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DEFINITION OF INTRUSION SCENARIOS AND EXAMPLE CONCENTRATION RANGES FOR THE DISPOSAL OF NEAR-SURFACE WASTE AT THE HANFORD SITE

R. L. Aaberg
W. E. Kennedy, Jr.

V. W. Thomas, Project Manager

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Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

The U.S. Department of Energy (DOE) is in the process of conducting performance assessments of its radioactive waste sites and disposal systems to ensure that public health and safety are protected, the environment is preserved, and that no remedial actions after disposal are required. For existing disposal sites, performance assessments will be conducted to ensure that the action taken will be adequate to isolate the disposed waste or remove existing contamination problems. Hanford Site low-level waste performance assessments are technical evaluations of waste sites or disposal systems that provide a basis for making decisions using established criteria. The purpose of this document is to provide a family of scenarios to be considered when calculating radionuclide exposure to individuals who may inadvertently intrude into near-surface waste disposal sites. Specific performance assessments will use modifications of the general scenarios described here to include additional site/system details concerning the engineering design, waste form, inventory, and environmental setting.

This document also describes an example application of the Hanford-specific scenarios in the development of example concentration ranges for the disposal of near-surface wastes. The overall goal of the example calculations is to illustrate the application of the scenarios in a performance assessment to assure that people in the future cannot receive a dose greater than an established limit. Again, specific performance assessments will use modified scenarios and data to establish acceptable disposal concentrations for specific disposal sites and conditions.

Six scenarios deemed to be credible under certain conditions were postulated:

- <u>Drilling</u>. A well is drilled through the underground waste form and radioactive material is brought to the surface and distributed among the surface soils.
- <u>Post-Drilling</u>. An individual is exposed at later times to the radioactive waste that was distributed in surface soils during the Drilling Scenario.
- <u>Excavation</u>. A construction worker excavates into the waste form mixing the radioactive material with the surface soil.

- Post-Excavation. An individual living on or near the waste site is exposed to the distributed waste/soil mixture from the Excavation Scenario.

- Residential Garden. An individual lives over the disposal site and raises garden crops over the buried waste. There are three subcases: two with different assumed root uptake rates based on disposal depth and a third with inclusion of biotic transport of contaminants by native vegetation and animals after loss of institutional control.

- Farming. This scenario is similar to the Residential Garden Scenarios, but includes animal product ingestion pathways.

As a demonstration of the use of the intruder scenarios, example disposal concentration limits are developed for selected radionuclides based on previously established annual exposure limits. DOE-defined limits applicable to intrusion are found in DOE Order 5400.5 and are 100 mrem/yr for continuous exposure and 500 mrem/yr for short-term exposure. By dividing the intrusion dose limits by the dose-per-unit concentration evaluated for each scenario, ranges of example disposal concentrations for selected radionuclides were developed. Ranges of disposal concentrations in the examples reflect three key factors: 1) the dependency of the scenario on depth of disposal (the waste can be disposed at a range of depths below the earth's surface, and not all of the scenarios can credibly occur at all depths), 2) the appropriate annual exposure limit for each scenario (100 versus 500 mrem/yr), and 3) the time after disposal that intrusion is assumed to occur. Example concentration limits found in this document are based on doses calculated using the GENII software system (Napier et al. 1988b). Assignment of parameters used in GENII, discussed in Appendix A, represent implicit assumptions in the scenario applications. For each radionuclide, the most restrictive concentration limit from the scenarios evaluated was identified. Specific assessments for proposed waste disposal sites will follow this general scenario analysis approach in establishing acceptable radionuclide concentration limits for disposal.

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1.0 INTRODUCTION

The U.S. Department of Energy (DOE), under the guidance of DOE Order 5820.2A, Chapter III (DOE 1988), requires low-level radioactive waste to be managed and disposed in a manner that will 1) protect the health and safety of the public, 2) preserve the environment, and 3) ensure that no remedial actions will be necessary after termination of operations. The DOE is in the process of conducting site-specific performance assessments to ensure compliance with requirements of that DOE Order. Performance assessments are generally the process of conducting technical evaluations of waste site/disposal systems to provide a basis for decisions concerning design, acceptable waste loadings, and regulatory compliance. A more formal definition of performance assessment was provided by the DOE Low-Level Waste (LLW) Program Office (Case and Otis 1988) as being "a systematic analysis of a LLW management disposal facility and its environs for the purpose of demonstrating compliance with specific radiological performance objectives." The DOE has provided a series of documents on the performance assessment process: Guidelines for Radiological Performance Assessment of DOE Low-Level Radioactive Waste, Treatment, Storage, or Disposal Sites (Case and Otis 1988), Recommended Format and Content for DOE Low-Level Waste Disposal Facility Radiological Performance Assessment Reports (Case et al. 1989), and Intruder Scenarios for Site-Specific Low-Level Radioactive Waste Classification (Kennedy and Peloquin 1988). Additional guidance on the performance assessment process has been provided by the U.S. Nuclear Regulatory Commission (NRC) in Background Information for the Development of a Low-Level Waste Performance Assessment Methodology (Shippers and Harlan 1989).

To assist the DOE in conducting these performance assessments at the Hanford Site, the Pacific Northwest Laboratory (PNL) developed a family of scenarios for calculating radiation doses to individuals who may inadvertently intrude into near-surface waste disposal sites. These scenarios will serve as a reference for consistently evaluating the acceptability of plans for the near-surface disposal of low-level waste at Hanford. The scenarios presented can be used directly or modified to include additional engineering design, waste form, inventory, and environmental data. Performance assessments for specific disposal sites may also include an analysis of other effects, including the potential for groundwater migration and potential impacts of nonradioactive hazardous materials in the wastes.

The scope of this document is limited in several ways:

1. Only the radiation exposure scenarios associated with inadvertent intruders are described. The example calculations do not apply to the intentional intruder, such as an archaeological explorer.

2. Only example calculations of limiting concentrations for disposal of specific radionuclides are provided. Establishment of final limiting concentrations for radionuclides for specific disposal systems and evaluation of consequences from disposal of hazardous (carcinogenic or noncarcinogenic) chemicals for specific disposal options are outside the scope of this analysis.

3. Potential impacts from migration of radioactive materials to accessible groundwater or surface water are not considered in this document. For long-lived mobile radionuclides such as technetium-99 or iodine-129, the limiting concentrations based on water contamination might be more restrictive than those based on the human intrusion scenarios presented in this document.

Also, other aspects of waste disposal, such as transportation of waste and occupational exposure are not considered; however, these other aspects may be important considerations in some site-specific performance assessments. A thorough analysis must consider all credible routes for exposure before final concentration limits are established.

This document presents background information from the literature on intruder scenarios, describes the family of low-level waste intruder scenario developed for the Hanford Site, and discusses scenario applicability and dose limits. It also summarizes the results of the example calculations. The appendixes contain a discussion of parametric values used to develop and evaluate the scenarios and details of the example calculations of allowable concentration limits in waste to be disposed.

2.0 BACKGROUND

Scenarios for intrusion into low-level waste sites are descriptions of postulated activities of individuals who inadvertently come into contact with disposed waste. Scenarios are assumed to occur at specific points in time, generally 100 years after disposal. Generally, the earlier the scenario occurs, the more restrictive is the disposal case because less radioactive decay has occurred. Consequences of each scenario may also depend on the depths at which the waste is disposed and the magnitude of the intrusion event (i.e., the volume of waste an individual disturbs during intrusion).

To be credible, scenarios by which a person is postulated to be exposed to contaminants from waste disposed at the Hanford Site must cover a range of waste disposal configurations (for example, variable disposal depth and the presence or absence of a protective barrier/marker system). The scenarios, coupled with selected waste disposal configurations, are evaluated for this report using computerized mathematical models to calculate radiation doses to the exposed individuals. The radiation doses, in terms of either the annual dose received per unit concentration of individual radionuclides in the waste or the total dose from a known concentration of radionuclides in waste, are calculated for this report using the GENII software package (Napier et al. 1988b). The GENII software package (which consists of the code and supporting data libraries) is the method approved by the Hanford Environmental Dose Overview Panel for use at the Hanford Site for estimating radiation doses to the public from Site operations. The method is consistent with the dosimetry requirements of the DOE (1988a; 1988b). Maximum allowable concentrations of radionuclides in the waste to be disposed of may be calculated for each intruder scenario by dividing established annual exposure limits by previously calculated dose-per-unit concentrations.

The overall goal of intruder scenario analyses is to ensure protection for people who may be inadvertently exposed to the disposed waste some time in the future. Regulatory guidance provided by the NRC in 10 CFR 61 (NRC 1982a) is commonly used as a benchmark when developing preliminary exposure scenarios. Scenarios developed in this document are based on previous work found in the literature for a number of disposal situations considered by the NRC, NEA/OECD, and DOE. This section provides background information from the literature relating to identification and description of human intruder scenarios that may apply to low-level waste disposal sites at Hanford.

2.1 INADVERTENT INTRUDERS

Human intrusion into a disposal site may occur at any time after loss of institutional control. Based on information in DOE Order 5820.2A, Chapter III (1988), this analysis considers a person who inadvertently intrudes into disposed waste approximately 100 years after disposal. This date is based on a 100-year period of active control of the disposal site consisting of staffing and environmental monitoring. The presence of a 5-m-thick soil cover over the waste (assumed as a standard configuration), in conjunction with passive controls (stable waste form, fences, markers, and zoning and land-use records), may discourage human intrusion for a much longer period.

Scenarios identified in this report do not consider the potential activities of intentional intruders. These intruders include archaeological or mineral explorers, or others intentionally attempting to recover items from a known radioactive burial ground. Inadvertent intruders are those individuals who have no knowledge of the site and may not appreciate the potential consequences of their actions. Also, other aspects of waste disposal, such as occupational or transportation exposures, are not considered.

2.2 DESCRIPTION OF INTRUDER SCENARIOS FROM THE LITERATURE

Intruder scenarios have been described and analyzed in a series of previous studies reported in the literature. Significant generic evaluations include 1) the analysis conducted for the draft and final environmental impact statements supporting the commercial low-level waste regulations by the NRC (1981b, 1982b,; Oztunali and Roles 1986), 2) an evaluation of shallow-land disposal reference levels for long-lived radionuclides by the NEA/OECD (1987), 3) previous waste management intruder scenario analyses conducted for the Hanford Site (DOE 1987), and 4) other intruder scenarios developed for the DOE site-specific low-level waste classification program (Kennedy and Peloquin 1988) and for the NRC in evaluating residual radioactive contamination from decommissioning (Kennedy and Peloquin 1990). The following sections provide background information from these previous intruder scenario evaluations.

2.2.1 Commercial Low-Level Waste Management Studies

Inadvertent-intruder scenarios were modeled by the NRC (1981a; 1981b; 1982b; 1986) and resulted in the establishment of shallow-land disposal limits for low-level waste in 10 CFR 61 (NRC 1982b). The NRC scenarios were generic (not site-specific) and used the radiation dosimetry system in ICRP Publication 2 (1959). Nevertheless, the NRC approach was applicable to analyses of scenarios at Hanford, with some revision. The NRC approach of evaluating a set of intrusion scenarios may be used to establish disposal limits for waste on the Hanford Site, as illustrated by example calculations in Appendix B of this document. Intrusion scenarios were based on exposure to radionuclides via three major pathways: inhalation of contaminated dust, ingestion of contaminated foods, and external exposure to radiation.

In establishing its waste-loading limits for burial, the NRC separated the inadvertent intruder scenarios into two separate categories: 1) excavation into the disposed waste or construction of a building at the disposal site, and 2) living on and consuming food grown at the disposal site. These two categories of intruder scenarios included three different scenarios, which are described in four NRC documents: Data Base for Radioactive Waste Management, NUREG/CR-1759 (NRC 1981a), Draft Environmental Impact Statement on 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste", NUREG-0782 (NRC 1981b), Final Environmental Impact Statement on 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste", NUREG-0945 (NRC 1982b), and Update of Part 61 Impacts Analysis Methodology, NUREG/CR-4370 (NRC 1986). The NRC has designed these scenarios to be generic; that is, they are not specific to any disposal site or region of the country.

The first NRC intruder scenario, called the Intruder-Construction Scenario, involves the construction of a house directly on top of the disposed waste. Construction workers are assumed to contact the waste directly and are subsequently exposed via inhalation of radioactive particles and external radiation. The second scenario, the Intruder-Discovery Scenario, is considered a subset of this scenario; an intruder contacts the waste, recognizes it, and leaves the disposal site. Again, inhalation and external exposure are the major exposure pathways, but the impacts are less because of the short contact with the waste. The third NRC intruder scenario is the Intruder-Agriculture Scenario. In this scenario, individuals live in the house constructed on the disposal site and raise crops and animals in the surrounding contaminated soil. The exposure pathways include ingestion of contaminated food, inhalation of resuspended dust, and exposure to external radiation.

2.2.2 International Waste Acceptance Criteria

The NEA/OECD has proposed a number of intruder scenarios for use in developing low-level waste acceptance criteria for waste disposal activities. The NEA report entitled Shallow Land Disposal of Radioactive Waste: Reference Levels for the Acceptance of Long-Lived Radionuclides (NEA/OECD 1987) describes the derivation of their waste acceptance criteria. Four intruder scenarios are described:

1. A House Construction Scenario, in which a hole for a house foundation is excavated into the waste
2. A Residential Scenario, in which people live in the constructed house and food is grown in contaminated soil
3. A Road Construction Scenario in which the excavation extends 10 m below grade
4. Establishment of a farm above the disposal site where plant roots penetrate the waste.

The NEA/OECD scenarios were generic, though some differences were assumed for temperate and arid climates. These scenarios were a composite of the scenarios used in the United States, France, and Great Britain.

2.2.3 Hanford Site Studies

Another set of exposure scenarios was postulated by the DOE in Final Environmental Impact Statement: Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes (DOE 1987). In that report, several intruder scenarios were used to assess the impacts from shallow-land disposal of radioactive waste. The intruder scenarios include a Drilling Scenario, a Post-Drilling Scenario, and a Residential Garden Scenario. These scenarios were designed for use at Hanford, and therefore employ Hanford-specific is assumed to be credible only where the protective barrier/marker system is not employed.

Additional studies at the Hanford Site considered establishing a method for determining allowable contamination levels for decommissioned facilities. Scenarios for release of contaminated soil are found in A Manual for Applying the Allowable Residual Contamination Level Method for Decommissioning Facilities on the Hanford Site (Napier et al. 1988a). These scenarios are generally consistent with the basic construction and residential garden scenarios found in other Hanford Site waste management studies.

2.2.4 Other Low-Level Waste Studies

An evaluation of intruder scenarios was conducted for the DOE site-specific, low-level waste classification program (Kennedy and Peloquin 1988). This evaluation revisited the 10 CFR 61 intruder scenarios and added well-drilling and post-drilling scenario descriptions. The intent was to account for human activities that may penetrate waste 5 m or more below the surface.

An evaluation of the technical basis for translating contamination levels to annual dose for residual radioactive contamination remaining after decommissioning (Kennedy and Peloquin 1990) was conducted for the NRC. This evaluation used a scenario involving surface soil contamination. The residential use (surface soil) scenario is similar to the Intruder-Agriculture Scenario defined by the NRC and considers inhalation, direct exposure, and ingestion of contaminated food products.

3.0 SCENARIO DESCRIPTIONS

Six basic intruder scenarios postulated for the analysis of low-level waste disposal at the Hanford Site are described in detail in this section. This set of intruder scenarios is believed to reasonably describe potential intruder events and encompass the scenarios postulated in the literature by groups including the NRC and NEA/OECD. These scenarios are also similar to those described in previous Hanford Site and DOE documents (DOE 1987; Kennedy and Peloquin 1989), where Hanford-specific parameters are used. Scenarios from the most recent Hanford environmental impact statement (DOE 1987) have been extensively reviewed by technical peers and are considered defensible and appropriate for low-level waste management activities.

It is important to note that these intruder scenarios are entirely hypothetical. In other words, scenario events are simply assumed to occur; no attempt has been made to assign probabilities to their potential occurrences. Each intruder scenario involves a number of exposure pathways and assumptions, as described in detail in the following subsections. Information regarding parameter values used for each scenario are found in Appendix A. Example calculations for each scenario are provided in Appendix B.

3.1 DRILLING SCENARIO

Drilling into disposed waste results in transfer of waste and drill tailings to the surface. Monuments, barriers, and markers will reduce the likelihood of drilling, but they are assumed not to preclude it (DOE 1987). Drilling, either for water wells or for mineral exploration, may provide little indication that the waste has been encountered. This scenario applies regardless of the depth of overburden.

In the Drilling Scenario, a well 30 cm in diameter is assumed to be bored through the waste form. The total volume of waste brought to the surface is a function of both drill core diameter and thickness of the waste form. As a reference basis for this scenario, the underground waste zone is assumed to be 5 m thick; thus, the volume of the exhumed waste is assumed to be 0.35 m^3. The volume of the drill core is assumed to be all waste, without bulk dilution by nonactive material. If the thickness of the waste is other than 5 m, the maximum concentrations for this scenario would have to be re-evaluated, after adjustment to account for the appropriate thickness of the waste zone.

Radiation exposure pathways considered in the Drilling Scenario include inhalation of contaminated dust while drilling through waste and external exposure to penetrating radiation from the waste brought to the surface for the remainder of the drilling operation. Air dust loadings for this type of operation will depend on the type of drilling method used and the local soil properties. The air dust loading may vary from about 10^{-4} to 10^{-2} g/m^3; the dust loading in a clean airstream may be approximately 2 x 10^{-5} g/m^3 (Sehmel 1984). For this scenario, drilling through the actual waste layer is assumed to take 1 hour. During this time the driller breathes air-suspended material, with an assumed respirable airborne particulate concentration of 10^{-4} g/m^3. The basis for this assumption is that wash boring, jet percussion, cable-tool (percussion), and mud rotary drilling techniques involve the use of either water or a water/mud slurry, which substantially reduces the amount of airborne contamination.

External exposure to penetrating radiation from waste material brought to the surface, diluted with surface soil, and spread over 100 m^2 could last an undefined time. For this scenario analysis, the exposure duration is assumed to be 40 hours, or that relating to the occupational exposure of the well driller.

3.2 EXCAVATION SCENARIO

Several plausible excavation events can be postulated that involve removal of substantial quantities of earth. These include construction of a highway or a canal, and, on a smaller scale, basements. In these cases, workers operating heavy machinery can be assumed to be in a "hole in the ground" essentially surrounded by contaminated soil. The hole could range from relatively small (basement) to quite large (highway or canal), but the external exposure dose rate and the level of airborne contamination would be about the same in either case.

Proper records and federal ownership would reduce the likelihood of major excavation (DOE 1987). However, excavation is assumed credible because records and controls may be lost or ignored, and a protective barrier and marker system may not be employed. The protective barrier/marker system is assumed to preclude excavation because the excavator is alerted to the potential danger by the markers. Excavation of unmarked sites is assumed to be credible for depths of up to 5 m or less and to occur no sooner than 100 years after disposal.

This scenario is related to the Drilling Scenario, because they both involve exhumation and have similar routes of exposure. Exposure pathways in the Excavation Scenario are exposure to airborne contamination and external exposure to penetrating radiation. It is assumed that the excavator has removed the clean overburden and is working in an area surrounded by decomposed waste. Waste is assumed to have a packing fraction of 0.75 (containers taking up 75% of the volume, with uncontaminated material between), which would be representative of stacked waste. The worker in the hole would be exposed to direct radiation from radionuclides in the waste and to suspended contaminated dust from construction activity. An individual operating heavy equipment is assumed to work in a contaminated area for 2 working weeks, or 80 hours.

The dust loading during this time could vary over a large range. For this analysis a relatively high airborne particle concentration of 5×10^{-3} g/m^3 is assumed; this is equivalent to a limit for occupational exposure to nuisance dust (ACGIH 1983, ACGIH 1988). For comparison, a dust loading of 1×10^{-1} g/m^3 is barely tolerable (Sehmel 1984).

3.3 POST-DRILLING SCENARIO

The doses to people who directly contact the buried wastes through drilling or digging activities represent only a portion of the potential impacts of intrusion into the disposal site. Drilling operations result in contaminated waste being distributed in the local environment (air and ground surface). This contamination could represent a source of radiation exposure to people who move onto the drill site and reside for an extended time. People who live on or near the waste could be exposed to direct radiation from contamination in the soil and to ingestion of foods grown in the contaminated soil.

The Post-Drilling Scenario has three exposure pathways: exposure to airborne contamination via inhalation, external exposure to penetrating radiation, and consumption of contaminated produce. As defined by the Drilling Scenario, 0.35 m^3 of waste are brought to the surface. For the Post-Drilling Scenario this waste is assumed to be further distributed throughout a 15-cm-deep plow layer in a garden that is 2500 m^2 in area. Twenty-five percent of the fruit and vegetables in the exposed individual's diet is assumed to come from this garden. This assumption is consistent with results of a U.S. Department of Agriculture survey, which determined percentages of homegrown vegetables (25%) and fruits (20%) consumed (EPA 1989). It is assumed that this garden is not large enough to support livestock. This diet fraction is applied to the default ingestion rates of the average individual assumed for dose calculations used in GENII for the Hanford Site.

The individual is assumed to spend 4380 h/yr residing at home (indoors), 1700 h/yr outdoors, and 100 h/yr outdoors in gardening activities on the site. The individual is assumed to breathe air with the following contaminated dust loadings: 50 $\mu g/m^3$ (5×10^{-5} g/m^3) indoors, 100 $\mu g/m^3$ during normal outdoor activity, and 500 $\mu g/m^3$ (5×10^{-4} g/m^3) while gardening (NRC 1990). There may be additional dust in the air from uncontaminated sources.

For external exposure, the individual is assumed to spend 1800 h/yr outdoors and 4380 h/yr indoors. The outdoor exposure is assumed to involve an unshielded source. Shielding is assumed to be provided by the house for the time spent indoors. Previous studies have considered shielding factors associated with the atmospheric deposition of radioactive material from passing plumes (Aldrich et al. 1978; Jensen 1985; Kocher 1978). Estimated shielding factors from these studies range from about 0.02 to 0.6, with the majority of values reported from 0.04 to about 0.4 (Jensen 1985). For this study, a value of 0.33 is assumed.

3.4 POST-EXCAVATION SCENARIO

The Post-Excavation Scenario is very similar to the Post-Drilling Scenario in that some of the waste is distributed in the local environment. The difference is in the amount of contaminated material brought to the surface. This scenario is applicable only when contaminated material is brought to the surface from the Excavation Scenario. Hence, this scenario is not credible for waste with cover depths greater than 5 m or where the marker system is employed.

One hundred cubic meters of material with a waste-packing factor of 0.75 is brought to the surface, representing 75 m^3 of waste. The waste material is assumed to be mixed in a 15-cm surface layer over an area of 2500 m^2, on which a garden is grown. The resultant fraction of waste in the top 15 cm of soil is therefore 0.2.

Exposure pathways in the Post-Excavation Scenario are the same as in the Post-Drilling Scenario: exposure to airborne contamination via inhalation, external exposure to penetrating radiation, and exposure by ingestion of contaminated foods. Twenty-five percent of the exposed individual's food intake is assumed to come from this garden. This garden is not large enough to support livestock; it is assumed that no contaminated meat or milk are consumed.

The individual is assumed to distribute time at the contaminated site in the same manner as for the Post-Drilling Scenario: 4380 h/yr residing at home (indoors), 1700 h/yr outdoors, and 100 h/yr outdoors in gardening activities on the site. For external exposure, a shielding factor of 0.33 is used in the calculations for indoor exposure.

3.5 RESIDENTIAL GARDEN SCENARIOS

In the Residential Garden Scenarios, the resettlement or reoccupation of the Hanford Site is assumed after the Site has been released for public use.

Three variations of the Residential Garden Scenario are described in the following subsections. These are 1) waste buried less than 5 m deep (Residential Garden A), 2) waste buried 5 to 10 m deep (Residential Garden B) and 3) biotic transport of waste to the surface by native animals and vegetation (Residential Garden with Biotic Transport).

Without active institutional controls, and with disregard of passive institutional controls such as permanent markers and public records, waste disposal areas could eventually be used for residential purposes. People could build homes and grow food crops over the disposal site. For the Residential Garden Scenarios, the disposal area is assumed to be resettled after loss of institutional control, 100 years after disposal. Residents do not disturb the buried waste, but they grow food crops that have roots which penetrate the underground waste form. This type of intrusion is termed biotic transport. Exposure pathways include ingestion of contaminated food crops, external exposure to the penetrating radiation from radioactive materials in the waste, and inhalation of contaminated dust.

3.5.1 Residential Garden A

The major exposure pathways in each of the Residential Garden Scenarios are plant root uptake of radionuclides and consumption of contaminated produce. An individual waste disposal site is assumed to be too small to allow production of contaminated milk and beef. One quarter of the vegetable portion of an exposed individual's diet is grown on the disposal site. The level of crop contamination is assumed to be a function of the depth of waste burial, integrity of the waste form, overall surface area used for gardening, and other considerations that affect the fraction of roots that contact the waste. The fraction of roots penetrating into the disposed waste is assumed to be 30% for wastes buried 1 to 5 m deep (Napier et al. 1988a). This scenario does not apply for wastes protected by the protective barrier/marker system.

3.5.2 Residential Garden B

The only difference between this scenario and the previous Residential Garden A is the fraction of roots penetrating into the disposed waste. This fraction is assumed to be 1% for wastes buried greater than 5 m but less than 10 m (Napier et al. 1988a). This scenario does not apply for wastes buried deeper than 10 m (it is assumed that roots do not penetrate that deeply) or for wastes protected by a protective barrier/marker system.

3.5.3 Residential Garden with Biotic Transport

This scenario is the same as Residential Garden B, above, with additional radioactive contamination brought to the surface via long-term biotic transport. Surface contamination is an additional pathway for ingestion, inhalation, and external exposure.

The amount of material brought to the surface is a function of waste depth, climate, and length of time after loss of institutional control (biotic transport is assumed to be controlled during institutional control). For the Hanford Site, biotic transport is assumed to occur in an arid climate with soil/waste movement by native plants, insects, and mammals. Biotic transport takes place after loss of institutional control, 100 years after disposal. Exposure pathways include ingestion of contaminated food crops, external exposure to both buried waste and surface contamination, and inhalation of contaminated dust brought to the surface by biotic transport.

3.6 FARMING SCENARIO

This scenario is similar to Residential Garden B, above, but with the addition of animal product ingestion pathways, and more time spent exposed to dust and external radiation out-of-doors. The Farming Scenario is the only one in which animal-product pathways (meat, poultry, milk, eggs, and animal feed) are included. It applies only to sites with large contaminated areas; the minimum size waste site where this scenario is assumed to apply is approximately 20,000 m^2 (2 ha). The individual is assumed to grow 25% of the fruit and vegetable intake and 100% of the meat, milk, and eggs. It is assumed that an individual raising meat animals or a dairy cow would supply all needs for these products. Feed for the livestock is assumed to be grown on the site.

The individual is assumed to spend 4380 h/yr residing at home (indoors), and 4380 h/yr outdoors, engaged in farming activities on the site. The individual is assumed to breathe air with contaminated dust loadings of 50 $\mu g/m^3$ indoors and 100 $\mu g/m^3$ outdoors. There may be additional dust in the air from uncontaminated sources.

For the calculation of external exposure to contaminated soil, the individual is assumed to spend 4380 h/yr outdoors and 4380 h/yr indoors. A shielding factor of 0.33 is used in the calculation for external exposure indoors, similarly to what was described for the previous scenarios.

4.0 SCENARIO APPLICABILITY AND EXAMPLE SCENARIO CALCULATIONS

Each of the intruder scenarios described in the previous section applies to a different set of disposal circumstances. This section provides a discussion of when each scenario potentially applies in a performance assessment, presents example scenario calculations, and summarizes and discusses example results. Example calculations are used to define ranges of limiting soil concentrations in units of curies per cubic meter of waste at the time of disposal. Values within these ranges may be applicable for selected radionuclides at various times after site closure. Discussions of the time dependence of the scenario results, comparisons of the results for selected radionuclides, and identification of limiting (lowest disposal) concentration for selected radionuclides are also provided. Details concerning the parameters selected for each scenario are found in Appendix A, and details concerning the example calculations are found in Appendix B.

4.1 SCENARIO AND PATHWAY APPLICABILITY

Each intruder scenario is designed to be credible under certain circumstances. Depth of disposal, presence or absence of a protective barrier/marker system, and time of intrusion after site closure are the primary discriminators for determining scenario applicability. Table 4.1 shows the depth and conditions that apply for each intruder scenario.

If the waste were disposed such that its surface was at a depth between 1 and 5 m, all five defined intruder scenarios would apply. When the waste is disposed at depths in excess of 5 m, but less than or equal to 10 m, the Drilling, Post-Drilling, and Residential Garden Scenarios apply. For the Residential Garden Scenarios, because no bulk mixing of the waste with surface soils occurs, root penetration is the controlling process. Because of the depth to waste for Residential Garden B and Biotic Transport scenarios, only 1% of the roots from plants growing over the site are assumed to contact the waste. Either a barrier or stabilized waste form may further limit the intrusion of roots into the waste zone. When the waste is disposed of at

TABLE 4.1. Scenario Applicability as a Function of Burial Depth

Burial Depth of Waste Form	Drilling	Excavation	Farm or Residential Garden	Post-Drilling	Post-Excavation
1 to 5 m	Yes	Yes[a]	Yes[b]	Yes	Yes
5 to 10 m	Yes	No	Yes[c]	Yes	No
Greater than 10 m	Yes	No	No	Yes	No
Protective Barrier/Marker System ≥ 5 m	Yes	No	No	Yes	No
Waste form: impermeable soil matrix	Yes	No	No	Yes	No

(a) Assumes protective barrier/marker system is not present.
(b) 30% of plant roots penetrate into waste.
(c) 1% of plant roots penetrate into waste.

depths in excess of 10 m or in conjunction with a protective barrier/marker system of at least 5 m, only the Drilling and Post-Drilling Scenarios apply.

Table 4.2 shows which pathways are applicable for each identified scenario. It should be noted that inhalation and external dose are calculated for each scenario; however, the exposure duration and air concentrations used will vary among scenarios.

TABLE 4.2. Pathway Applicability as a Function of Scenario

Pathway	Drilling	Excavation	Residential Garden	Farming	Post-Drilling and Post-Excavation
Inhalation	Yes	Yes[a]	Yes[a]	Yes	Yes
External	Yes	Yes[b]	Yes[b]	Yes	Yes
Ingestion					
Plant Products	No	No	Yes	Yes	Yes
Animal Products		No	No	No	YesNo

(a) Inhalation of material brought to the surface by the action of plant roots or other biotic transport.
(b) External exposure from both buried waste and surface contamination, if applicable.

It should be noted again that the Farming Scenario applies to contaminated land areas large enough to support grazing animals. Deep-rooted forage crops (alfalfa, for example) are assumed to penetrate the waste zone and provide animal feed. Site- or waste-specific performance assessments must evaluate the potential post-disposal conditions that may be present and determine which intruder scenarios apply.

4.2 EXAMPLE SCENARIO CALCULATIONS

Example scenario calculations were performed for each scenario using the parameters described in Appendix A to demonstrate the types of results that may be obtained in a full performance assessment. The calculations were performed for assumed unit concentrations, 1 Ci/m^3, of waste at the time of disposal. Table 4.3 lists the radionuclides considered in this study. These radionuclides are typical of those found in low-level waste streams at the Hanford Site. Appendix B gives the results of the example calculations for selected radionuclides in units of rem per year per curie per cubic meter of each radionuclide in the waste, at 100, 500, and 1000 years after disposal. The following subsections provide discussions of the example calculation of waste disposal limits.

4.2.1 Calculation of Example Waste Disposal Limits

To calculate the example waste disposal limits for selected radionuclides, both the dose-per-unit concentration and a selected maximum dose limit must be used. The maximum dose limits have been defined by DOE to be 100 mrem/yr for continuous exposure and 500 mrem/yr for short-term exposures, as discussed in DOE Order 5400.5 (DOE 1990). These dose limits are the whole-body effective dose equivalent (EDE), as required by DOE for public dose calculations. Table 4.4 shows the maximum allowable doses (in rem per year) applied to the intruder scenarios. For the example calcuations in Appendix B, these dose limits were divided by the dose-per-unit concentrations to yield the example limiting concentrations for the radionuclides considered in this study. The resulting example waste disposal limits are in units of curies per cubic meter for waste that could be disposed for each scenario so that the dose to future intruders does not exceed the assumed dose limits. Complete listings of these example waste disposal limits are found in Appendix B.

TABLE 4.3. Radionuclides Considered in This Study

Radionuclide	Half-Life, yr
^{3}H	1.2E+01
^{14}C	5.7E+03
^{60}Co	5.3E+00
^{59}Ni	8.0E+04
^{63}Ni	1.0E+02
^{79}Se	6.5E+04
^{90}Sr+D[a]	2.9E+01
^{94}Nb	2.0E+04
^{99}Tc	2.1E+05
^{129}I	1.6E+07
^{137}Cs+D	3.0E+01
^{151}Sm	9.0E+01
^{154}Eu	8.8E+00
^{155}Eu	4.9E+00
^{238}U+D[b]	4.5E+09
^{237}Np+D	2.1E+06
^{239}Pu	4.4E+04
^{241}Pu+D	1.4E+01
^{241}Am	4.3E+02

(a) +D means "plus decay products in equilibrium."
(b) Decay products include ^{234}Th and ^{234}Pa

TABLE 4.4. Dose Limits for the Scenarios Considered in this Study

Scenario	Dose Limit to an Individual, rem/yr
Drilling	0.5
Excavation	0.5
Post-Drilling	0.1
Post-Excavation	0.1
Residential Garden	0.1
Farming	0.1

4.2.2 Example Ranges of Disposal Limits

As previously discussed, not all intruder scenarios will apply to a specific disposal system because of the type of waste form, depth of disposal, and presence of protective barrier/marker systems. This means that for the same radionuclide, different disposal concentration limits may be developed and defended based on specific design information. As an example of the potential impact of disposal system design on the calculated disposal concentration limit, ranges of the limiting concentrations are developed using the example results in Appendix B. Table 4.5 lists ranges of limiting concentrations for disposal of selected radionuclides, for intrusion times of 100, 500, and 1000 years. These ranges were developed from the range in calculated disposal limits for the six identified intruder scenarios.

In instances where the dose calculated for a given radionuclide is very small, the maximum specific activity of the radionuclide determines the limiting concentration. No doses for the ingestion pathway were calculated for ^{3}H and ^{14}C in the Residential Garden and Farming Scenarios, because the models include no root uptake.

The ranges shown in Table 4.5 are typically quite large. For example, for ^{90}Sr with intrusion at 100 years after disposal, the most limiting (smallest) example waste concentration is obtained for the Residential Garden (30% roots) Scenario with a value of about 2 x 10^{-3} Ci/m^3, and the least limiting (largest) value of 4500 Ci/m^3 was obtained for the Drilling Scenario. These results establish a range of limiting concentrations for ^{90}Sr that covers six orders of magnitude. For other radionuclides, the complete range may be greater (nine orders of magnitude for ^{99}Tc) or somewhat narrower (i.e., generally from four to five orders of magnitude). It may be possible to establish a still narrower range of limiting concentrations or set a single limit for a specific disposal system if certain scenarios can be eliminated from consideration because of system design features. The performance assessment process includes the consideration of alternative disposal designs using intruder scenarios to define concentration limits that meet the individual dose criteria for future intruders.

TABLE 4.5. Example Ranges of Limiting Concentrations Developed Using Intruder Scenarios

Radionuclide	Intruder Scenario Waste Disposal Limit Range, Ci/m^3		
	100 Years	500 Years	1000 Years
^{3}H	1E+07 - N/A[a]	N/A	N/A
^{14}C	3E+02 - N/A	3E+02 - N/A	3E+02 - N/A
^{60}Co	8E+01 - 5E+05	N/A	N/A
^{59}Ni	2E+00 - 6E+04	2E+00 - 6E+04	2E+00 - 6E+04
^{63}Ni	1E+00 - 7E+07	2E+01 - N/A	7E+02 - N/A
^{79}Se	5E-03 - 1E+06	5E-03 - 1E+06	5E-03 - 1E+06
^{90}Sr+D[b]	2E-03 - 5E+03	3E+01 - 7E+07	6E+06 - N/A
^{94}Nb	3E-04 - 4E+00	3E-04 - 4E+00	3E-04 - 4E+00
^{99}Tc	3E-04 - 4E+05	3E-04 - 4E+05	3E-04 - 4E+05
^{129}I	3E-04 - 3E+03	3E-04 - 3E+03	3E-04 - 3E+03
^{137}Cs+D	7E-03 - 4E+01	7E+01 - 4E+05	7E+06 - N/A
^{151}Sm	2E+01 - 6E+06	5E+02 - 1E+08	2E+04 - N/A
^{154}Eu	8E-01 - 1E+04	N/A	N/A
^{155}Eu	2E+04 - 1E+08	N/A	N/A
^{238}U+D	8E-03 - 1E+02	8E-03 - 1E+02	8E-03 - 1E+02
^{237}Np	8E-06 - 1E+01	8E-06 - 1E+01	8E-06 - 1E+01
^{239}Pu	6E-03 - 1E+03	6E-03 - 1E+03	6E-03 - 1E+03
^{241}Pu+D	9E-02 - 1E+04	2E-01 - 2E+04	4E-01 - 5E+04
^{241}Am	3E-03 - 4E+02	6E-03 - 7E+02	1E-02 - 2E+03

(a) N/A - Limits are not applicable because the concentration is limited by specific activity or a dose could not be calculated due to model limitations (^{3}H, ^{14}C).
(b) Where +D means "plus decay products in equilibrium."

4.3 DISCUSSION OF SCENARIO RESULTS

Example waste disposal concentration limits shown in Appendix B can be summarized and discussed in a variety of ways beyond comparing ranges derived from differing scenarios. Figure 4.1 shows the time-dependent relationship of all six scenarios for ^{90}Sr. The log of the limiting waste concentration versus time after disposal is plotted to illustrate the range of results. As shown in this figure, the calculated disposal concentration limit increases with time of intrusion, reflecting the effect of radioactive decay. This

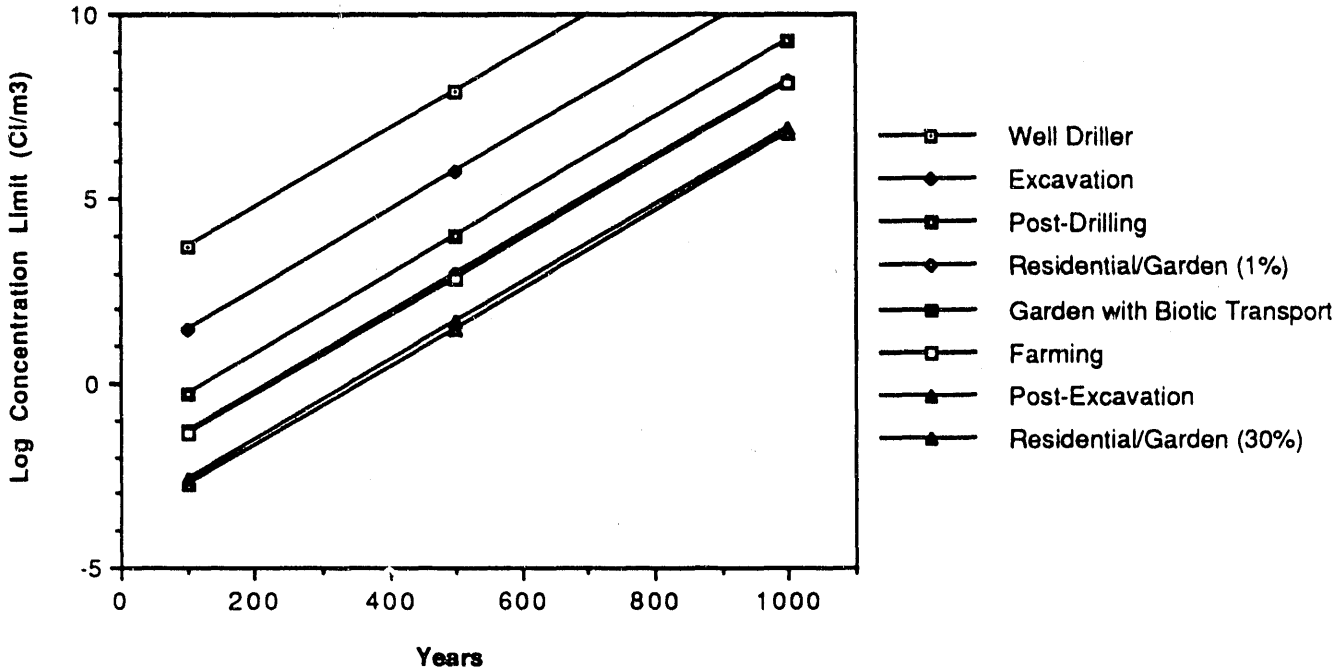

FIGURE 4.1. Log of the Disposal Concentration Limit for ^{90}Sr Versus Time of Intrusion for all Intruder Scenarios

figure also shows the relationships among the scenario results. There is a tight clustering of results for the Post-Drilling, Farming, and Residential Garden (1% root penetration) Scenarios. The Residential Garden (30% root penetration) and Post-Excavation Scenarios produce the most limiting (lowest) disposal concentration, while the Excavation and Drilling Scenarios produce the least limiting (highest) disposal concentration. Waste disposal systems that are designed to prevent excavation (post-excavation) or residential gardens could contain higher concentrations than those that are not.

Results for selected radionuclides for the Post-Excavation Scenario are compared in Figure 4.2. The figure indicates concentration limits for ^{60}Co, ^{90}Sr+D, ^{129}I, ^{238}U+D and ^{239}Pu. Iodine-129 has the most limiting (lowest) disposal concentration limit, while ^{60}Co has the least limiting (highest) disposal concentration limit. The slope of the lines in Figure 4.2 reflects the half-life of the radionuclides.

Biotic transport of buried material to the surface can have an impact on concentration limit for long-lived radionuclides such as ^{239}Pu, ^{238}U, and

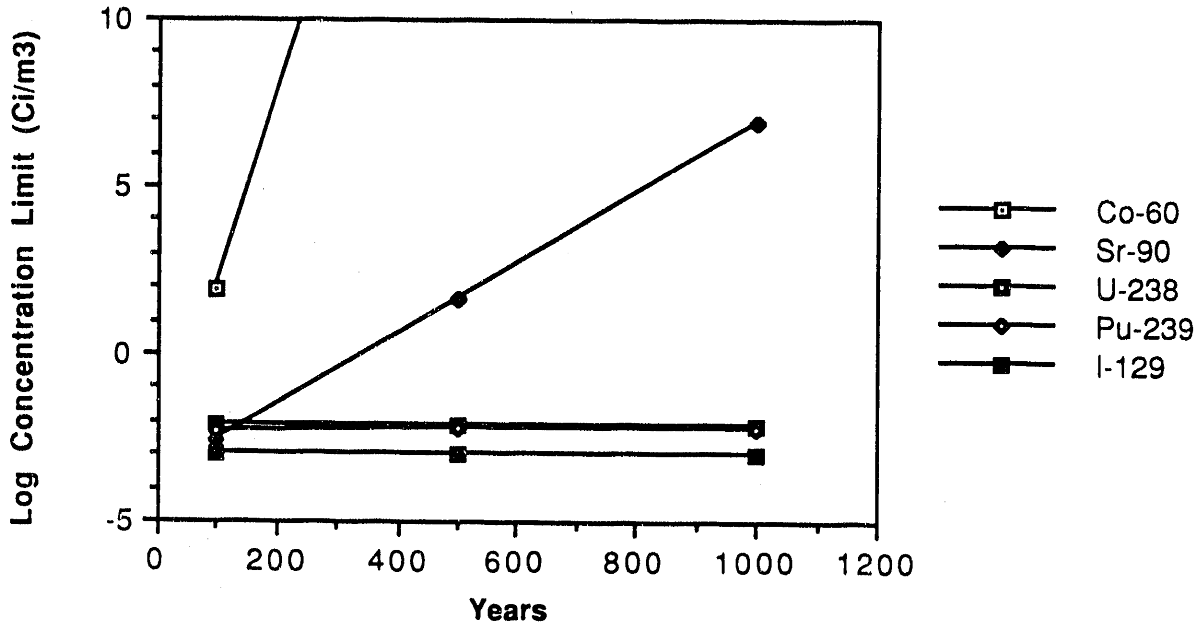

FIGURE 4.2. Log of the Disposal Concentration Limit Versus Time of Intrusion for the Post-Excavation Scenario

^{94}Nb. The limit becomes more restrictive for long times after disposal because biotic transport is assumed to bring material to the surface, increasing the doses from inhalation and external radiation. Increases in the inhalation dose from ^{239}Pu and ^{238}U and external dose from ^{94}Nb caused by biotic transport make the concentration limits for these radionuclides more restrictive with time.

5.0 DISCUSSION

This document provides a family of scenarios to be considered in waste performance assessments of low-level waste disposal sites at Hanford. These assessments address radiation exposure to individuals who may inadvertently intrude into near-surface waste disposal sites containing radioactive material. Specific performance assessments can modify the general scenarios defined here to include additional details on the engineering design, waste form, inventory, and environmental setting of the site/disposal system.

Parameter values and assumptions for each of the intruder scenarios were chosen from Hanford Site data, were selected from documented sources, or they were selected because they have gained acceptance from use in previous assessments. Thus, the parameter values and assumptions used do not represent average conditions for all potentially exposed individuals, nor do they represent bounding (worst) cases that may be encountered. The parameters have been selected, based on the professional judgement of the study contributors, to produce high estimates of the radiation doses that may potentially be received by an intruder. At the same time, they should produce more reasonable estimates than parameters chosen to produce bounding results.

It is difficult to create reasonable scenarios for future conditions. In some cases, events that are bounding have been purposefully omitted. An example is a child who eats soil after drilling or excavation has brought contamination to the surface. Although this scenario may happen, it requires coupled events (intrusion and a child who routinely eats soil) and was judged to produce a bounding result inappropriate for the purposes of this study.

The concentration limits in Section 4.0 were developed to demonstrate the range of results that may be produced using intruder scenarios. The ranges, by radionuclide, were developed from the results of all six intruder scenarios, with no attempt to eliminate scenarios because of assumed disposal system design features. Specific performance assessments can eliminate selected scenarios from consideration, to produce concentration limits for specific disposal systems at the Hanford Site.

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APPENDIX A

PARAMETER SELECTION

APPENDIX A

PARAMETER SELECTION

This appendix contains a discussion of the parameters used with the GENII software package for the intruder scenarios described in Section 3.0. Many of the parameters for transport and accumulation of radionuclides in the food chain have been documented in Kennedy et al. (1986). Other parameters may be found in Standardized Methods and Data for Hanford Environmental Dose Calculations (McCormack, et al. 1984).

The GENII software package uses the dosimetry model recommended by the International Commission on Radiation Protection, in ICRP Publication 26 (1977) and ICRP Publication 30 (1979-1982), with updates from ICRP Publication 48 (1986). The dose conversion factors used are equivalent to those currently recommended by the U.S. Department of Energy (DOE 1988). External dose factors are equivalent to Kocher (Kocher 1981; ORNL 1981).

The GENII software package allows calculation of the radiation dose to humans from three major exposure routes: ingestion, inhalation, and external radiation. Not all of the parameters are applicable to every scenario because some scenarios do not involve exposure by some pathways. The ingestion pathway, for example, is not applicable to the Drilling or Excavation Scenarios.

A.1 RANGES FOR MAJOR SCENARIO OR PATHWAY PARAMETERS

Table A.1 contains expected ranges of parameter values and those selected for each scenario. These ranges were established based on values found in the literature, assumed for similar scenarios, or used in other radiological performance assessments. Parameters are arranged by major intruder scenario and exposure pathway. For the example problems considered in this study (Appendix B), an attempt has been made to select values within the expected range, rather than at the extremes.

TABLE A.1. Expected Ranges for Pathway Parameters and the Values Selected for the Scenarios in This Study

Scenario or Pathway Parameter	Expected Range	Selected Value	Comments
Water Well Drilling			
Inhalation			
- Duration	0 to 40 h	1 h 40 h	Drilling through waste Overall operations
- Breathing rate	125 to 333 cm^3/sec	270 cm^3/sec	ICRP recommendations for standard man
- Concentration	10^{-6} to 10^{-2} g/m^3	10^{-4} g/m^3	Drilling through waste
- Particle size	0.1 to 10 μm AMAD	1.0 μm AMAD[(a)]	ICRP generic value from ICRP 30
External			
- Duration	0 to 40 h	40 h	Overall operations
Excavation			
Inhalation			
- Duration	0 to 100 h	80 h	Two work-weeks
- Breathing rate	125 to 333 cm^3/sec	270 cm^3/sec	ICRP recommendations for standard man
- Concentration	10^{-6} to 10^{-2} g/m^3	5×10^{-3} g/m^3	TLV for respirable dust
- Particle size	0.1 to 10 μm AMAD	1.0 μm AMAD[(a)]	ICRP generic value
External			
- Duration	0 to 100 h	80 h	Two work-weeks

TABLE A.1. (contd)

Parameter	Expected Range	Selected Value	Comments
Post-Drilling and Post-Excavation			
· Inhalation			
- Duration	0 to 8760 h	100 h 1700 h 4380 h	Gardening Outdoors Indoors
- Breathing rate	125 to 333 cm^3/sec	270 cm^3/sec	ICRP recommendations for standard man
- Concentration	10^{-6} to 10^{-3} g/m^3	$5x10^{-4}$ g/m^3 $1x10^{-4}$ g/m^3 $5x10^{-5}$ g/m^3	Gardening dust Yardwork dust Indoors
- Particle size	0.1 to 10 μm AMAD	1.0 μm AMAD	ICRP generic value
· External			
- Duration	0 to 8760 h	1800 h 4380 h	Outdoors Indoors
- Shielding factor	0 to 1.0	0.33	House shielding factor
· Ingestion			
- Vegetables/fruit	0 to 660 kg/yr	73 kg/yr	25% of average diet
· Air concentration for leaf deposition	10^{-6} to 10^{-3} g/m^3	$1x10^{-4}$ g/m^3	Garden dust

TABLE A.1. (contd)

Scenario or Pathway Parameter	Expected Range	Selected Value	Comments
Resettlement/Home Garden with and without Biotic Transport			
· Inhalation			
- Duration	0 to 8760 h	100 h 1700 h 4380 h	Gardening Outdoors Indoors
- Breathing rate	125 to 333 cm^3/sec	270 cm^3/sec	ICRP recommendations for standard man
- Concentration	10^{-6} to 10^{-3} g/m^3	$5x10^{-4}$ g/m^3 $1x10^{-4}$ g/m^3 $5x10^{-5}$ g/m^3	Gardening dust Yardwork dust Indoors
- Particle size	0.1 to 10 μm AMAD	1.0 μm AMAD	ICRP generic value
· External			
- Duration	0 to 8760 h	1800 h 4380 h	Outdoors Indoors
- Shielding factor	0 to 1.0	5 m of soil	Overburden shielding
· Ingestion			
- Vegetables/fruit	0 to 660 kg/yr	73 kg/yr	25% of average diet

TABLE A.1. (contd)

Scenario or Pathway Parameter	Expected Range	Selected Value	Comments
Farming			
· Inhalation			
- Duration	0 to 8760 h	4380 h 4380 h	Farming Activities Indoors
- Breathing rate	125 to 330 cm^3/s	270 cm^3/s	ICRP recommendations for Reference Man
- Concentration	10^{-6} to 10^{-3} g/m^3	1×10^{-4} g/m^3 5×10^{-5} g/m^3	Farming dust Indoors
- Particle size	0.1 to 10 μm AMAD	1.0 μm AMAD	ICRP generic value
· External			
- Duration	0 to 8760 h	4380 h 4380 h	Outdoors Indoors
- Shielding factor	0 to 1.0	5 m of soil	Overburden shielding
· Ingestion			
- Vegetables/fruit	0 to 660 kg/yr	73 kg/yr	25% of average diet
- Meat/poultry/eggs	0 to 128 kg/yr	99 kg/yr	100% of average diet
- Milk	0 to 274 L/yr	230 L/yr	100% of average diet

(a) AMAD means the activity mean aerodynamic diameter of the airborne particulate material.

A.2 INPUT PARAMETERS TO THE GENII SOFTWARE PACKAGE

Table A.2 lists the parameters used in GENII for each scenario for intrusion 100 years after disposal. Parameter values for the other cases (i.e., intrusion after 500 and 1000 years) are the same, except for the times in the first two rows concerning the intake period. A short explanation of the parameters and how they are derived follows. This discussion parallels the order in Table A.2, which in turn is similar to the GENII input and output files.

A.2.1 Near-Field Parameters

Intruder scenarios are generally near-field cases in which there is a narrowly focused, single site. For the example problems considered in Appendix B, the intake periods were assumed to be 100, 500, and 1000 years after disposal. For the Residential Garden Scenario with biotic transport, the time after loss of institutional control, was therefore 0, 400, and 900 years, respectively. Measures to prevent biotic transport are assumed to take place only during the period of institutional control.

In cases with surface contamination (Post-Drilling, Post-Excavation), the contamination of food crops in the ingestion pathway is from root uptake of radionuclides from the upper soil (i.e., the contamination and the plant roots are assumed to be in the top 15 cm of soil).

Roots are assumed to be in deep soil (penetrating the waste form) in the Residential Garden and Farming Scenarios. The Residential Garden Scenario is divided into separate cases to permit representation of conditions for waste buried at different depths. Residential Garden A and Residential Garden B refer to two different fractions of plant roots (30% and 1%, respectively) that penetrate into the waste. An additional scenario similar to Residential Garden B shows the effect of biotic transport, which simulates the movement of waste to the surface by plants, insects, and mammals. Radioactive material is assumed to be brought to the surface by biotic processes and to accumulate in the soil after loss of institutional control.

Manual redistribution is assumed in the Drilling, Excavation, Post-Drilling, and Post-Excavation Scenarios. A given amount of contamination is exhumed, diluted with nonactive soils, and spread over an assumed area. This process provides a surface soil concentration less than the deep-soil (buried waste) concentration. If the surface soil is at the same concentration as the deep waste, the manual redistribution factor is 0.15 m^3/m^2, representing a 15-cm-deep surface layer. For the Drilling Scenario, the manual redistribution factor (a dilution factor) is calculated to be 0.0035 m^3/m^2. This dilution results from removal of a drill core of waste 30 cm in diameter by 5 m in length (0.35 m^3) to the surface and the mixing this volume of waste in 100 m^2 of non-radioactive soil. If the thickness of waste is other than 5 m, the factor must be adjusted accordingly. For the Post-Drilling Scenario, the 0.35 m^3 drilled core is mixed over 2500 m^2; the resulting manual redistribution factor is 0.00014 m^3/m^2.

For the Excavation Scenario, the worker is assumed to be completely surrounded by waste. The waste to which the worker is exposed is 75% of the concentration disposed, because it is assumed to be diluted by 25% fill material. The manual redistribution factor is therefore 0.75 x 0.15, or 0.11. In the Post-Excavation Scenario, 100 m^3 material from the site (waste, with 25% uncontaminated fill) is assumed to be removed from the excavation and mixed into a 2500 m^2 area. The manual redistribution factor is therefore 3.0×10^{-2} m^3/m^2.

A source of limited area as created by the above scenarios produces a lower external dose rate than the infinite plane source assumptions found in the GENII data library. For sources less than 1250 m^2, modifications to the external dose rate are needed (Kennedy et al. 1986). Such source-area modification factors are used for the Drilling Scenario, where contamination is assumed to be spread over only 100 m^2.

A.2.2 Waste Form Availability

The half-life of the waste form/package is not used in this analysis because the waste form is assumed to be untreated and readily available for uptake. The waste is assumed to be incorporated into the soil after 100 years of institutional control. The waste-form availability parameter may be used for site-specific analyses where the waste is incorporated into a matrix, giving it added stability.

A.2.3 External Exposure

The thickness of the buried waste is used as shielding material in the calculation of external dose from undisturbed buried waste, as in the

Residential Garden and Farming Scenarios. No such shielding is available in the scenarios where the buried waste is brought to the surface and distributed (manual redistribution).

Hours of exposure to ground contamination (effective) is a weighted combination of time spent outdoors in the contaminated area with no shielding factor and time spent indoors with a shielding factor afforded by housing materials. For Post-Drilling, Post-Excavation, and Residential Garden Scenarios, a combination of 1800 h/yr outside (with no shielding factor) and 4380 h/yr indoors (times shielding factor 0.33) gives an effective 3245 h/yr of external exposure to the unshielded soil. The Farming Scenario, with 4380 h/yr indoors and 4380 h/yr outdoors in the contaminated area, yields an effective unshielded exposure of 5825 h/yr.

A.2.4 Inhalation

Hours of inhalation exposure per year (effective) is calculated as the weighted average of the hours of exposure at the given mass loading factor. The mass loading model is used to calculate air concentrations to estimation inhalation doses from dusty air. The mass-loading factor, with units of g/m^3, is the concentration of contaminated particles in the air. The AMAD (activity mean aerodynamic diameter) for airborne particulate material is assumed to be 1.0 μm.

Air concentrations are calculated from the surface soil concentrations, using a scenario-dependent mass-loading factor. For the Drilling Scenario, the mass-loading factor is assumed to be 1×10^{-4} g/m^3 for the assumed 1 hour required to drill through the waste layer. For the Excavation Scenario, the mass-loading factor is taken to be 5×10^{-3} g/m^3. For the Residential Garden, Post-Drilling and Post-Excavation Scenarios, a concentration-weighted exposure time is calculated. The exposure durations of 100 h/yr at 5×10^{-4} g/m^3, 1700 h/yr at 1×10^{-4} g/m^3, and 4380 h/yr at 5×10^{-5} g/m^3 are equivalent to a weighted average 4390 h/yr at a mass-loading of 1×10^{-4} g/m^3. For the Farming Scenario, the weighted average mass-loading factor is 1×10^{-4} g/m^3 for 6570 h/yr.

A.2.5 Biotic Transport of Buried Waste

In the third Residential Garden Scenario, biotic transport is considered during a decay/buildup period and during the intake period. Pre-intake conditions are assumed to be arid and non-agricultural. A further description of biotic transport and appropriate modeling approaches is given by McKenzie et al. (1986).

A.2.6 Plant Product Ingestion

The ingestion pathway is included for all scenarios except the Drilling and Excavation Scenarios. In the Post-drilling, Post-excavation, Residential Garden, and Farming Scenarios, the individual is assumed to grow and consume 25% of the fruit and vegetable portion of the diet on the contaminated site. Categories of foodstuffs available in GENII include leafy vegetables, other vegetables, fruit, and grain. The quantities listed in Table A.2 correspond to 25% of the intake assumed for the average individual for Hanford (McCormack et al. 1984).

A.2.7 Animal Product Ingestion

The Farming Scenario includes consumption of fruits and vegetables, plus the animal products milk, meat, poultry, and eggs (plus the animal feed consumption pathway). The quantities of these products listed in Table A.2 correspond to 100% of the intake assumed for the average individual for Hanford (McCormack et al. 1984). It is assumed that an individual raising meat animals or a dairy cow would supply all needs for these products. Feed for the livestock is assumed to be grown on the site. The Farming Scenario applies only to sites with a large contaminated area. The minimum size waste site where this scenario is assumed to apply is approximately 2 ha (20,000 m^2) or about 5 acres.

TABLE A.2. Parameters Used in the GENII Code for Intruder Scenarios

DRILLER	EXCAVATE	POST-DRILL	POST-EXC	GARDEN A	GARDEN B	BIOTIC	FARMING	PARAMETER DESCRIPTION
								NEAR-FIELD PARAMETERS
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	Inventory disposed n years prior to beginning of intake period
0	0	0	0	0	0	0	0	LOIC occurred n years prior to beginning of intake period
0.0E+00	0.0E+00	1.0E+00	1.0E+00	7.0E-01	9.9E-01	9.9E-01	9.9E-01	Fraction of roots in upper soil (top 15 cm)
0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.0E-01	1.0E-02	1.0E-02	1.0E-02	Fraction of roots in deep soil
3.5E-03(a)	1.1E-01(b)	1.4E-04(c)	3.0E-02(d)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	Manual redistribution: deep soil/surface soil dilution factor (m3/m2)
100.0	1250.0	1250.0	1250.0	1250.0	1250.0	1250.0	1250.0	Source area for external dose modification factor (m2)
								WASTE FORM AVAILABILITY
0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	Waste form/package half life, yr
0.0E+00*	0.0E+00*	0.0E+00*	0.0E+00*	5.0E+00	5.0E+00	5.0E+00	5.0E+00	Thickness of buried waste, m (* thickness accounted for in waste vol)
5.0E+00	5.0E+00	5.0E+00	5.0E+00	5.0E+00	5.0E+00	5.0E+00	5.0E+00	Depth of soil overburden, m
								EXTERNAL EXPOSURE
4.0E+01	8.0E+01	3.2E+03(e)	3.2E+03(e)	3.2E+03(e)	3.2E+03(e)	3.2E+03(e)	5.8E+03(g)	Hours of exposure to ground contamination (effective)
								INHALATION
1.0E+00	8.0E+01	4.4E+03(f)	4.4E+03(f)	4.4E+03(f)	4.4E+03(f)	4.4E+03(f)	6.6E+03(h)	Hours of inhalation exposure per year (effective)
1	1	1	1	1	1	1	1	Resuspension model: 1-Mass Loading, 2-Anspaugh
1.0E-54	5.0E-03	1.0E-04	1.0E-04	1.0E-04	1.0E-04	1.0E-04	1.0E-04	Mass loading factor (g/m3)
								BIOTIC TRANSPORT OF BURIED SOURCE
NA	NA	NA	NA	NA	NA	T	NA	Is considered during inventory decay/buildup period.
NA	NA	NA	NA	NA	NA	T	NA	Is considered during intake period.
NA	NA	NA	NA	NA	NA	1	NA	Pre-Intake conditions: 1-Arid Non Ag,2-Humid Non Ag,3-Agriculture
								TERRESTRIAL FOOD INGESTION

VEGETABLE/FRUIT CONSUMPTION RATE (i)

		kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	FOOD TYPE	GROW TIME d	YIELD kg/m2	HOLDUP d
NA	NA	3.8E+00	3.8E+00	3.8E+00	3.8E+00	3.8E+00	3.8E+00	Leaf Veg	90.0	1.5	1.0
		3.5E+01	3.5E+01	3.5E+01	3.5E+01	3.5E+01	3.5E+01	Oth. Veg	90.0	4.0	10.0
		1.6E+01	1.6E+01	1.6E+01	1.6E+01	1.6E+01	1.6E+01	Fruit	90.0	2.0	10.0
		1.8E+01	1.8E+01	1.8E+01	1.8E+01	1.8E+01	1.8E+01	Cereals	90.0	0.8	10.0

TABLE A.2 (contd)

DRILLER	EXCAVATE	POST-DRILL	POST-EXC	GARDEN A	GARDEN B	BIOTIC	FARMING	PARAMETER DESCRIPTION	
								NEAR-FIELD PARAMETERS	
								ANIMAL FOOD INGESTION (j)	
							RATE kg/yr	FOOD TYPE	HOLDUP d
NA	NA	NA	NA	NA	NA	NA	7.0E+01	Meat	15.0
							8.5E+00	Poultry	1.0
							2.3E+02	Cow Milk	1.0
							2.0E+01	Eggs	1.0

(a) Based on 0.35 m^3 x 1 Ci/m^3 spread over 100 m^2 = 3.5E-3 Ci/m^2
(b) Based on 1 Ci/m^3 x 0.75 (waste/clean intersticial material) x .15m^3/m^2 (surface depth) = .11 Ci/m^2
(c) Based on .35 m^3 at 1 Ci/m^3 spread over 2500 m^2 = 1.4E-04 Ci/m^2. (Note: no dilution for uncontaminated material in small volume)
(d) Based on 100 m^3 of material from the waste later spread over 2500 m^2. (Clean cover material would also be excavated.) 100 m^3 x 0.75 (waste/clean intersticial material) x 1 Ci/m^3 /2500 m^2 = 3.0E-02 Ci/m^2
(e) Effective External hours based on 1800 outdoors plus 4380 hours at the site indoors, with shielding factor of 0.33 (1800 + .33 x 4380 = 3245).
(f) Effective hours of inhalation at the given mass loading factor; from Kennedy 1990, p. 3.46 (corrected): 100 hours at 5.0E-04 g/m^3 + 1700 hours at 1.0E-04 g/m^3 + 4380 hours at 5.0E-05 g/m^3 = 4390 hours at 1.0E-04 g/m^3.
(g) Effective External hours based on 4380 hours outdoors; 4380 hours indoors (4380 + 4380 x 0.33 = 5825).
(h) Effective hours of inhalation: 4380 hours at 1E-04 g/m^3; 4380 hours at 5.0E-05 g/m^3 = effective 6570 hours at 1.0E-04 g/m^3.
(i) Quantities of plant products consumed are based on 25% of the Hanford average diet; Holdup times correspond to those for the maximally exposed individual (MI).
(j) Quantities of animal products consumed are based on 100% of the Hanford average diet; Holdup times correspond to those for the maximally exposed individual (MI).

NA Not Applicable
T True

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APPENDIX B

EXAMPLE CALCULATIONS: DISPOSAL LIMITS

APPENDIX B

EXAMPLE CALCULATIONS: DISPOSAL LIMITS

This appendix contains a discussion of radiation dose calculations and potential disposal concentration limits for each intruder scenario described in this document. The example radionuclides considered are listed in Table 4.2 in subsection 4.2.

B.1 EXAMPLE DISPOSAL CONCENTRATION LIMITS

Doses, in terms of annual dose received per unit concentrations of individual radionuclides in the waste, are calculated using the GENII software package (Napier et al. 1988) for the intruder scenarios defined in Section 3.0. The input parameters, by pathway and scenario, are discussed in Appendix A.

For the example problems considered in this appendix, maximum allowable concentrations of radionuclides in the waste to be disposed of are calculated by scenario and time after disposal. These disposal concentration limits are derived by dividing established annual exposure limits (Section 4.2) by the calculated dose-per-unit concentrations for each scenario. The resulting waste disposal concentration limits indicate the example concentrations that may safely be disposed of in a near-surface burial ground at the Hanford Site provided that each scenario is applicable to a given disposal technology.

To determine if a mixture of radionuclides is at or below the allowable concentration, the following ratio may be used:

$$\sum_{i+1}^{n} \frac{C_i}{C_{Li}} \leq 1.0 \qquad \text{(B.1)}$$

where C_i = the concentration of radionuclide i in the waste, Ci/m^3

C_{Li} = the most limiting concentration among the applicable scenarios, Ci/m^3, a function of both time after disposal and dose limit.

n = the number of radionuclides in the mixture.

In the above expression, the ratio of the concentration of each radionuclide to its allowable concentration is summed over all radionuclides in the mixture. If this sum is less than or equal to one, the mixture is acceptable for disposal.

Doses and example concentration limits for each scenario and each radionuclide are given in Tables B.1 through B.8. In some cases, the concentration is limited by the specific activity of the radionuclide. The maximum activity possible for the pure substance is limited to 1E+10 Ci/m^3 for ^{3}H and ^{60}Co; activity is limited to 2E+8 to 3E+9 Ci/m^3 for ^{63}Ni, ^{90}Sr, ^{137}Cs, ^{151}Sm, ^{154}Eu and ^{155}Eu. Limits for ^{3}H and ^{14}C are not shown in Tables B.5 through B.8 (the Residential Garden and Farm Scenarios) because root uptake is not included in the models.

Limiting concentrations for each scenario and radionuclide are summarized in Table B.9. A further discussion of the results is provided in Sections 4.0 and 5.0.

TABLE B.1. Example Limiting Concentrations for Well Drilling Scenario Based on a Dose Limit of 500 mrem/yr

Radionuclide	Concentration Limit, Ci/m³ 100 Years	500 Years	1000 Years
^{3}H	S/A [(a)]	S/A	S/A
^{14}C	2.3E+06	2.5E+06	2.6E+06
^{60}Co	5.4E+05	S/A	S/A
^{59}Ni	6.0E+04	6.0E+04	6.0E+04
^{63}Ni	6.7E+07	S/A	S/A
^{79}Se	1.4E+06	1.4E+06	1.4E+06
^{90}Sr+D [(b)]	4.5E+03	7.4E+07	S/A
^{94}Nb	1.6E+00	1.7E+00	1.7E+00
^{99}Tc	3.6E+05	3.6E+05	3.6E+05
^{129}I	3.1E+03	3.1E+03	3.1E+03
^{137}Cs+D	4.2E+01	4.2E+05	S/A
^{151}Sm	6.4E+06	1.4E+08	S/A
^{154}Eu	5.3E+03	S/A	S/A
^{155}Eu	1.0E+08	S/A	S/A
^{238}U+D	1.0E+02	1.0E+02	1.0E+02
^{237}Np+D	1.0E+01	1.0E+01	1.0E+01
^{239}Pu	1.1E+03	1.1E+03	1.1E+03
^{241}Pu+D	1.1E+04	2.1E+04	4.5E+04
^{241}Am	3.8E+02	7.0E+02	1.6E+03

(a) S/A - Concentration limited by specific activity.
(b) +D means "plus decay products in equilibrium."

TABLE B.2. Example Limiting Concentrations for Excavation Scenario Based on a Dose Limit of 500 mrem/yr

Radionuclide	Concentration Limit, Ci/m^3 100 Years	500 Years	1000 Years
^{3}H	1.9E+07	S/A [(a)]	S/A
^{14}C	2.6E+03	2.8E+03	2.9E+03
^{60}Co	5.0E+03	S/A	S/A
^{59}Ni	4.5E+02	4.5E+02	4.5E+02
^{63}Ni	2.5E+03	4.2E+04	1.3E+06
^{79}Se	2.8E+02	2.8E+02	2.8E+02
^{90}Sr+D [(b)]	2.9E+01	5.0E+05	S/A
^{94}Nb	1.4E-02	1.4E-02	1.4E-02
^{99}Tc	5.2E+02	5.2E+02	5.2E+02
^{129}I	1.6E+01	1.6E+01	1.6E+01
^{137}Cs+D	3.6E-01	3.6E+03	S/A
^{151}Sm	1.9E+02	4.2E+03	1.9E+05
^{154}Eu	4.5E+01	S/A	S/A
^{155}Eu	8.8E+05	S/A	S/A
^{238}U+D	2.2E-02	2.2E-02	2.2E-02
^{237}Np+D	3.8E-03	3.8E-03	3.8E-03
^{239}Pu	8.6E-03	8.6E-03	8.6E-03
^{241}Pu+D	2.0E-01	3.8E-01	8.8E-01
^{241}Am	6.7E-03	1.3E-02	2.9E-02

(a) S/A - Concentration limited by specific activity.
(b) +D means "plus decay products in equilibrium."

TABLE B.3. Example Limiting Concentrations for Post-Drilling Scenario Based on a Dose Limit of 100 mrem/yr

Radionuclide	Concentration Limit, Ci/m^3 100 Years	500 Years	1000 Years
^{3}H	2.8E+09	S/A [a]	S/A
^{14}C	6.7E+04	7.1E+04	7.1E+04
^{60}Co	1.8E+04	S/A	S/A
^{59}Ni	4.8E+02	4.8E+02	4.8E+02
^{63}Ni	4.5E+02	7.1E+03	2.3E+05
^{79}Se	3.3E+00	3.3E+00	3.3E+00
^{90}Sr+D[b]	5.6E-01	9.1E+03	S/A
^{94}Nb	5.6E-02	5.6E-02	5.6E-02
^{99}Tc	1.9E-01	1.9E-01	1.9E-01
^{129}I	2.3E-01	2.3E-01	2.3E-01
^{137}Cs+D	1.4E+00	1.4E+04	S/A
^{151}Sm	5.6E+03	1.2E+05	5.6E+06
^{154}Eu	1.7E+02	S/A	S/A
^{155}Eu	3.4E+06	S/A	S/A
^{238}U+D	1.6E+00	1.6E+00	1.6E+00
^{237}Np+D	2.4E-03	2.4E-03	2.5E-03
^{239}Pu	1.3E+00	1.3E+00	1.3E+00
^{241}Pu+D	1.9E+01	3.6E+01	8.3E+01
^{241}Am	6.3E-01	1.2E+00	2.7E+00

(a) S/A - Concentration limited by specific activity.
(b) +D means "plus decay products in equilibrium."

TABLE B.4. Example Limiting Concentrations for Post-Excavation Scenario Based on a Dose Limit of 100 mrem/yr

Radionuclide	Concentration Limit, Ci/m^3 100 Years	500 Years	1000 Years
^{3}H	1.3E+07	S/A [(a)]	S/A
^{14}C	3.1E+02	3.2E+02	3.4E+02
^{60}Co	8.3E+01	S/A	S/A
^{59}Ni	2.2E+00	2.2E+00	2.2E+00
^{63}Ni	2.2E+00	3.4E+01	1.1E+03
^{79}Se	1.5E-02	1.6E-02	1.6E-02
^{90}Sr+D [(b)]	2.6E-03	4.5E+01	8.3E+06
^{94}Nb	2.6E-04	2.6E-04	2.6E-04
^{99}Tc	9.1E-04	9.1E-04	9.1E-04
^{129}I	1.1E-03	1.1E-03	1.1E-03
^{137}Cs+D	6.7E-03	6.7E+01	6.7E+06
^{151}Sm	2.6E+01	5.6E+02	2.6E+04
^{154}Eu	8.3E-01	S/A	S/A
^{155}Eu	1.6E+04	S/A	S/A
^{238}U+D	7.7E-03	7.7E-03	7.7E-03
^{237}Np+D	1.1E-05	1.1E-05	1.1E-05
^{239}Pu	5.6E-03	5.9E-03	5.9E-03
^{241}Pu+D	9.1E-02	1.7E-01	3.7E-01
^{241}Am	3.0E-03	5.6E-03	1.3E-02

(a) S/A - Concentration limited by specific activity.
(b) +D means "plus decay products in equilibrium."

TABLE B.5. Example Limiting Concentrations for Residential Garden Scenario (30% Roots in Waste) Based on a Dose Limit of 100 mrem/yr

Radionuclide	Concentration Limit, Ci/m^3 100 Years	500 Years	1000 Years
^{3}H	- (a)	-	-
^{14}C	-	-	-
^{60}Co	2.2E+04	S/A (b)	S/A
^{59}Ni	2.0E+00	2.0E+00	2.0E+00
^{63}Ni	1.4E+00	2.3E+01	7.1E+02
^{79}Se	1.0E-02	1.0E-02	1.0E-02
^{90}Sr+D (c)	1.8E-03	2.9E+01	5.6E+06
^{94}Nb	1.4E-01	1.4E-01	1.4E-01
^{99}Tc	2.6E-04	2.6E-04	2.6E-04
^{129}I	3.2E-04	3.2E-04	3.2E-04
^{137}Cs+D	4.0E-01	4.0E+03	S/A
^{151}Sm	2.3E+01	5.0E+02	2.3E+04
^{154}Eu	1.1E+03	S/A	S/A
^{155}Eu	3.2E+06	S/A	S/A
^{238}U+D	2.8E-01	2.8E-01	2.8E-01
^{237}Np+D	7.7E-06	7.7E-06	7.7E-06
^{239}Pu	2.8E-01	2.8E-01	2.9E-01
^{241}Pu+D	2.0E-01	3.6E-01	8.3E-01
^{241}Am	6.7E-03	1.2E-02	2.8E-02

(a) Dash indicates that concentration limit is not applicable to this scenario because there is no root uptake in the ^{3}H or ^{14}C models.
(b) S/A - Concentration limited by specific activity.
(c) +D means "plus decay products in equilibrium."

TABLE B.6. Example Limiting Concentrations for Residential Garden Scenario (1% Roots in Waste) Based on a Dose Limit of 100 mrem/yr

Radionuclide	Concentration Limit, Ci/m^3 100 Years	500 Years	1000 Years
^{3}H	- [(a)]	-	-
^{14}C	-	-	-
^{60}Co	4.0E+05	S/A [(b)]	S/A
^{59}Ni	5.9E+01	5.9E+01	5.9E+01
^{63}Ni	4.3E+01	7.1E+02	2.2E+04
^{79}Se	3.0E-01	3.0E-01	3.0E-01
^{90}Sr+D[(c)]	5.3E-02	9.1E+02	1.6E+08
^{94}Nb	3.7E+00	3.7E+00	3.7E+00
^{99}Tc	7.7E-03	7.7E-03	7.7E-03
^{129}I	1.0E-02	1.0E-02	1.0E-02
^{137}Cs+D	1.2E+01	1.2E+05	S/A
^{151}Sm	6.7E+02	1.5E+04	6.7E+05
^{154}Eu	1.0E+04	S/A	S/A
^{155}Eu	9.1E+07	S/A	S/A
^{238}U+D	8.3E+00	8.3E+00	8.3E+00
^{237}Np+D	2.3E-04	2.3E-04	2.3E-04
^{239}Pu	8.3E+00	8.3E+00	8.3E+00
^{241}Pu+D	5.9E+00	1.1E+01	2.4E+01
^{241}Am	2.0E-01	3.8E-01	8.3E-01

(a) Dash indicates that concentration limit is not applicable to this scenario because there is no root uptake in the ^{3}H or ^{14}C models.
(b) S/A - Concentration limited by specific activity.
(c) +D means "plus decay products in equilibrium."

TABLE B.7. Example Limiting Concentrations for Garden with Biotic Transport Scenario (1% Roots in Waste) Based on a Dose Limit of 100 mrem/yr

Radionuclide	Concentration Limit, Ci/m^3 100 Years	500 Years	1000 Years
^{3}H	- [(a)]	-	-
^{14}C	-	-	-
^{60}Co	3.4E+05	S/A [(b)]	S/A
^{59}Ni	5.9E+01	5.6E+01	5.6E+01
^{63}Ni	4.3E+01	6.7E+02	2.1E+04
^{79}Se	3.0E-01	2.9E-01	2.9E-01
^{90}Sr+D [(c)]	5.3E-02	7.1E+02	1.3E+08
^{94}Nb	2.9E+00	7.7E-02	5.9E-02
^{99}Tc	7.1E-03	7.1E-03	7.7E-03
^{129}I	1.0E-02	1.0E-02	1.0E-02
^{137}Cs+D	1.1E+01	1.4E+04	S/A
^{151}Sm	6.7E+02	1.3E+04	5.6E+05
^{154}Eu	8.3E+03	S/A	S/A
^{155}Eu	9.1E+07	S/A	S/A
^{238}U+D	8.3E+00	1.6E+00	1.0E+00
^{237}Np+D	2.3E-04	2.0E-04	2.0E-04
^{239}Pu	8.3E+00	1.3E+00	7.7E-01
^{241}Pu	5.9E+00	9.1E+00	1.7E+01
^{241}Am	2.0E-01	2.9E-01	5.9E-01

(a) Dash indicates that concentration limit is not applicable to this scenario because there is no root uptake in the ^{3}H or ^{14}C models.
(b) S/A - Concentration limited by specific activity.
(c) +D means "plus decay products in equilibrium."

TABLE B.8. Example Limiting Concentrations for Farming Scenario (1% Roots in Waste) Based on a Dose Limit of 100 mrem/yr

Radionuclide	Concentration Limit, Ci/m^3 100 Years	500 Years	1000 Years
^{3}H	- (a)	-	-
^{14}C	-	-	-
^{60}Co	2.0E+05	S/A (b)	S/A
^{59}Ni	4.5E+01	4.5E+01	4.5E+01
^{63}Ni	3.3E+01	5.6E+02	1.7E+04
^{79}Se	4.8E-03	4.8E-03	4.8E-03
^{90}Sr+D(c)	4.3E-02	7.1E+02	1.3E+08
^{94}Nb	3.4E+00	3.4E+00	3.4E+00
^{99}Tc	6.7E-03	6.7E-03	6.7E-03
^{129}I	3.1E-03	3.1E-03	3.1E-03
^{137}Cs+D	3.0E+00	2.9E+04	S/A
^{151}Sm	5.3E+02	1.1E+04	5.3E+05
^{154}Eu	5.9E+03	S/A	S/A
^{155}Eu	7.1E+07	S/A	S/A
^{238}U+D	7.1E+00	7.1E+00	7.1E+00
^{237}Np+D	2.2E-04	2.2E-04	2.2E-04
^{239}Pu	8.3E+00	8.3E+00	8.3E+00
^{241}Pu+D	5.9E+00	1.1E+01	2.4E+01
^{241}Am	2.0E-01	3.8E-01	8.3E-01

(a) Dash indicates that concentration limit is not applicable to this scenario because there is no root uptake in the ^{3}H or ^{14}C models.
(b) S/A - Concentration limited by specific activity.
(c) +D means "plus decay products in equilibrium."

TABLE B.9 Example Limiting Scenario by Radionuclide With No Credit for Barrier/Marker Systems, for Intrusion 100 Years After Disposal

Radionuclide	Scenario	Dose Limit, Rem	Annual EDE, Rem	Limiting Concentration, Ci/m^3
^{3}H	Post-Excavation	0.1	7.8E-09	1.3E+07
^{14}C	Post-Excavation	0.1	3.2E-04	3.1E+02
^{60}Co	Post-Excavation	0.1	1.2E-03	8.3E+01
^{59}Ni	Residential Garden A	0.1	5.0E-02	2.0E+00
^{63}Ni	Residential Garden A	0.1	6.9E-02	1.4E+00
^{79}Se	Farming - 1% Roots	0.1	2.1E+01	4.8E-03
^{90}Sr+D[(a)]	Residential Garden A	0.1	5.7E+01	1.8E-03
^{94}Nb	Post-Excavation	0.1	3.9E+02	2.6E-04
^{99}Tc	Residential Garden A	0.1	3.8E+02	2.6E-04
^{129}I	Residential Garden A	0.1	3.1E+02	3.2E-04
^{137}Cs+D	Post-Excavation	0.1	1.5E+01	6.7E-03
^{151}Sm	Residential Garden A	0.1	4.4E-03	2.3E+01
^{154}Eu	Post-Excavation	0.1	1.2E-01	8.3E-01
^{155}Eu	Post-Excavation	0.1	6.1E-06	1.6E+04
^{238}U+D	Post-Excavation	0.1	1.3E+01	7.7E-03
^{237}Np+D	Residential Garden A	0.1	1.3E+04	7.7E-06
^{239}Pu	Post-Excavation	0.1	1.8E+01	5.6E-03
^{241}Pu+D	Post-Excavation	0.1	1.1E+00	9.1E-02
^{241}Am	Post-Excavation	0.1	3.3E+01	3.0E-03

(a) +D means "plus decay products in equilibrium."

B.2 REFERENCE

Napier, B. A., R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell. 1988. Hanford Environmental Dosimetry Upgrade Project, GENII - the Hanford Environmental Radiation Dosimetry Software Package. PNL-6584, Vols. 1-3, Pacific Northwest Laboratory, Richland, Washington.

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