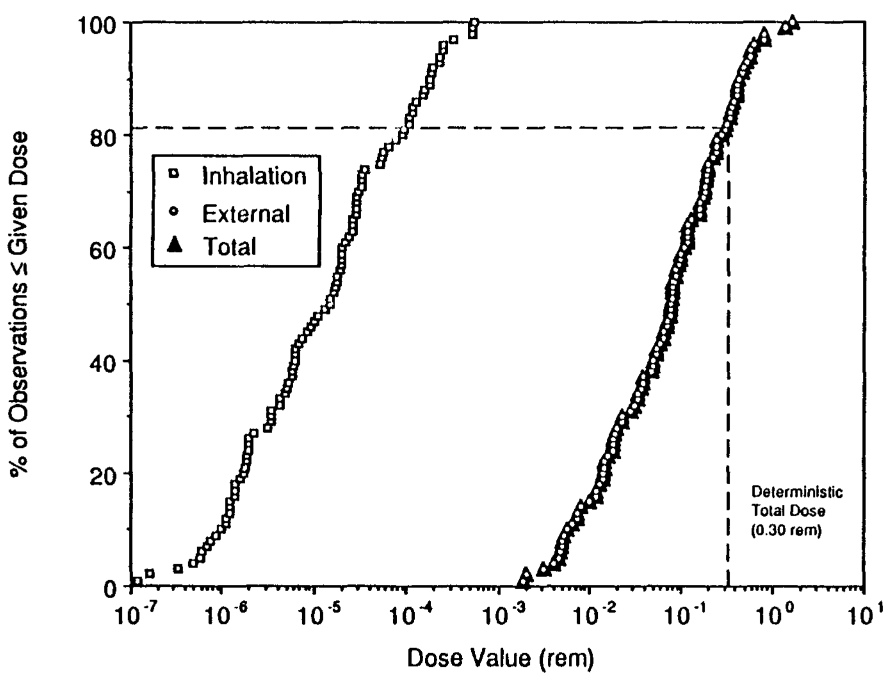

Figure C.10 Frequency distribution of inhalation, external, and total doses from ^{60}Co from uncertainty analysis of Scenario No. 4 - STP Incinerator Operator

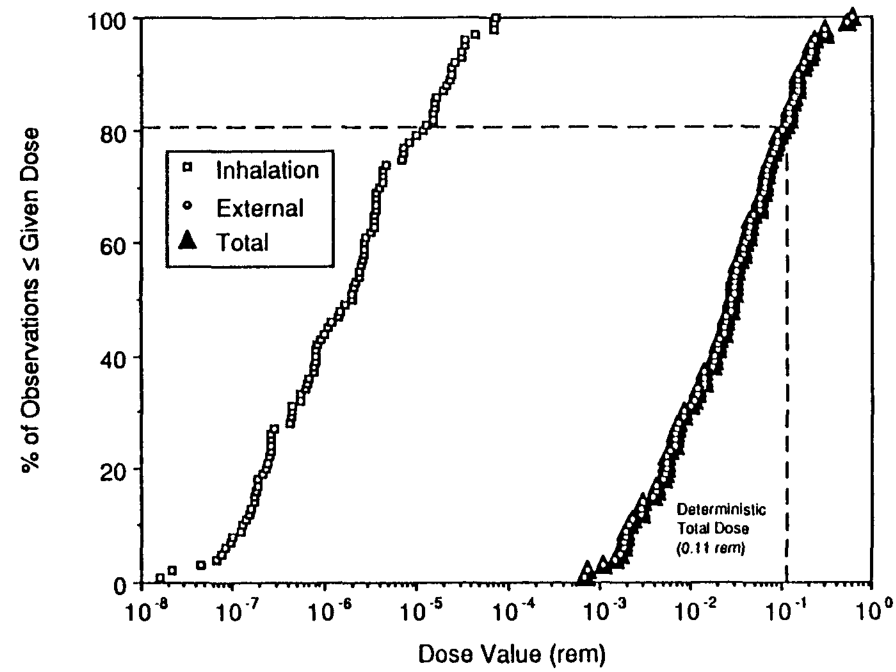

Figure C.11 Frequency distribution of inhalation, external, and total doses from ^{192}Ir from uncertainty analysis of Scenario No. 4 - STP Incinerator Operator

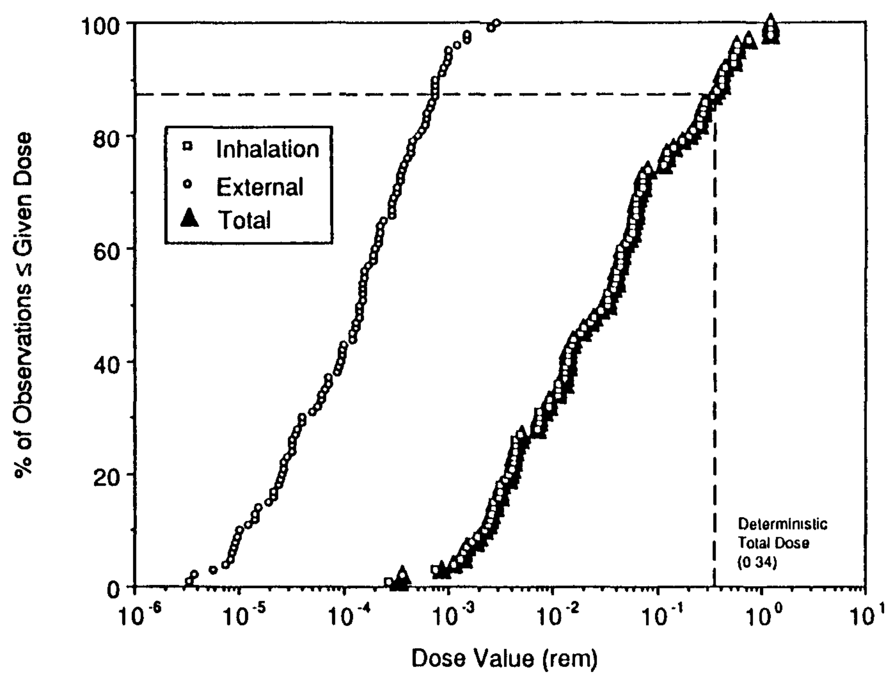

Figure C.12 Frequency distribution of inhalation, external, and total doses from ^{241}Am from uncertainty analysis of Scenario No. 4 - STP Incinerator Operator

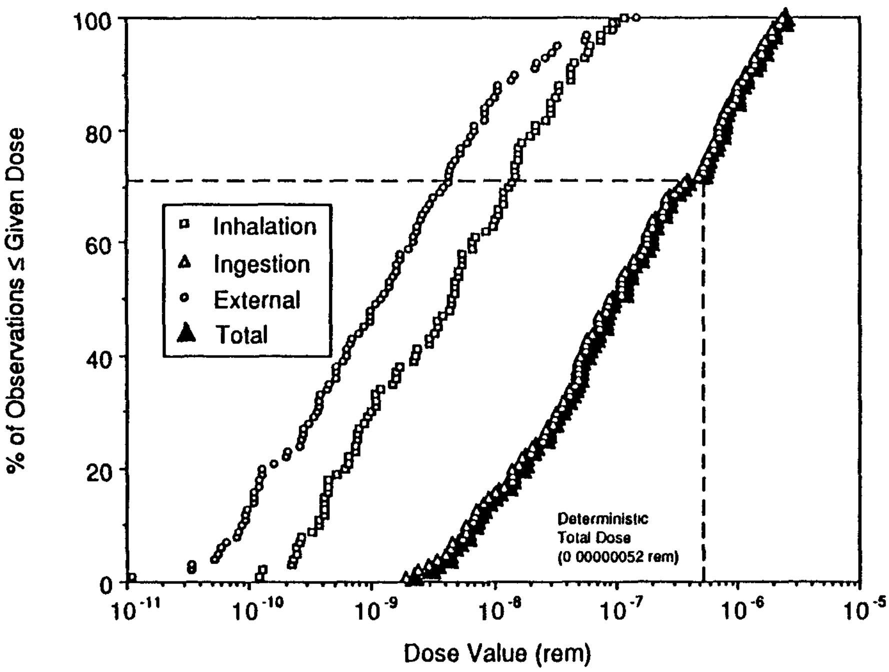

Figure C.13 Frequency distribution of inhalation, ingestion, external, and total doses from ^{137}Cs from uncertainty analysis of Scenario No. 5 - Sludge Incinerator Effluent

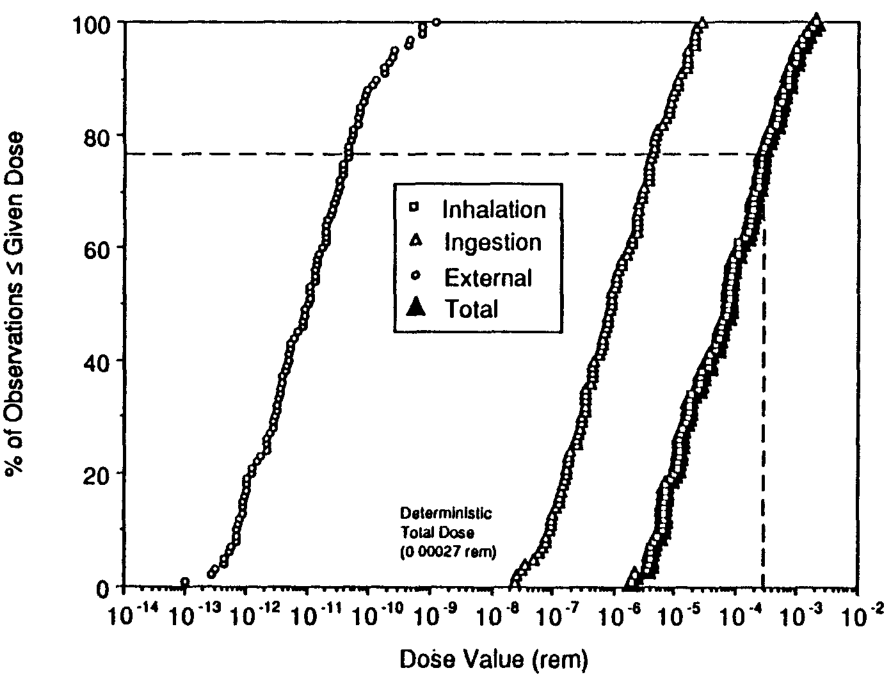

Figure C.14 Frequency distribution of inhalation, ingestion, external, and total dose from ^{241}Am from uncertainty analysis of Scenario No. 5 - Sludge Incinerator Effluent

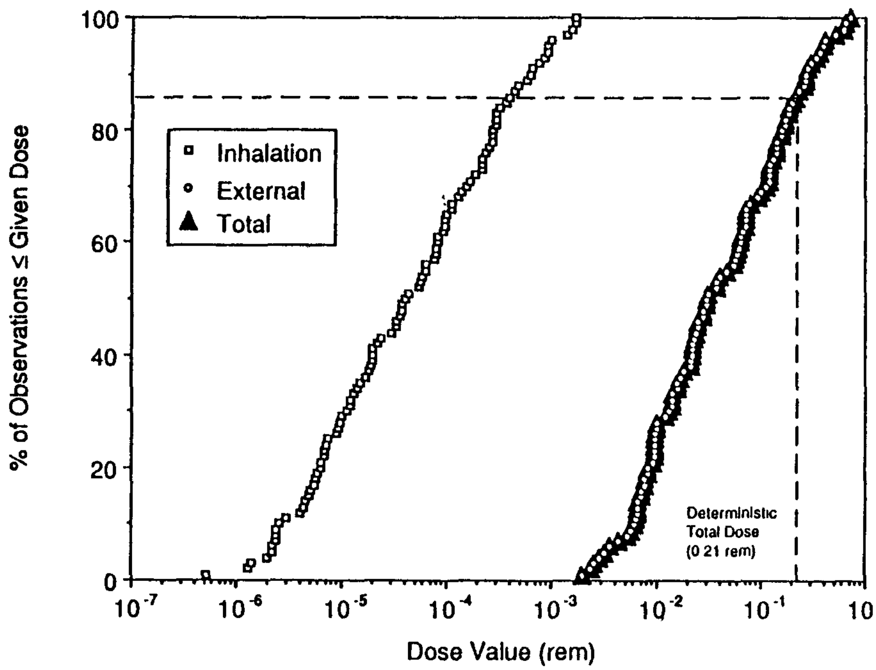

Figure C.15 Frequency distribution of inhalation, external, and total doses from ^{60}Co from uncertainty analysis of Scenario No. 6 - Incinerator Ash Disposal Truck Driver

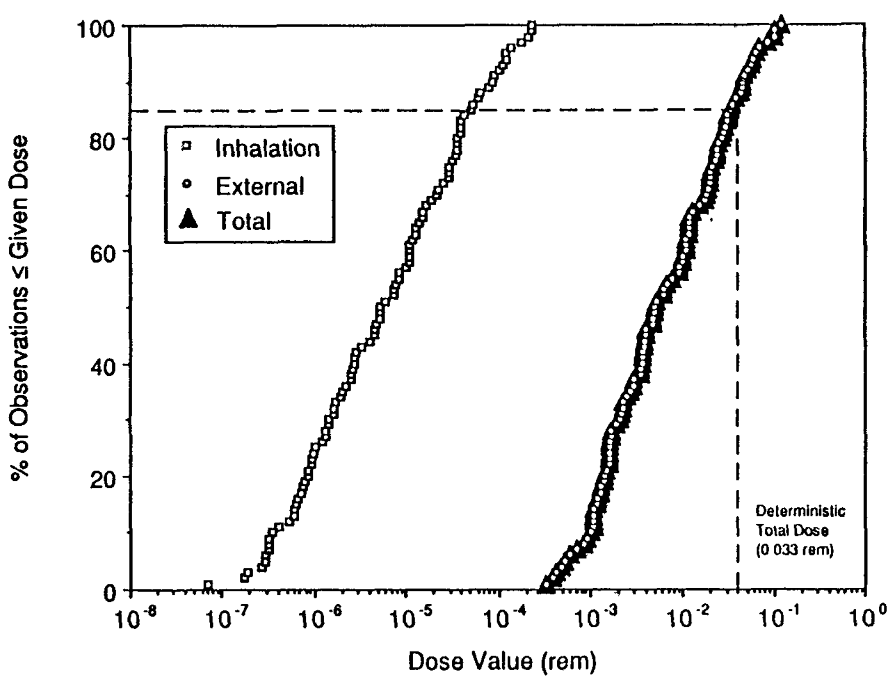

Figure C.16 Frequency distribution of inhalation, external, and total doses from ^{192}Ir from uncertainty analysis of Scenario No. 6 - Incinerator Ash Disposal Truck Driver

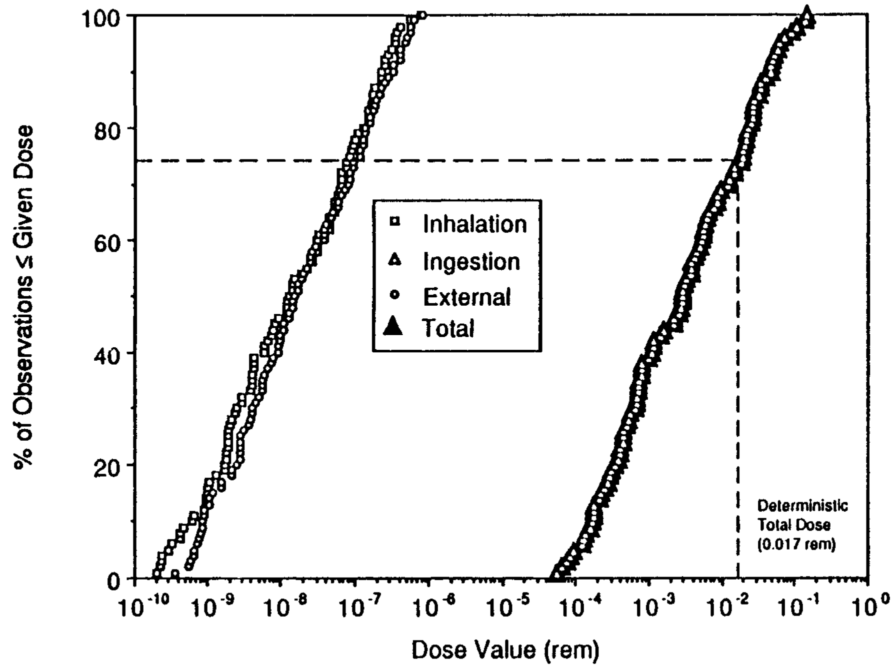

Figure C.17 **Frequency distribution of inhalation, ingestion, external, and total doses from ^{90}Sr from uncertainty analysis of Scenario No. 7 - Sludge Application to Agricultural Soil**

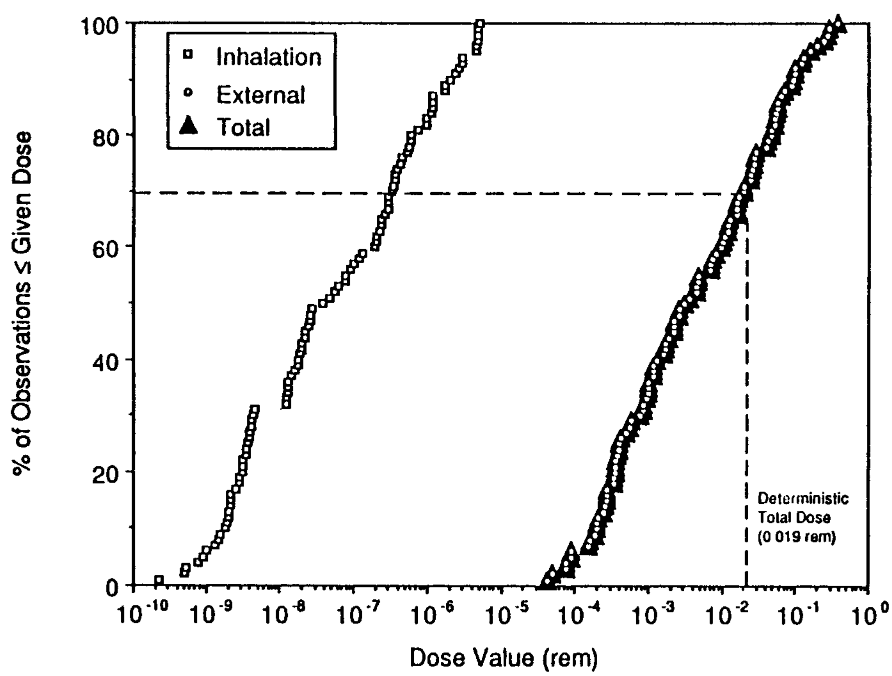

Figure C.18 **Frequency distribution of inhalation, external, and total doses from ^{60}Co from uncertainty analysis of Scenario No. 8 - Sludge Application to Non-Agricultural Soil**

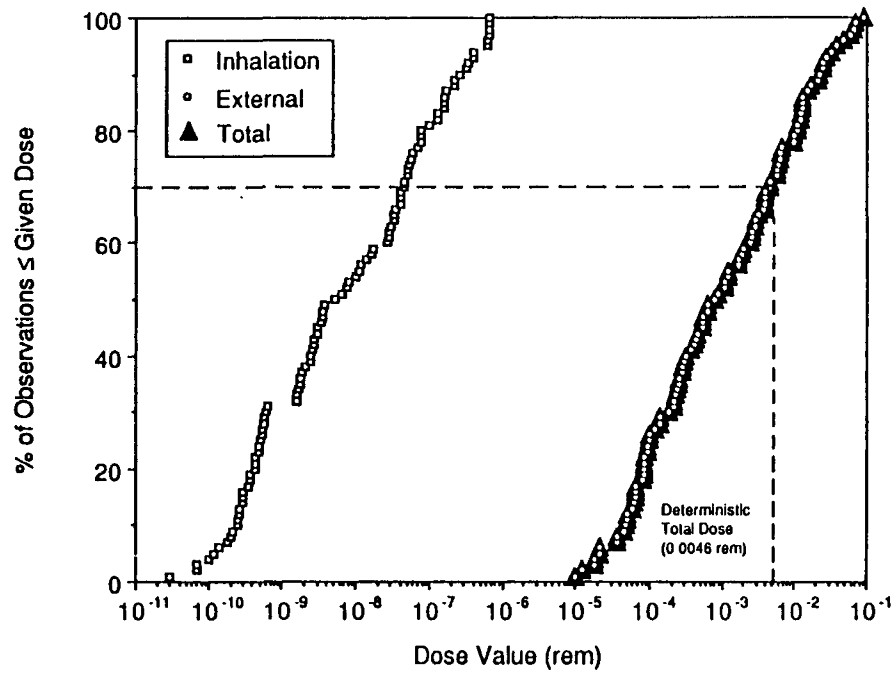

Figure C.19 **Frequency distribution of inhalation, external, and total doses from ^{137}Cs from uncertainty analysis of Scenario No. 8 - Sludge Application to Non-Agricultural Soil**

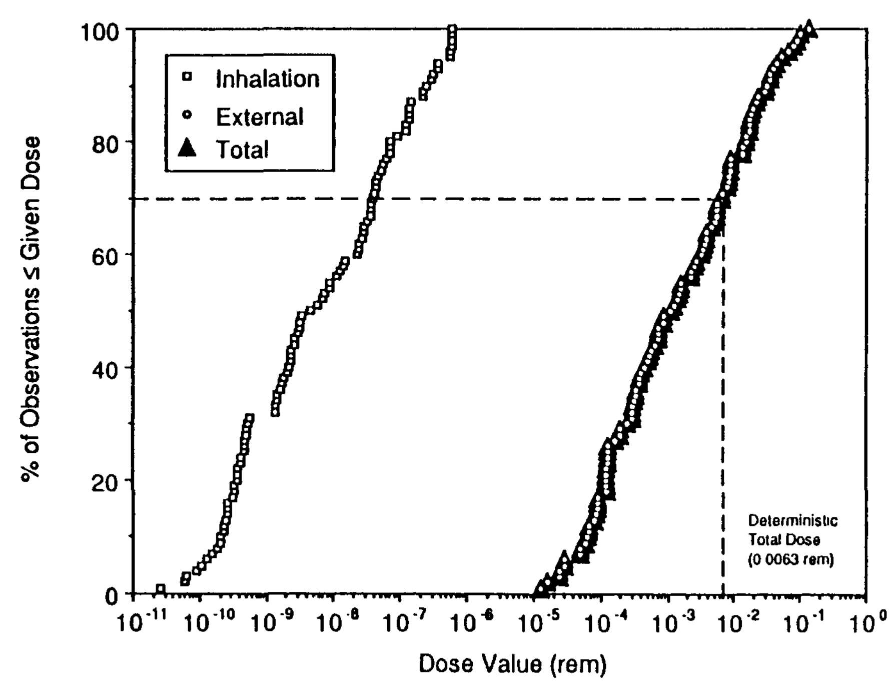

Figure C.20 **Frequency distribution of inhalation, external, and total doses from ^{192}Ir from uncertainty analysis of Scenario No. 8 - Sludge Application to Non-Agricultural Soil**

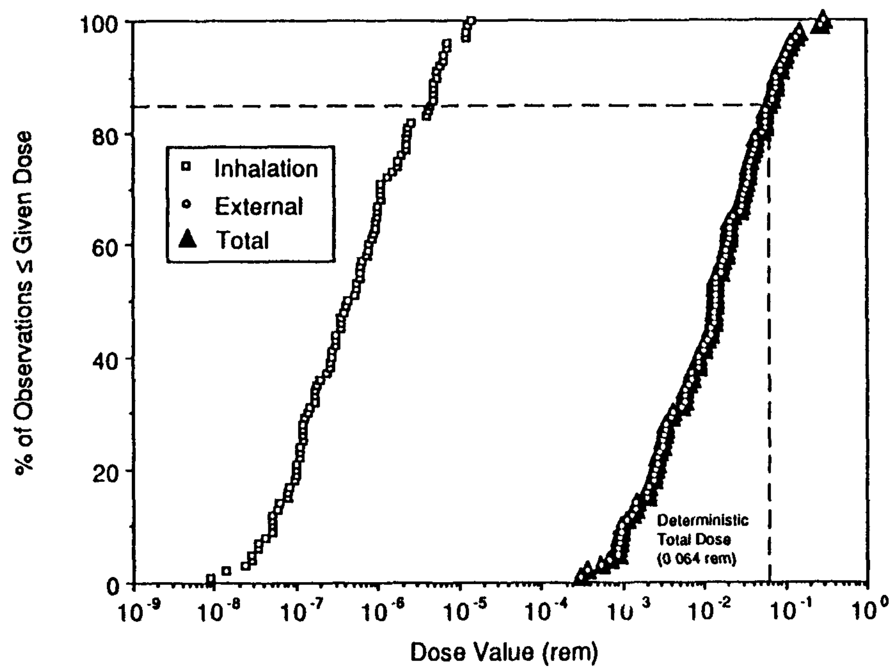

Figure C.21 Frequency distribution of inhalation, external, and total doses from ^{60}Co from uncertainty analysis of Scenario No. 9 - Landfill Equipment Operator

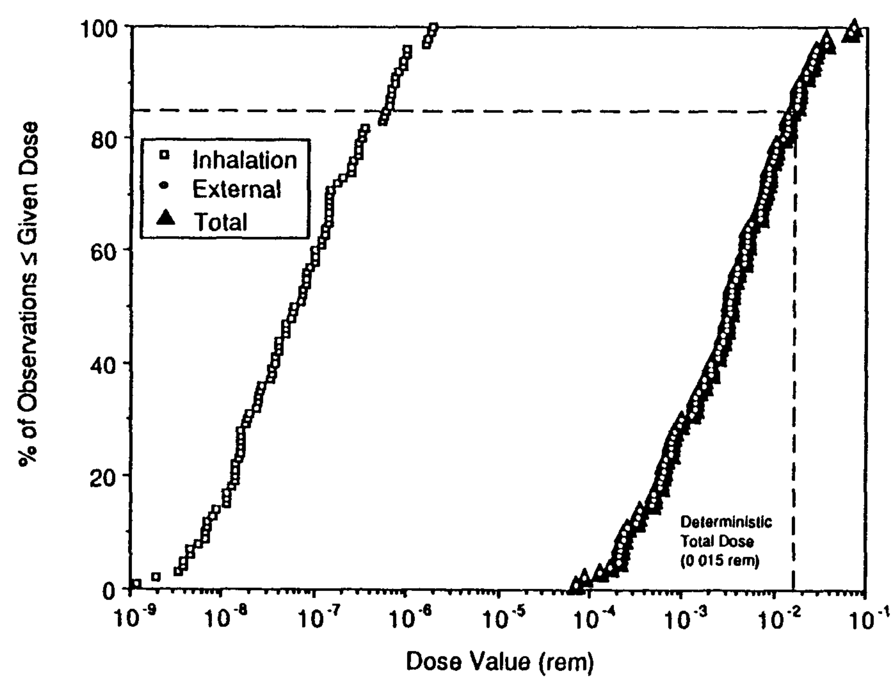

Figure C.22 Frequency distribution of inhalation, external, and total doses from ^{137}Cs from Uncertainty Analysis of Scenario No. 9 - Landfill Equipment Operator

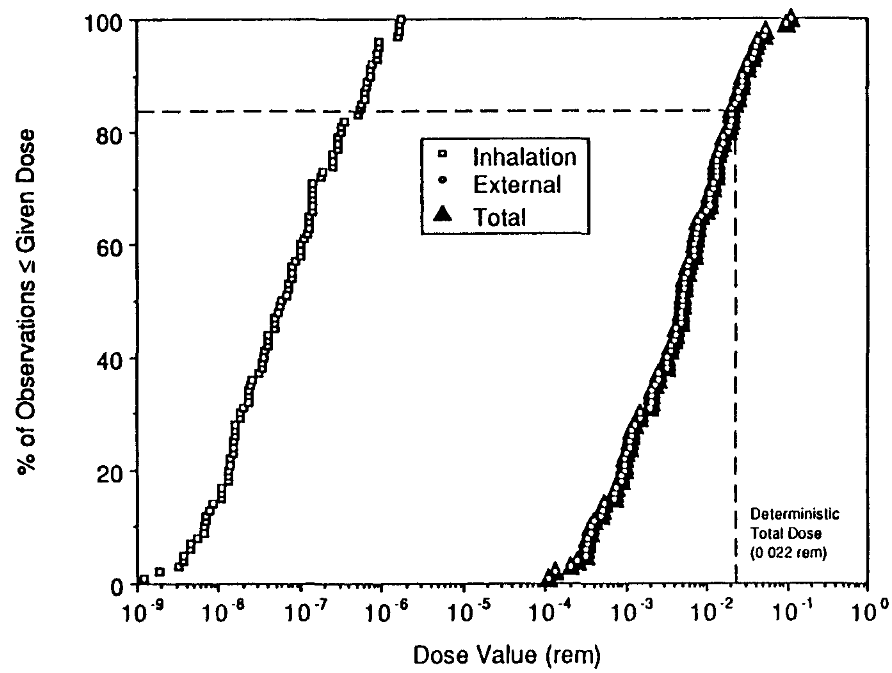

Figure C.23 **Frequency distribution of inhalation, external, and total doses from ^{192}Ir from uncertainty analysis of Scenario No. 9 - Landfill Equipment Operator**

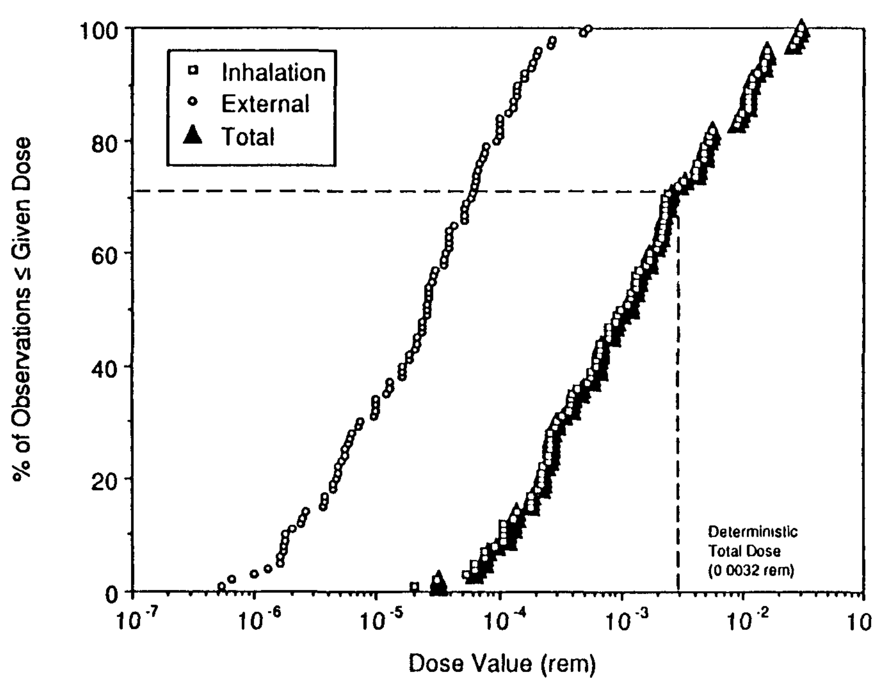

Figure C.24 **Frequency distribution of inhalation, external, and total doses from ^{241}Am from uncertainty analysis of Scenario No. 9 - Landfill Equipment Operator**

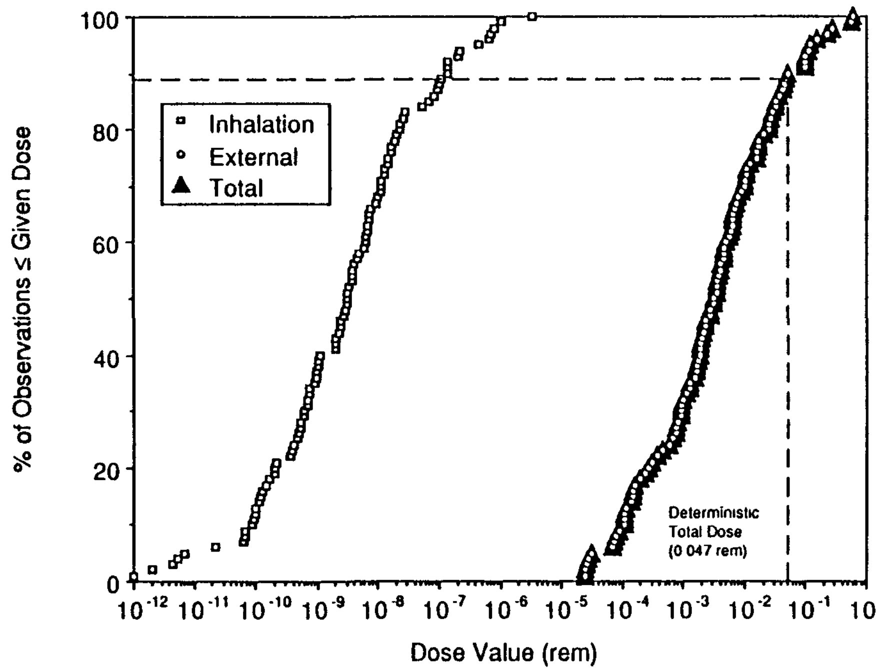

Figure C.25 Frequency distribution of inhalation, external, and total doses from ^{60}Co from uncertainty analysis of Scenario No. 10 - Landfill Intrusion and Construction

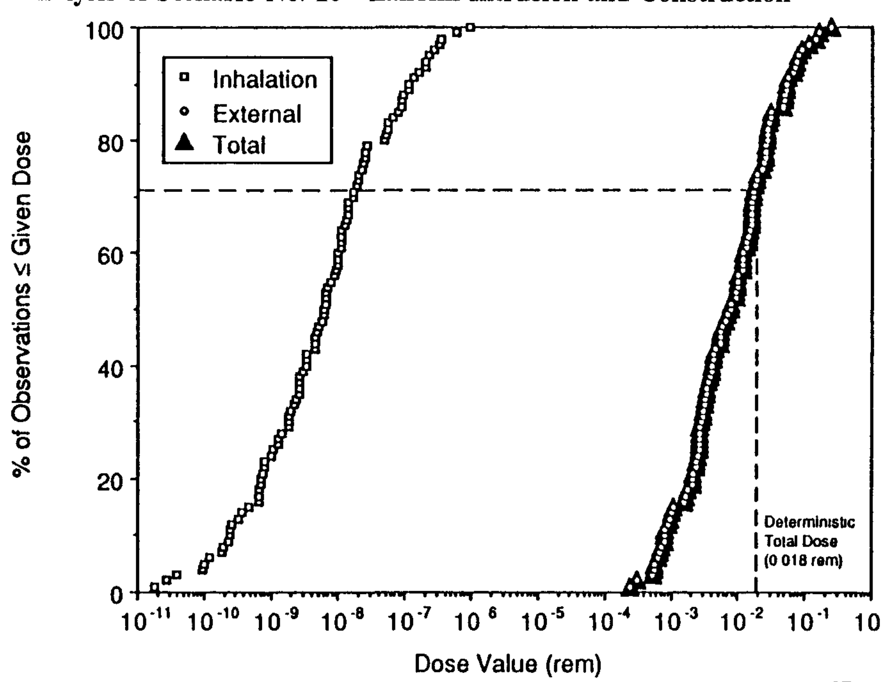

Figure C.26 Frequency distribution of inhalation, external, and total doses from ^{137}Cs from uncertainty analysis of Scenario No. 10 - Landfill Intrusion and Construction

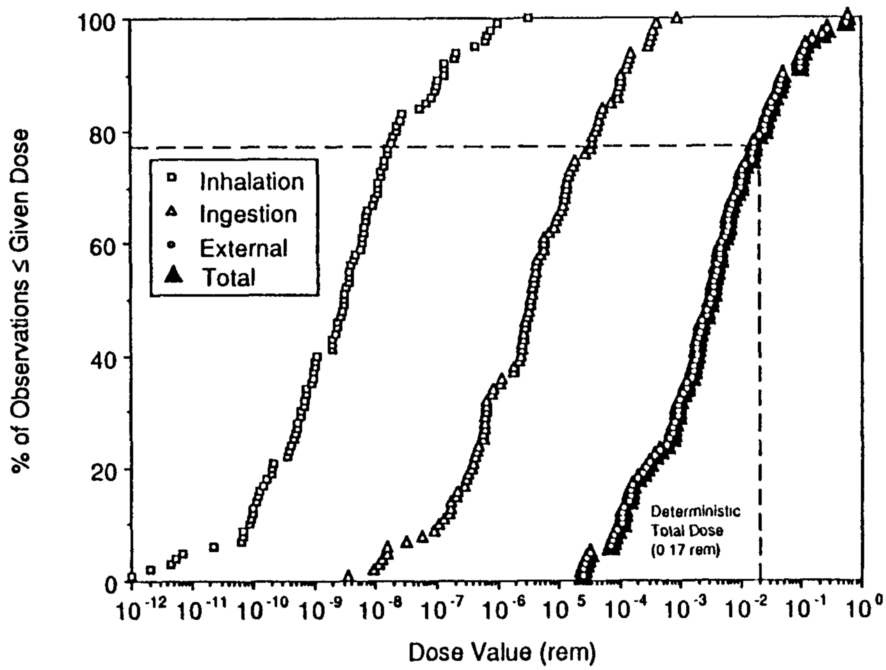

Figure C.27 Frequency distribution of inhalation, ingestion, external, and total doses from ^{60}Co from uncertainty analysis of Scenario No. 11 - Landfill Intrusion and Residence

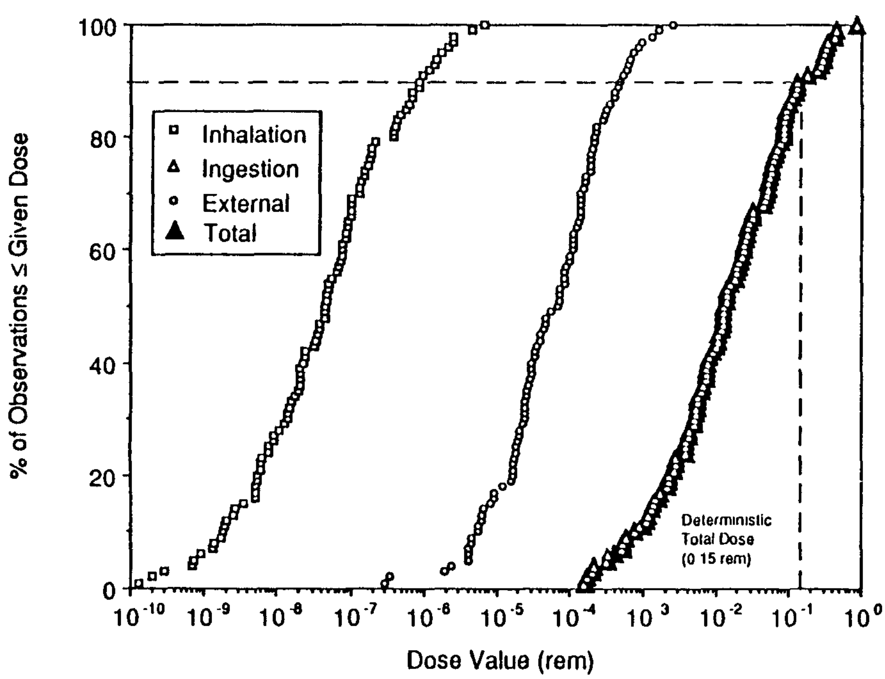

Figure C.28 Frequency distribution of inhalation, ingestion, external, and total doses from ^{90}Sr from uncertainty analysis of Scenario No. 11 - Landfill Intrusion and Residence

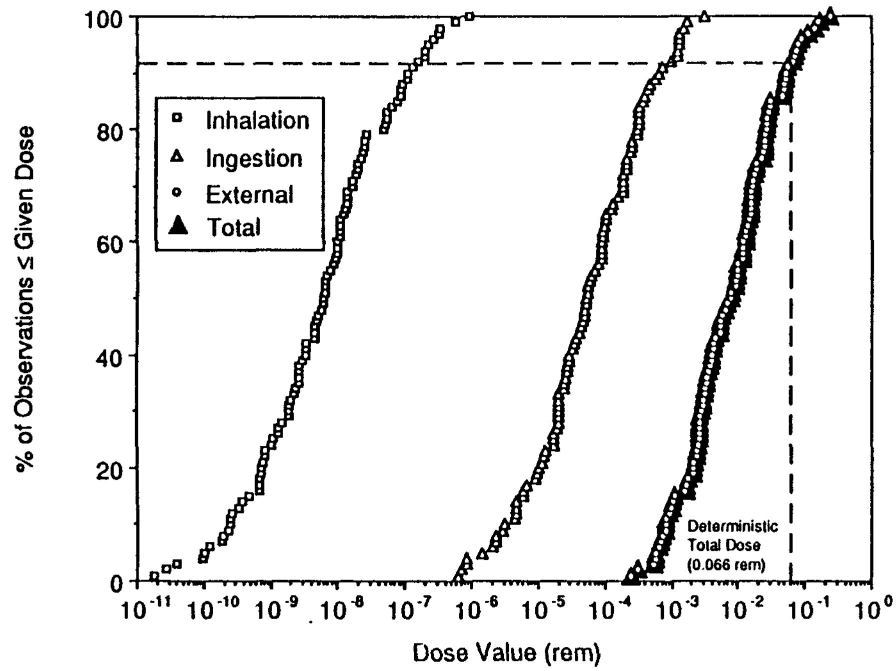

Figure C.29 Frequency distribution of inhalation, external, and total doses from ^{137}Cs from uncertainty analysis of Scenario No. 11 - Landfill Intrusion and Residence

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