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An Automated Inadvertent Intruder Analysis Application

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LIST OF ACRONYMS AND ABBREVIATIONS

ACRONYMS

CIG	Components in Grout
DCF	Dose Conversion Factor
EDE	Effective Dose Equivalent
GUI	Graphical User Interface
QA	Quality Assurance
PA	Performance Assessment

ABBREVIATIONS

μCi	microCurie
AG	used to denote Agriculture scenario
Ci	Curie
cm	centimeter
kg	kilogram
m	meter
mm	millimeter
mrem	millirem
Res	used to denote Resident scenario
PD	used to denote Post-Drilling scenario
yr	year

1. INTRODUCTION

Savannah River National Laboratory (SRNL) is responsible for the radiological performance assessment analysis for Savannah River Site (SRS) waste disposal facilities (McDowell-Boyer 2000), which results in limits on the amounts of radiological substances that can be placed in the waste disposal facilities. To arrive at these limits, the performance assessment considers numerous potential exposure pathways that could occur in the future. One set of exposure scenarios, known as inadvertent intruder analysis, considers the impact on hypothetical individuals who are assumed to inadvertently intrude onto the waste disposal site. Inadvertent intruder analysis considers three distinct scenarios for exposure referred to as the agriculture scenario, the resident scenario, and the post-drilling scenario. Each of these scenarios has specific exposure pathways that contribute to the overall dose for the scenario.

For the inadvertent intruder analysis, the calculation of dose for the exposure pathways is a relatively straightforward algebraic calculation that utilizes dose conversion factors. These calculations have been performed using an Excel spreadsheet, which is adequate since the calculations are algebraic. However, use of a spreadsheet has introduced some vulnerabilities relative to quality assurance (QA) of the calculations. The calculations must be checked cell by cell even though the same calculation is being repeated. Inputs, such as dose conversion factors, are repeated for the same radionuclide that appears in different decay chains and again these must be checked cell by cell to ensure consistency. Formulas in spreadsheets typically use relative cell references and the formulas must be checked carefully to ensure that the correct cells are referenced. Review of the spreadsheet calculation showed that errors may be introduced because of these considerations. In addition, other typographical errors could be introduced in transcribing the results from the spreadsheet to document tables.

An application has been developed that mitigates the QA vulnerabilities encountered with the spreadsheet. The application is a computer program, which has the advantage that calculations are performed by the same function or subroutine, which need only be checked one time. Input values are entered only one time and thereafter used by the program as needed, thus eliminating redundant input. The application produces output in forms that can be used directly without manually transcribing results.

Section 2 of this document describes this computer application including its capabilities, inputs required and output generated. Section 3 covers verification of the calculations. Section 4 provides a detailed user guide. Finally, assurance that the application performs as described is provided by the design check in Appendix B.

2. DESCRIPTION OF THE INTRUDER APPLICATION

This section describes the automated inadvertent intruder analysis application, hereafter referred to simply as the Intruder application. The functional requirements for the application are covered first, followed by a discussion of the basic approach. Discussions then cover the relevant scenarios, decay chain calculations, and the fit for shielding data. The three different types of calculations performed with the application are introduced. Finally, the input required and output files produced are discussed.

2.1 Functional Requirements

The initial functional requirements specified for the Intruder application are as follows:

- Perform consistent calculations via programmed subroutines or functions
- Input values only one time and keep standard input under configuration control
- Have a graphical user interface (GUI) that makes the application easy to use
- Be able to reproduce the "CIG SA 6-23-03.xls" sample Excel calculation (Cook 2003)
- Output results to Excel and output final tables directly to Word

As the work progressed, there were additional functional requirements specified to extend the capabilities of the application:

- Compute a "no leaching" case in which the full decay chain is determined and the activities are calculated at specified times using the Bateman equation, i.e. decouple the calculation from the PORFLOW calculation.
- Provide a transient no leaching calculation that models the soil covers and barriers as layers that can degrade and erode with time, thus removing the prescription of a single calculation time for a scenario and instead calculating the limit over time to find the bounding limit.
- Output results as plain text files in a standard format so that the intruder analysis results can be easily rolled up with results from other analyses via an automated program. A separate text file should be written for each scenario.

2.2 Basic Approach

Given the functional requirements, the basic approach decided upon was to program the application in Visual Basic 6 and to maintain the input in Excel files. Visual Basic is a good programming environment to create the graphical user interface (GUI) and it interfaces easily with the Microsoft Office products Excel and Word for both input and output. Visual Basic also produces compiled program code that executes quickly. The expectation was that calculations would only take a few minutes, even for the transient calculations.

The decision to maintain the input in Excel was driven primarily by the project team's familiarity and comfort with Excel. A relational database such as Access was considered, but the amount of input data being handled is not very large and is easily structured in a few worksheets. Security for configuration control was another issue and the ability to lock Excel worksheets was deemed adequate security at the file level.

The programming strategy is to have a generalized program that reads input files with given formats but that does not restrict the input to a specific set of radionuclides. That is, the goal is to permit radionuclides to be added in the future through input without altering the program. This strategy has been implemented everywhere in the program except for the fit to shielding data (Section 2.5). The shielding data was added late in the development and was hard-wired to a set of nuclides to meet schedule needs. Generalizing the fit to shielding data through input is a goal for future improvement.

2.3 Review of Scenarios

The inadvertent intruder analysis is described in detail in the Performance Assessment (McDowell-Boyer 2000), which is the primary reference for this type of analysis and includes descriptions of the waste disposal units relative to this analysis. The analysis assumes three distinct scenarios named agriculture, resident, and post-drilling.

The agriculture scenario is based on the assumption that a house is built directly on top of a waste disposal unit and that any soil cover over the waste disposal unit has eroded over time such that digging of the foundation extends into the waste. It is further assumed that the waste removed by digging is mixed with soil in a garden used to grow vegetables. Based on these assumptions, there are six exposure pathways.

- Internal exposure from ingestion of vegetables that take up radionuclides from the soil in the garden
- Internal exposure from ingestion of soil from the garden, primarily from soil on the surface of vegetables
- External exposure from the soil while working in the garden
- Internal exposure from inhalation of particulates while working in the garden
- External exposure from the waste disposal unit while residing in the home
- Internal exposure from inhalation of particulates while residing in the home

The resident scenario is based on the assumption that a house is built directly on top of a waste disposal unit but digging of the foundation does not extend into the waste because of an impenetrable barrier or because sufficient soil cover remains. In this case there is only one exposure pathway, which is external exposure from the waste disposal unit through some shielding thickness while residing in the home.

The post-drilling scenario is based on the assumption that a well is dug near the house and the drilling extends through the waste disposal unit. The soil removed from drilling is mixed with soil in a garden used to grow vegetables. With this assumption there are four exposure pathways, which are the same as the garden-based exposure pathways in the agriculture scenario.

- Internal exposure from ingestion of vegetables that take up radionuclides from the soil in the garden
- Internal exposure from ingestion of soil from the garden, primarily from soil on the surface of vegetables
- External exposure from the soil while working in the garden
- Internal exposure from inhalation of particulates while working in the garden

The calculational strategy for determining limits for each parent radionuclide based on these scenarios is laid out in detail in Appendix C of the Performance Assessment (McDowell-Boyer 2000). For each exposure pathway, an effective dose equivalent (EDE) in rem/yr for each radionuclide in the decay chain is calculated based on published dose conversion factors while assuming a unit concentration (1 $\mu Ci/m^3$) in the waste disposal unit. For each scenario, these exposure pathway EDEs for each radionuclide can be summed to get an overall scenario EDE for each radionuclide. Then, for a given calculational time, the activity of each radionuclide in the decay chain can be determined from the initial inventory (activity) of the parent radionuclide. If the initial inventory of the parent is assumed to be 1 Ci spread over the waste disposal unit volume, then the calculated activity for each radionuclide in the decay chain along with its scenario EDE can be used to determine the resulting dose for that radionuclide. The dose for each radionuclide in the decay chain is summed to yield the effective dose from the parent based on an inventory of 1 Ci of the parent in the waste disposal unit volume. If we now assume a dose limit, say 100 mrem/yr, then the previous result can be inverted to set a limit on the inventory of the parent in the waste disposal unit volume.

The equations for the EDE and dose calculations are given in Appendix C of the Performance Assessment (McDowell-Boyer 2000). Those equations were programmed in Visual Basic for the Intruder application and are given in Appendix A of this document.

2.4 Decay Chain Calculations

In past Performance Assessments the decay chain calculations were performed within the PORFLOW calculation used for groundwater analysis and the results were passed to the intruder analysis. One of the functional requirements for the Intruder application is that a no leaching analysis be performed, which requires that the full decay chain calculation be performed within the application.

There are two aspects to a full decay chain calculation. First, given decay input for each radionuclide, we can determine what radionuclides make up a decay chain. In cases where there is a branch to two daughters, two chains result after the branch. Thus, starting with a parent there may be three or four chains after all branches are considered. A subroutine was written to determine all the daughters in the decay chain and to break out the separate chains resulting from branches.

The second aspect to the decay chain calculation is to calculate the activity for each member of a single chain at a given time. The generalized expression for the number of atoms of a member of a generalized decay chain at any given time is known as the Bateman equation, which is described in most nuclear engineering texts (Foster and Wright 1980). A subroutine had been written in FORTRAN by Collard (2004) to carry out the Bateman equation calculation for a single decay chain. This subroutine was converted to Visual Basic for use in the Intruder application.

For each separate chain the Bateman equation is calculated for a specified time to determine activity for each member of the chain. The separate chains are then merged to get the total activity for each member of the full decay chain. Thus, for a given parent, the full decay chain with activities for each member is calculated.

A computer program to perform this same decay chain calculation was written by Eckerman (1996) and is available from the Oak Ridge National Laboratory (ORNL) website. This program was used to verify the decay chain calculations in the Intruder application as described in Section 3.2.

2.5 Fit for Shielding Data

The resident scenario has one exposure pathway, which is external exposure from the waste disposal unit through some shielding thickness while residing in the home. The past strategy for accounting for the shielding came from Dave Kocher and is described by Lee (2004). Kocher used a table that has shielding dose conversion factor (DCF) values at discrete soil shielding thicknesses of 0, 1, 5, 15, 30, 45, and 100 cm. The log of the DCF value versus the thickness is almost linear. For intermediate thicknesses, Kocher used linear interpolation of log(DCF) to determine the appropriate DCF.

For the Intruder application, we need a fit to Kocher's data to automatically calculate the DCF for a given shielding thickness. In addition, as the shielding thickness approaches zero, we need to recover the zero thickness case from Federal Guidance Report 12 (FGR12), which is what is used in the agriculture scenario [see Lee (2004) for information about FGR12]. The approach taken is to use a piecewise linear fit of log(DCF). The first piece is between 0 and 5 cm, which uses the FGR12 value at 0 cm and Kocher's value at 5 cm. The second piece is between 5 and 100 cm, which uses Kocher's values at both ends. The third piece is for shielding thickness greater than 100 cm, which uses the same value as 100 cm since the data does not extend beyond 100 cm (note that this is conservative because more shielding should lower the DCF).

Note that we could have used piecewise linear fits between each of Kocher's discrete thickness values. We used only the fit between 5 and 100 cm because it computes values very close to the intermediate thickness values and the computed value is always slightly larger and hence conservative.

At the current time these fits for shielding DCF are hard-wired into the Intruder application for a given set of radionuclides, which was done to meet schedule needs. Thus, to add radionuclides requires a modification to the program. This restriction can be easily removed and is a goal for future work.

2.6 Types of Calculation

Corresponding to the functional requirements, there are three different types of calculation that may be performed, referred to as Cases 1, 2, and 3.

The Case 2 calculation, labeled "2. Specify times, input fraction remaining" in the application, corresponds to the spreadsheet analysis that has been used in the PA where fraction remaining comes from PORFLOW calculations, i.e. leaching is considered.

The Case 1 calculation, labeled "1. Specify times, compute fraction remaining" in the application, is like Case 2 but with no leaching so fraction remaining is computed from the Bateman equation as described in Section 2.4.

The Case 3 calculation, labeled "3. Transient calculation" in the application, uses a transient layer model (see Section 2.7.2) to perform a transient calculation with no leaching. The potential erosion of cover material over time is accounted for in the transient, which can impact some of the exposure pathways. The transient calculation also accounts for the decay chain calculation over time.

Cases 1 and 2 are useful for scoping and for comparing to past analyses. Case 3 is a new approach in which the maximum dose is computed over a range of time. This approach accounts for competing effects such as decay and buildup of daughter radionuclides and thus ensures that the maximum dose is found over the time range of interest.

2.7 Input Files

The input for the Intruder application is Excel files, each with a specific structure. There are two input files that are always required, one that contains radionuclide input values (*IntruderInput.xls*) and the other that contains waste disposal unit input information (*DisposalUnitInput.xls*). A third input file is required for the case where fraction remaining is computed by PORFLOW and passed to the Intruder application (*FractionRemainingInput.xls*).

2.7.1 Radionuclide Input

Standard radionuclide input is contained in the file *IntruderInput.xls*. This file contains data that has been checked and ordinarily the user should not need to change this data. In fact, the worksheets are locked so that a user does not inadvertently change the data. There are four worksheets in this Excel file: Parents, Parameter Values, Nuclide Input, and Nuclide Decay.

- The Parents worksheet contains a single column that must be in column A and must have the heading "Nuclide" followed by the parent radionuclides. This column is read until a blank cell is found to delineate the end of the list. This column has a list of all the parent radionuclides to be considered. The rest of the worksheets contain data for these parents and all their daughters.

- The Parameter Values worksheet contains values for parameters that are used throughout the intruder calculations. The placement and order of the parameter descriptions, value, and units must not be changed. Ordinarily the user will not change any of these parameter values. If a value is changed, the units cannot be changed and it must be expressed in the units shown.

- The Nuclide Input worksheet contains dose conversion factors (DCF) for internal and external exposure using the input structure shown in Figure 1. The inputs in this worksheet are as follows:
  - **IngestDCF** is the DCF for ingestion of the radionuclide (rem/µCi).
  - **InhaleDCF** is the DCF for inhalation of the radionuclide (rem/µCi).
  - **SoilRatio** is the ratio of radionuclide concentration taken from the soil into the plant.
  - **Ex15cmSoil** is the DCF for external exposure from a uniform distribution of the radionuclide in 15 cm of surface soil (rem/yr per µCi/m^3).
  - **ExInfSoil_no** is the DCF for external exposure from a uniform distribution of the radionuclide in an infinite depth of soil with no shielding (rem/yr per µCi/m^3).
  - **ExInfSoil_45** is the DCF for external exposure from a uniform distribution of the radionuclide in an infinite depth of soil with 45 cm of soil shielding (rem/yr per µCi/m^3).
  - **ExInfSoil_100** is the DCF for external exposure from a uniform distribution of the radionuclide in an infinite depth of soil with 100 cm of soil shielding (rem/yr per µCi/m^3).

  Lee (2004) describes these inputs and the sources for the values.

	A	B	C	D	E	F	G	H
1	Nuclide	IngestDCF	InhaleDCF	SoilRatio	Ex15cmSoil	ExInfSoil_no	ExInfSoil_45	ExInfSoil_100
2		*(rem / µCi)*	*(rem / µCi)*		*(rem/yr) per*	*(rem/yr) per*	*(rem/yr) per*	*(rem/yr) per*
3					*(µCi/m3)*	*(µCi/m3)*	*(µCi/m3)*	*(µCi/m3)*
84	Pu-238	3.20E+00	3.92E+02	1.94E-05	9.43E-08	9.46E-08	3.89E-17	0.00E+00
85	Pu-239	3.54E+00	4.29E+02	1.94E-05	1.78E-07	1.85E-07	6.53E-12	5.25E-17
86	Pu-240	3.54E+00	4.29E+02	1.94E-05	9.16E-08	9.17E-08	2.33E-17	0.00E+00

Figure 1. Nuclide Input Worksheet Structure

- The Nuclide Decay worksheet has decay information for each radionuclide including half life and resulting daughters with branching fractions using the input structure shown in Figure 2. Lee (2004) describes the sources of these inputs.

	A	B	C	D	E	F	G
1	**Nuclide**	**Half Life**	**Units**	**Daughter1**	**Branch1**	**Daughter2**	**Branch2**
32	Cm-242	1.6280E+02	days	Pu-238	1		
33	Cm-243	2.9100E+01	years	Pu-239	0.9976	Am-243	0.0024
34	Cm-244	1.8100E+01	years	Pu-240	1		

Figure 2. Nuclide Decay Worksheet Structure

2.7.2 Disposal Unit Input

The Excel input file *DisposalUnitInput.xls* contains information required by the model for each of the disposal units. There is a worksheet for each disposal unit, with each worksheet having the same format.

The top part of the disposal unit worksheet, shown in Figure 3, has basic information that has been used in past PA intruder analyses. The geometry factor for each scenario and the waste volume are needed for each of the intruder calculation types. The fixed analysis time for each scenario and the shielding thickness for the Resident scenario are used for Cases 1 and 2 but not for the Case 3 transient calculation.

	A	B	C
1		**Facility**	E-Area
2		**Disposal Unit Name**	Slit Trenches
3		**Abbreviated Name**	SlitTrenches
4		**Agriculture Geometry Factor**	0.6
5		**Resident Geometry Factor**	0.6
6		**Post-Drilling Geometry Factor**	1
7		**Waste Volume (m3)**	28800
8		**Agriculture Analysis Time (yr)**	10000
9		**Resident Analysis Time (yr)**	100
10		**Post-Drilling Analysis Time (yr)**	100
11		**Resident Shielding Thickness (cm)**	100

Figure 3. Disposal Unit Input – Top of Worksheet

The bottom part of the disposal unit worksheet, shown in Figure 4, has input for a "transient layer model". The PA document (McDowell-Boyer 2000) describes the logic for determining when various scenarios occur. There are basically two considerations: (1) erosion of soil-like material at some constant erosion rate and (2) degradation of an impenetrable barrier (e.g. concrete, grout) to soil-like material. For the Intruder application, these elements are incorporated into a simple one-dimensional "transient layer model" as shown below. Cover material above the waste is represented as distinct layers with thickness, erosion rate, and degradation time, with layers listed in order from the surface downward to the top of the waste.

13	**Transient Layer Model (Surface to Top of Waste)**				
14	**Layer**	**Thickness (m)**	**Description**	**Erosion Rate (mm/yr)**	**Degradation Time (yr)**
15	1	0.9144	Soil cover (36")	1.4	0
16	2	0.3048	Erosion barrier (12")	1.00E-10	0
17	3	2.855	Soil backfill (112.4")	1.4	0

Figure 4. Disposal Unit Input – Bottom of Worksheet

If a layer has zero degradation time, then it is soil-like and erodes with time at the constant rate specified from the surface downward. If a degradation time is specified, then the layer is an impenetrable barrier. This impenetrable barrier does not start to degrade until all material above it has eroded and then it remains impenetrable until its degradation time has elapsed, at which time it becomes soil-like and begins to erode at the specified rate. Note that the erosion barrier in the example above is not impenetrable since it has zero degradation time. To simulate resistance to erosion, an extremely small but nonzero erosion rate is specified.

Note that at the time of release of this document, the disposal unit input is fully complete only for the Slit Trenches and Intermediate-Level Vaults, although partial information is available for the other E-Area disposal units. There are no Z-Area (i.e. Saltstone) disposal units specified at this time.

2.7.3 Fraction Remaining Input

In past Performance Assessments the decay chain calculations and transport were performed within the PORFLOW calculation and the fraction remaining results were passed to the intruder analysis. In the intruder Excel spreadsheet calculation (Cook 2003), the parent and relevant daughters are listed along with the activity as a fraction of the parent's initial activity, called fraction remaining. For the Intruder application, we need to be able to reproduce past analyses, so we need an input file that has the same decay chain information with fraction remaining. The decay chain information in the spreadsheet is presented in a slightly complicated notation to indicate daughters that are assumed to be in equilibrium with a radionuclide higher in the chain.

The notation used in the spreadsheet is shown in Figure 5 in the column "Radionuclide". Parents are shown left justified, e.g. Th-232 and Am-242m. An indention of one or two levels indicates a daughter in the chain. Thus, the chain for Th-232 includes Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Pb-212, Bi-212, and Tl-208.

A plus sign indicates that following indented radionuclides are in equilibrium with the less indented, plus-marked nuclide and thus have the same fraction remaining. A break in the indention level indicates a break in those radionuclides in equilibrium with the previous plus sign level. Thus, Ac-228 is in equilibrium with Ra-228 and the four radionuclides Rn-220, Pb-212, Bi-212, and Tl-208 are in equilibrium with Ra-224.

Similarly, the parent Am-242m has daughters Am-242, Cm-242, Pu-238, and U-234. The daughters Am-242 and Cm-242 are in equilibrium with the parent Am-242m, while Pu-238 and U-234 are not in equilibrium and will have their own fraction remaining value.

I
Radionuclide
Th-232
Ra-228+
Ac-228
Th-228
Ra-224+
Rn-220
Pb-212
Bi-212
Tl-208
Am-242m+
Am-242
Cm-242
Pu-238
U-234

Figure 5. Decay Chain Notation using Plus Sign

For an automated application, the use of indentions is unreliable and an alternate explicit notation was devised for the Excel input file *FractionRemainingInput.xls*, which is shown in Figure 6.

	A	B	C	D	E	F	G	H	I
1	**Parent**	**Daughter**	**Combine**	**BranchFrac**	**F-Res**	**F-PD**	**F-Ag**		**Radionuclide**
2	Th-232				1.0E+00	1.0E+00	9.9E-01		Th-232
3		Ra-228		1	1.0E+00	1.0E+00	9.5E-01		Ra-228+
4			Ac-228	1					Ac-228
5		Th-228		1	1.0E+00	1.0E+00	9.5E-01		Th-228
6		Ra-224		1	1.0E+00	1.0E+00	9.5E-01		Ra-224+
7			Rn-220	1					Rn-220
8			Pb-212	1					Pb-212
9			Bi-212	1					Bi-212
10			Tl-208	0.3593					Tl-208
11	Am-242m				6.3E-01	2.5E-01	4.1E-02		Am-242m+
12			Am-242	0.99524					Am-242
13			Cm-242	0.827					Cm-242
14		Pu-238		1	2.0E-03	1.8E-03	4.2E-04		Pu-238
15		U-234		1	3.6E-07	1.6E-06	2.7E-06		U-234

Figure 6. Decay Chain Notation for Intruder Application

The parent is listed explicitly in a column labeled “Parent”. There are two daughter columns, one labeled “Daughter” and the other labeled “Combine”. An entry in the column “Combine” is combined with the previous entry in the “Daughter” or “Parent” column, i.e. it is in equilibrium. Thus, we see that Ac-228 is combined with Ra-228; Rn-220, Pb-212, Bi-212, and Tl-208 are combined with Ra-224; Am-242 and Cm-242 are combined with Am-242m. The original “Radionuclide” column is shown at the right for reference but is not required in the input.

The other required inputs are the branching fraction in column “BranchFrac” and the fraction remaining for each of the three scenarios (F-Res for resident, F-PD for post-drilling, and F-Ag for agriculture). The fraction remaining corresponds to specific times and the user must ensure that this input corresponds to the scenario times specified by the user in the graphical user interface for the Intruder application (see Section 4). Note that for those radionuclides combined with a previous entry, the fraction remaining is not given because they are the same as for the previous entry, i.e. they are in equilibrium.

2.8 Output Files

A requirement in Section 2.1 is that the Intruder application writes results to Excel and writes final tables directly to Word. Besides the summary output to Excel, there is a variety of detailed output that may be useful in understanding contributions from various exposure pathways and/or from various members of a decay chain. The output files vary depending on which of the three cases are run. Following is a summary of the output files available from the Intruder application.

2.8.1 Case 1 Output

There is always a summary Excel file for Case 1 named *Results_Case1.xls*. A sample of the output format is shown in Figure 7. Note that the header includes the name of the disposal unit and that the scenario calculation times are given in Italics for each scenario. An entry of “---“ is used to clearly show where there is effectively no limit because it exceeds the corresponding threshold value given in the header. The results are given for each scenario that was chosen to be included in the calculation. For each scenario the calculated dose from 1 Ci of the parent in the waste disposal unit volume is given along with the corresponding concentration limit (Conc) and the corresponding inventory limit (Inv).

	A	B	C	D	E	F	G	H	I	J	K	L
1		Inadvertent Intruder Analysis Results for Engineered Trench using No Leaching Calculation at Prescribed Scenario Times										
2		The entry "---" indicates a value greater than or equal to the threshold value of 1E+20.										
3												
4		Agriculture Scenario at 700 Years				Resident Scenario at 100 Years				Post-Drilling Scenario at 300 Years		
5		AG Dose	AG Conc	AG Inv		Res Dose	Res Conc	Res Inv		PD Dose	PD Conc	PD Inv
6	Nuclide	(rem/yr)	(uCi/m3)	(Ci/Unit)		(rem/yr)	(uCi/m3)	(Ci/Unit)		(rem/yr)	(uCi/m3)	(Ci/Unit)
7	H-3	6.69E-22	---	---		0.00E+00	---	---		6.50E-13	5.34E+12	1.54E+11
8	C-14	2.88E-04	1.20E+04	3.47E+02		0.00E+00	---	---		5.04E-05	6.89E+04	1.98E+03
9	Na-22	6.50E-83	---	---		3.51E-17	9.90E+16	2.85E+15		1.24E-39	---	---

Figure 7. Sample from Excel Summary Output File for Case 1

If the option is checked to write a Word document, then this same summary information is written to the file *Results_Case1.doc* as a Word table. A sample of the output format is shown in Figure 8. One table is written for each scenario and the waste disposal unit, the scenario, and the calculation time are given in the table title.

Table 6.x-xx Intruder-Based Radionuclide Disposal Limits for Engineered Trench – Agriculture Scenario at 700 Years

Radionuclide	Concentration Limit (μCi/m^3)	Inventory Limit (Ci/Unit)	Radionuclide	Concentration Limit (μCi/m^3)	Inventory Limit (Ci/Unit)
H-3	---	---	W-188	---	---
C-14	1.20E+04	3.47E+02	Pb-210	1.50E+12	4.33E+10
Na-22	---	---	Bi-207	3.86E+08	1.11E+07
Al-26	4.36E+01	1.25E+00	Ra-226	7.80E+01	2.25E+00

Figure 8. Sample from Word Summary Output File for Case 1

If the option is checked to write text files, then the summary information is written in a standard format so that the intruder analysis results can be easily rolled up with results from other analyses via an automated program. A sample of the output format is shown in Figure 9. A separate file is written for each scenario with names such as *Results_Case1_AG.txt* where AG refers to agriculture scenario. PD is used to refer to post-drilling scenario and Res is used to refer to resident scenario The entries are tab delimited and text is inside double quotes.

```
""              ""               "Concentration" "Inventory"
""              "Time of Limit"  "Limit"         "Limit"
"Radionuclide"  "(Years)"        "(uCi/m3)"      "(Ci/Unit)"
"H-3"           700              1.00E+20        1.00E+20
"C-14"          700              1.20E+04        3.47E+02
"Na-22"         700              1.00E+20        1.00E+20
```

Figure 9. Sample from Text Summary Output File for Case 1

If the option is checked for detailed output of Dose Pathways, then the Excel file *Dose_Pathways_Case1.xls* is written. This file contains the calculated dose for each exposure pathway for each scenario as shown in Figure 10. The agriculture scenario has six exposure pathways and the cumulative total is shown in red. The resident scenario only has one exposure pathway and this is shown in blue. The post-drilling scenario has four exposure pathways and the cumulative total is shown in red. This detailed output clearly shows which exposure pathways are dominant for each parent radionuclide.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Nuclide	AG Veg	AG Soil	AG Garden	AG Garden	AG Home	AG Home	AG Dose		Res Home		PD Veg	PD Soil	PD Garden	PD Garden	PD Dose
2		Ingest	Ingest	Exposure	Inhale	Exposure	Inhale	Total		Exposure		Ingest	Ingest	Exposure	Inhale	Total
3		(rem/yr)	(rem/yr)	(rem/yr)	(rem/yr)	(rem/yr)	(rem/yr)	(rem/yr)		(rem/yr)		(rem/yr)	(rem/yr)	(rem/yr)	(rem/yr)	(rem/yr)
4	H-3	6.69E-22	5.73E-26	0.00E+00	1.24E-29	0.00E+00	3.10E-28	6.69E-22		0.00E+00		6.50E-13	5.57E-17	0.00E+00	1.20E-20	6.50E-13
5	C-14	2.88E-04	2.11E-07	3.22E-10	4.57E-11	5.63E-08	1.14E-09	2.88E-04		0.00E+00		5.04E-05	3.70E-08	5.63E-11	8.00E-12	5.04E-05
6	Al-26	6.72E-06	1.61E-06	3.76E-04	1.89E-09	7.93E-02	4.73E-08	7.97E-02		5.74E-05		1.12E-06	2.68E-07	6.27E-05	3.16E-10	6.41E-05

Figure 10. Sample from Detailed Dose Pathways Output File for Case 1

2.8.2 Case 2 Output

The output for Case 2 is essentially the same as for Case 1. There is always a summary output file named *Results_Case2.xls*. As shown in Figure 11, this file has the same format as for Case 1 with the exception of some additional information in the header. Case 2 requires the additional input file for fraction remaining and the source of this input is given in the header. This fraction remaining input may be missing for some selected parents and in this case a message is written in red that identifies the parents that are omitted.

	A	B	C	D	E	F	G	H	I	J	K	L
1		Inadvertent Intruder Analysis Results for Engineered Trench using Leaching/Decay Calculation at Prescribed Scenario Times										
2		Fraction remaining for leaching/decay come from input file E:\WPT\PA-GUI\GUI9cor2\FractionRemainingInput.xls										
3		Note that the following parents are not in the fractions remaining input and are omitted: Na-22 Al-26 S-35 Cl-36 Ar-39 K-40 (										
4		The entry "---" indicates a value greater than or equal to the threshold value of 1E+20.										
5												
6		Agriculture Scenario at 700 Years				Resident Scenario at 100 Years				Post-Drilling Scenario at 300 Years		
7		AG Dose	AG Conc	AG Inv		Res Dose	Res Conc	Res Inv		PD Dose	PD Conc	PD Inv
8	Nuclide	(rem/yr)	(uCi/m3)	(Ci/Unit)		(rem/yr)	(uCi/m3)	(Ci/Unit)		(rem/yr)	(uCi/m3)	(Ci/Unit)
9	H-3	0.00E+00	---	---		0.00E+00	---	---		4.47E-15	7.77E+14	2.24E+13
10	C-14	2.33E-04	1.49E+04	4.30E+02		0.00E+00	---	---		5.04E-05	6.89E+04	1.98E+03
11	Co-60	7.98E-42	---	---		4.74E-11	7.33E+10	2.11E+09		4.67E-22	---	---

Figure 11. Sample from Excel Summary Output File for Case 2

The Word document *Results_Case2.doc* is the same as for Case 1 with the addition of the header information discussed above. All other output files for Case 2 are exactly the same format as those for Case 1 and include the text files *Results_Case2_AG.txt*, *Results_Case2_Res.txt*, *Results_Case2_PD.txt*, and the detailed dose pathways Excel file *Dose_Pathways_Case2.xls*.

2.8.3 Case 3 Output

Case 3 is different than Cases 1 and 2 in that it is a transient analysis. There is always a summary Excel file for Case 3 named *Results_Case3.xls.* A sample of the output format is shown in Figure 12. The result shown is the maximum dose, which is most limiting, and the time when this maximum occurs, along with the corresponding concentration and inventory limits. The end calculation time is shown in the header. Otherwise the summary results output is of similar format as that for Cases 1 and 2.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1		Inadvertent Intruder Analysis Results for Engineered Trench using Transient No Leaching Calculation for 1000 Years.													
2		The entry "---" indicates a value greater than or equal to the threshold value of 1E+20.													
3															
4		AG Dose	AG Conc	AG Inv	Max Time		Res Dose	Res Conc	Res Inv	Max Time		PD Dose	PD Conc	PD Inv	Max Time
5	Nuclide	(rem/yr)	(uCi/m3)	(Ci/Unit)	(yr)		(rem/yr)	(uCi/m3)	(Ci/Unit)	(yr)		(rem/yr)	(uCi/m3)	(Ci/Unit)	(yr)
6	H-3	2.73E-29	---	---	920		9.86E-29	---	---	899.428571		4.96E-08	7.00E+07	2.01E+06	100
7	C-14	1.31E-05	2.65E+05	7.63E+03	1000		5.50E-08	6.31E+07	1.82E+06	899.428571		5.17E-05	6.72E+04	1.94E+03	100
8	Na-22	5.46E-106	---	---	899.428571		3.51E-17	9.90E+16	2.85E+15	100		1.71E-16	2.03E+16	5.84E+14	100

Figure 12. Sample from Excel Summary Output File for Case 3

Case 3 has a second file that is always written named *Components_Case3.xls*. This file gives the decay chain component contributions to the maximum dose reported in *Results_Case3.xls.* There is a bold header line with the parent radionuclide, the time in years of the maximum dose, and the dose maximum (rem/yr) for 1 Ci of the parent in the waste volume. Subsequent lines give the decay chain radionuclide, the activity (fraction remaining), and the dose contribution of the radionuclide towards the total.

If the option is checked to write Word documents, then the summary results and components results are written to the Word files *Results_Case3.doc* and *Components_Case3.doc*. The components Word table is intended for inclusion in an appendix because it is thought that the full decay chain with computed fraction remaining and dose contribution of each component would be of interest. An sample of the components document format is shown in Figure 13.

Table A.1 Detailed Decay Chain Contributions to Maximum Intruder-Based Radionuclide Dose Limit for Engineered Trench – Agriculture Scenario with Transient Calculation for 1000 Years

In the following, the bold header line gives the parent radionuclide, the time in years of the maximum dose, and the maximum dose (rem/yr) for 1 Ci of the parent in the waste disposal unit.
Subsequent lines give the decay chain radionuclide, the activity (fraction remaining), and the dose contribution of the radionuclide towards the total.

Zero dose cases, where there is no maximum, are skipped and include the following parent radionuclides: S-35, Sc-46, W-181, W-185, W-188

Sn-126	**899.4 yr**	**5.37E-02**
Sn-126	9.94E-01	6.68E-04
Sb-126m	9.94E-01	4.21E-02
Sb-126	1.39E-01	1.09E-02

Sb-125	**899.4 yr**	**7.89E-101**
Sb-125	7.07E-99	7.88E-101
Te-125m	1.71E-99	1.18E-103

I-129	**1000 yr**	**1.35E-04**
I-129	1.00E+00	1.35E-04

Ra-226	**899.4 yr**	**3.46E-02**
Ra-226	6.77E-01	1.02E-04
Rn-222	6.77E-01	7.26E-06
Po-218	6.77E-01	1.74E-07
Pb-214	6.77E-01	4.14E-03
At-218	1.35E-04	3.61E-09
Bi-214	6.77E-01	3.03E-02
Po-214	6.77E-01	1.58E-06
Pb-210	6.87E-01	1.32E-05
Bi-210	6.87E-01	1.13E-05
Po-210	6.87E-01	4.01E-06

Figure 13. Sample from Word Output File with Detailed Decay Chains for Case 3

The user can choose to write two detailed transient result files. If the option is checked for detailed output of Transient Limits, then the Excel file *Transient_Dose_Case3.xls* is written. This Excel file contains a worksheet for each scenario and a worksheet for thickness. For each scenario worksheet, such as that for PD shown in Figure 14, the first column is the time from start of the scenario to the end. There is a column for each parent radionuclide. The values on a row are the total calculated dose at the given time that results from an initial inventory of 1 Ci of the parent mixed into the entire waste volume for the particular disposal unit. Having this transient data in Excel allows for plots of the transient to be easily made.

	A	B	C	D	E	F	G	H	I
1	PD_Time	H-3	C-14	Al-26	S-35	Cl-36	Ar-39	K-40	Ca-41
2	100	4.96E-08	5.17E-05	6.41E-05	3.80E-131	4.07E-03	2.85E-09	2.00E-04	8.57E-06
3	110	2.83E-08	5.16E-05	6.41E-05	1.01E-143	4.07E-03	2.78E-09	2.00E-04	8.57E-06
4	120	1.61E-08	5.15E-05	6.41E-05	2.69E-156	4.07E-03	2.71E-09	2.00E-04	8.57E-06

Figure 14. Sample from PD Worksheet of Transient Limits Excel File for Case 3

The thickness worksheet in the Excel file *Transient_Dose_Case3.xls* contains thickness information for the agriculture and resident scenarios if these are chosen. A sample of the output format is shown in Figure 15. For the agriculture scenario, the cover thickness AG_Thickness as a function of time is given from the start of this scenario. The agriculture scenario starts when the digging depth for the house foundation equals the remaining cover thickness. As the cover erodes, more of the excavated soil contains waste. When the cover has completely eroded, all of the excavated soil is waste. A multiplier AG_multGeomFac is calculated that gives the fraction of waste in the excavated soil that is then mixed with garden soil. This multiplier varies from 0 to 1 and is given as a function of time.

	A	B	C	D	E	F	G
1	AG_Time	AG_Thickness	AG_multGeomFac		Res_Time	Res_Thickness	Res_ShieldThickness
2	(yr)	(m)			(yr)	(m)	(m)
3	899.4285714	3.00E+00	0.00E+00		100	4.12E+00	1.12E+00
4	900	3.00E+00	2.67E-04		110	4.11E+00	1.11E+00
5	910	2.99E+00	4.93E-03		120	4.09E+00	1.09E+00

Figure 15. Sample from Thickness Worksheet of Transient Limits Excel File for Case 3

In this same thickness worksheet, the cover thickness for the resident scenario, Res_Thickness, is given as a function of time. This cover thickness is greater than or equal to the excavation digging depth. The difference between the cover thickness and the digging depth is the thickness of material for shielding, Res_ShieldThickness, unless there is an impenetrable barrier in which case the shielding may be thicker. The transient data shows the cover thickness and the shielding thickness as a function of time.

If the Case 3 option is checked for detailed output of Transient Pathways, then an Excel file is written for the agriculture scenario named *AG_Transient_Pathways_Case3.xls* and another for the post-drilling scenario named *PD_Transient_Pathways_Case3.xls.* (Note that a file is not written for the resident scenario since the single pathway transient is contained in the previously mentioned *Transient_Dose_Case3.xls.*) Each of these Excel files contains a separate worksheet for each parent. The worksheet for Np-237 of the post-drilling scenario is shown in Figure 16. On each worksheet the name of the parent is highlighted in blue with a light blue background and the transient time is given in the first column followed by the exposure pathways that make up the scenario. All of these exposure pathway values are the calculated dose at the given time that result from an initial inventory of 1 Ci of the parent mixed into the entire waste volume for the particular disposal unit. The sum of all the exposure pathway doses is given at the end in red as the total scenario dose. This detailed transient output allows the user to see the contribution over time for each exposure pathway.

	A	B	C	D	E	F
1	Np-237	PD Veg	PD Soil	PD Garden	PD Garden	PD Dose
2	PD_Time	Ingest	Ingest	Exposure	Inhale	Total
3	(yr)	(rem/yr)	(rem/yr)	(rem/yr)	(rem/yr)	(rem/yr)
4	100	8.52E-04	8.16E-05	4.52E-06	2.14E-06	9.41E-04
5	110	8.52E-04	8.16E-05	4.52E-06	2.14E-06	9.41E-04
6	120	8.52E-04	8.16E-05	4.52E-06	2.14E-06	9.41E-04

Figure 16. Sample from Np-237 Worksheet of PD Transient Pathways Excel File for Case 3

3. VERIFICATION OF INTRUDER CALCULATIONS

As the Intruder application was developed, there were many checks that calculations and logic are performed correctly. For verification, a hierarchical approach is used to verify calculations for all three cases.

3.1 Comparison to CIG Spreadsheet Calculation

A primary requirement is to reproduce the "CIG SA 6-23-03.xls" sample Excel calculation (Cook 2003). The equivalent calculation in the Intruder application is Case 2 for Cement Stabilized Encapsulated Waste (CSEW), also known as Components in Grout (CIG), with a shielding thickness of 100 cm and with the checkbox to use exact values input for 100cm shielding. This case was run and compared to the original spreadsheet. Most of the results agreed exactly and the few differences can be explained either by inconsistent notation in the spreadsheet or by an error in the spreadsheet. The following explains each of the differences.

- Inconsistent notation for Pu-244 in spreadsheet

When Pu-244 is the parent in the spreadsheet it has the combined daughter Np-240m, which has larger DCFs for exposure. However, when Pu-244 is included as a daughter for Cm-248, it does not have Np-240m listed as its combined daughter. Instead, the exposure values for Pu-244 have been altered to include those of Np-240m. As described in Section 2.7.3, the consistent notation would be to list Np-240m as a daughter of Pu-244 that is to be combined (plus notation). When this change is made in the fraction remaining input file for the Intruder application, the inventory limits for the agriculture and post-drilling scenarios agree with the original spreadsheet.

- Inconsistent notation for Np-237 in spreadsheet

When Np-237 is the parent in the spreadsheet it has the combined daughter Pa-233, which has larger DCFs for exposure. However, when Np-237 is included as a daughter for Pu-241, Am-241, Cm-245, and Cf-249, it does not have Pa-233 listed as its combined daughter. Instead, the exposure values for Np-237 have been altered to include those of Pa-233. As described in Section 2.7.3, the consistent notation would be to list Pa-233 as a daughter of Np-237 that is to be combined (plus notation). When this change is made in the fraction remaining input file for the parents listed above, the inventory limits for all three scenarios agree with the original spreadsheet.

- Error in multiplication by branching fraction when not combined with parent

As described in Section 2.7.3, the plus notation in the spreadsheet that indicates that a daughter is combined with a parent is really indicating that the daughter is in equilibrium with the parent. In the case of equilibrium, the fraction remaining of the daughter is the branching fraction times the fraction remaining of the parent. In the spreadsheet, the branching fraction is multiplied when computing EDEs, which are later multiplied by the parent fraction remaining. For the case when a daughter is not combined with a parent, the EDE should <u>not</u> be multiplied by the branching fraction since the fraction remaining is given explicitly in the spreadsheet. This error occurs throughout the spreadsheet. However, in most cases the branching fraction is one or very nearly one, so the error does not have any impact. There are two cases where the error does have some impact (and is nonconservative).

1. Cm-248 (8.26% error for resident scenario)
   The daughter of Cm-248 is given as Pu-244 with a branching fraction of 0.9174. For the resident scenario, all of the contribution comes from Pu-244, so there is an error of

(1-0.9174) or 8.26%. Note that the error is insignificant for the agriculture and post-drilling scenarios because Cm-248 is the dominant contribution.

2. Cf-252 (3.09% error for agriculture and post-drilling scenarios)
   The daughter of Cf-252 is given as Cm-248 with a branching fraction of 0.96908. The EDEs for Cm-248 dominate, so the error in multiplying EDE by branching fraction propagates to the limits and there is an error of (1-0. 96908) or 3.09%.

One additional error in the spreadsheet was found when comparing Case 1 results:

- Error in fraction remaining formula for Th-228 in spreadsheet

There is an error in the computation of fraction remaining for Th-228 that has a significant impact on the limit in the spreadsheet. The fraction remaining is computed by simple exponential decay, but the formulas for 300 yr and 700 yr reference the incorrect cell for half life. In addition, the year is not correct in these formulas. When the formula is corrected, the fraction remaining is very small and the limit is >1E20 rather than the incorrect value of 460.

When the above errors and inconsistencies are corrected, the agreement between the Intruder application and the spreadsheet is within 0.5%. This verifies the Intruder application for Case 2.

3.2 Verification of Decay Chain Calculation

As described in Section 2.4, the decay chain calculation in the Intruder application determines the full decay chain descending from a parent and calculates the activity for each member of the chain at a given time. This same calculation is performed by the CHAINS program written by Eckerman (1996). A comparison was made between the output from CHAINS and the output from the Intruder calculation. The output from CHAINS includes the radionuclide decay information for each member of the chain including half life, daughters, and branching fractions. These values differ somewhat from the input for the Intruder application. In order to perform a valid comparison, a test version of the input for the Intruder application was modified to agree with the input used in CHAINS. The comparison was made with several parents, but a particularly challenging comparison is for Am-243, which has 16 members in the chain with four separate branches.
The results from the two programs agree to five significant figures with an error less than 0.0005%. This almost exact agreement verifies the decay chain calculation in the Intruder application.

3.3 Checks of Case 1 and Case 3 Calculations

The Case 2 calculation has been verified against the sample CIG spreadsheet and the decay chain calculation has been verified against Eckerman’s independent calculation. The only difference between Case 1 and Case 2 is the value for fraction remaining, i.e. the decay chain calculation. Otherwise, the calculation logic for Case 1 is identical to that for Case 2 in the Intruder application. Thus, since the Case 2 calculation and the decay chain calculation have been verified, the Case 1 calculation is effectively verified.

Case 3 represents a transient calculation that can be thought of as Case 1 calculations at different instances of time. Since Case 1 has been verified, we can use Case 1 to verify Case 3. A Case 3 transient was run and then select instances in time from the transient were used to run equivalent Case 1 calculations. The Case 1 calculations agree with the Case 3 calculations. Thus, Case 3 is effectively verified.

4. USER GUIDE FOR THE INTRUDER APPLICATION

The Intruder application has a Graphical User Interface (GUI) that is intended to make the application very easy to use. This user guide describes the layout of the GUI and discusses the options that are available.

The application is started by double clicking on the file *Intruder.exe*. If the input files *IntruderInput.xls* and *DisposalUnitInput.xls* are in the same directory as *Intruder.exe*, then these files are automatically read and the form shown in Figure 17 opens after a few seconds.

If either input file is not in the same directory as *Intruder.exe* or if the names are not exactly as above, then a browser appears asking the user to locate the appropriate input file.

The facility and associated disposal units are shown in the upper left of the form in Figure 17. Note that a grayed-out disposal unit name means that the input in the file *DisposalUnitInput.xls* is incomplete for any analysis. The current disposal unit input file is fully complete only for the E-Area Slit Trenches and Intermediate-Level Vaults. Other units may have information sufficient to run Cases 1 and 2 but do not have a transient layer model needed to run Case 3.

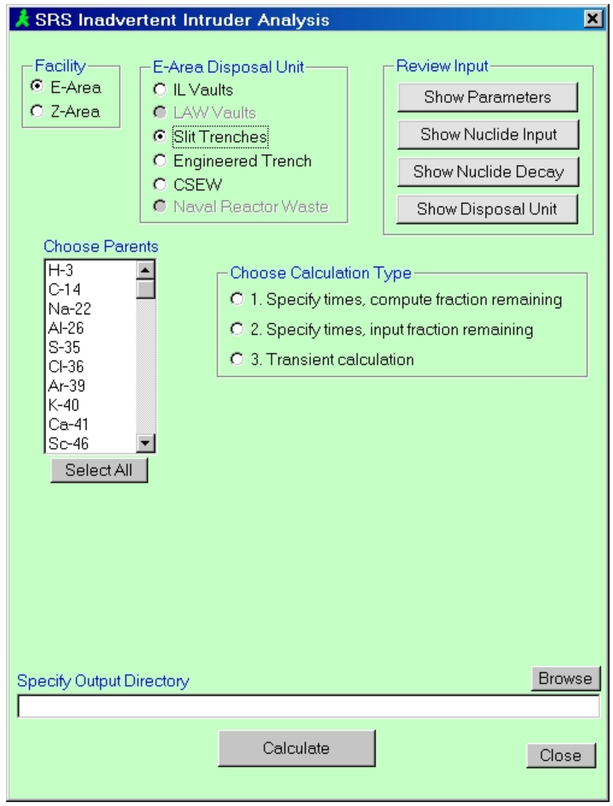


Figure 17. Initial Form at Start of Intruder Application

The upper right of the form in Figure 17 has buttons to review the input read from the input files. The first three buttons review input from the input file *IntruderInput.xls* and the last button reviews input from the input file *DisposalUnitInput.xls*.

If the first button at the upper right of Figure 17 labeled “Show Parameters” is clicked, then the display form in Figure 18 appears. Note that these values are exactly the same as the input data under the Parameter Values tab in the file *IntruderInput.xls*.

The values cannot be changed in this display form. If a different value is desired, it must be changed in the input file.

Parameters for Inadvertent Intruder Analysis

Parameters that are Independent of Disposal Unit

90	Consumption of contaminated vegetables [kg/yr]
1400	Density of soil [kg/m3]
0.2	Dilution factor for mixing of waste with soil in vegetable garden for agriculture scenario
0.02	Dilution factor for mixing of waste with soil in vegetable garden for post-drilling scenario
0.037	Consumption of contaminated soil [kg/yr]
0.01	Exposure time as fraction of year while working in garden
0.5	Exposure time as fraction of year while residing in home
0.7	Shielding factor of home for external exposure during indoor residence
8000	Air intake (breathing rate) [m3]
1.00E-07	Atmospheric mass loading of soil particulates while working in garden [kg/m3]
1.00E-08	Atmospheric mass loading of soil particulates while residing in home [kg/m3]
0.1	Dose limit [rem/yr]

Figure 18. Display for Parameters

Similarly, clicking on the buttons “Show Nuclide Input” and “Show Nuclide Decay” brings up the forms in Figures 19 and 20 that display the input data contained in the input file *IntruderInput.xls* in the worksheets Nuclide Input and Nuclide Decay.

Nuclide Input Values

Nuclide	IngestDCF	InhaleDCF	SoilRatio	Ex15cmSoil	ExInfSoil_no	ExInfSoil_45	ExInfSoil_100
Ac-225	1.11E-01	1.08E+01	1.51E-04	3.90E-05	4.00E-05	1.19E-08	1.05E-11
Ac-227	1.41E+01	6.70E+03	1.51E-04	3.06E-07	3.10E-07	1.61E-11	1.52E-16
Ac-228	2.16E-03	3.08E-01	1.51E-04	3.22E-03	3.70E-03	6.10E-05	7.19E-07
Al-26	1.46E-02	7.96E-02	1.72E-03	9.03E-03	1.09E-02	3.18E-04	7.87E-06
Am-241	3.64E+00	4.44E+02	1.08E-04	2.73E-05	2.73E-05	2.95E-13	7.90E-22
Am-242	1.41E-03	5.85E-02	1.08E-04	3.12E-05	3.12E-05	1.04E-09	7.27E-15
Am-242m	3.52E+00	4.26E+02	1.08E-04	1.05E-06	1.06E-06	1.57E-11	9.06E-17
Am-243	3.62E+00	4.40E+02	1.08E-04	8.88E-05	8.88E-05	2.52E-10	3.76E-15
Ar-39			0.00E+00	5.31E-07	5.40E-07	0.00E+00	0.00E+00
At-217			6.45E-02	1.01E-06	1.11E-06	6.48E-09	1.70E-11
At-218			6.45E-02	3.65E-06	3.65E-06		
Ba-133	3.66E-03	7.81E-03	6.45E-03	1.15E-03	1.24E-03	2.93E-06	2.23E-09
Ba-137m			6.45E-03	2.00E-03	2.25E-03	1.98E-05	6.64E-08
Bi-210	6.39E-03	1.96E-01	2.15E-03	2.17E-06	2.25E-06	0.00E+00	0.00E+00
Bi-211			2.15E-03	1.49E-04	1.60E-04	4.39E-07	3.38E-10
Bi-212	1.06E-03	2.16E-02	2.15E-03	6.26E-04	7.32E-04	1.38E-05	2.08E-07
Bi-213	7.22E-04	1.71E-02	2.15E-03	4.38E-04	4.79E-04	2.42E-06	7.52E-09
Bi-214	2.83E-04	6.59E-03	2.15E-03	5.09E-03	6.13E-03	1.70E-04	3.83E-06
Bk-249	1.20E-02	1.39E+00	6.60E-06	2.90E-09	2.91E-09	0.00E+00	0.00E+00
C-14	2.09E-03	2.09E-03	5.60E-01	8.41E-09	8.41E-09	0.00E+00	0.00E+00
Ca-41	1.27E-03	1.35E-03	1.51E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cd-113m	1.61E-01	1.53E+00	6.50E-02	3.99E-07	4.05E-07	0.00E+00	0.00E+00
Cf-249	4.74E+00	5.77E+02	6.60E-06	1.07E-03	1.16E-03	3.41E-06	3.05E-09
Cf-250	2.13E+00	2.62E+02	6.60E-06	7.40E-08	7.40E-08	4.54E-14	5.00E-21
Cf-251	4.85E+00	5.88E+02	6.60E-06	3.22E-04	3.29E-04	8.81E-08	1.51E-11
Cf-252	1.08E+00	1.57E+02	6.60E-06	1.10E-07	1.10E-07	4.49E-15	5.40E-23
Cm-242	1.15E-01	1.73E+01	6.45E-06	1.06E-07	1.07E-07	2.40E-16	0.00E+00
Cm-243	2.51E+00	3.07E+02	6.45E-06	3.53E-04	3.64E-04	2.21E-07	5.80E-11
Cm-244	2.02E+00	2.48E+02	6.45E-06	7.87E-08	7.87E-08	5.60E-17	0.00E+00
Cm-245	3.74E+00	4.55E+02	6.45E-06	2.10E-04	2.13E-04	1.53E-08	5.55E-13

Figure 19. Display for Nuclide Input

Nuclide Decay

Nuclide	Half Life	Units	Daughter1	Branch1	Daughter2	Branch2
Ac-225	1.0000E+01	days	Fr-221	1.0000		
Ac-227	2.1773E+01	years	Fr-223	0.0138	Th-227	0.9856
Ac-228	6.1500E+00	hours	Th-228	1.0000		
Al-26	7.1700E+05	years				
Am-241	4.3220E+02	years	Np-237	1.0000		
Am-242	1.6020E+01	hours	Pu-242	0.1730	Cm-242	0.8270
Am-242m	1.4100E+02	years	Np-238	0.0048	Am-242	0.9950
Am-243	7.3700E+03	years	Np-239	1.0000		
Ar-39	2.6900E+02	years				
At-217	3.2300E-02	seconds	Bi-213	1.0000		
At-218	1.5000E+00	seconds	Bi-214	1.0000		
Ba-133	3.8489E+03	days				
Ba-137m	2.5520E+00	minutes				
Bi-210	5.0130E+00	days	Po-210	1.0000		
Bi-211	2.1400E+00	minutes	Tl-207	0.9972	Po-211	0.0028
Bi-212	6.0550E+01	minutes	Tl-208	0.3593	Po-212	0.6407
Bi-213	4.5590E+01	minutes	Tl-209	0.0216	Po-213	0.9784
Bi-214	1.9900E+01	minutes	Po-214	0.9998		
Bk-249	3.3000E+02	days	Cf-249	1.0000		
C-14	5.7300E+03	years				
Ca-41	1.0300E+05	years				
Cd-113m	1.4100E+01	years				
Cf-249	3.5100E+02	years	Cm-245	1.0000		
Cf-250	1.3080E+01	years	Cm-246	0.9992		
Cf-251	8.9800E+02	years	Cm-247	1.0000		
Cf-252	2.6450E+00	years	Cm-248	0.9691		
Cm-242	1.6280E+02	days	Pu-238	1.0000		
Cm-243	2.9100E+01	years	Pu-239	0.9976	Am-243	0.0024
Cm-244	1.8100E+01	years	Pu-240	1.0000		

Figure 20. Display for Nuclide Decay

Clicking the button "Show Disposal Unit" brings up the form in Figure 21. The top portion and the bottommost portion of this form display the input from the file *DisposalUnitInput.xls* for the chosen disposal unit. The middle portion within the light blue outlines is not input but is a type of time calculator related to the transient layer model. This calculator is discussed in the upcoming section on the Case 3 transient calculation option.

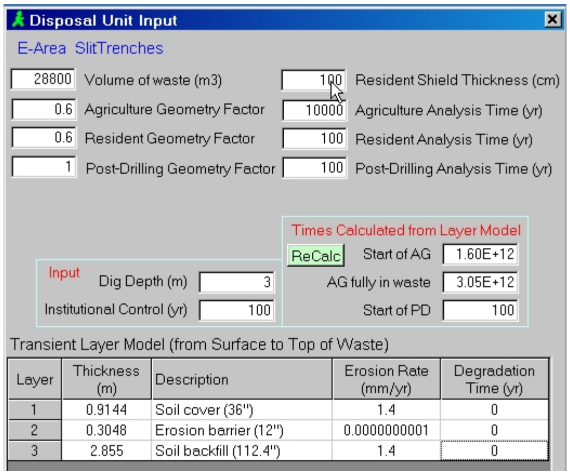


Figure 21. Display for Disposal Unit Input

The input from the Parents tab in the input file *IntruderInput.xls* appears as the list of parent radionuclides to be considered. The parents appear in a list box as shown in Figure 22 so that the user can choose the parents to be analyzed. The choices are made with standard Windows keystroke options: (1) choose a range by holding the Shift key down and (2) choose individual selections by holding the Ctrl key down. The Select All button selects all the parents in the list.

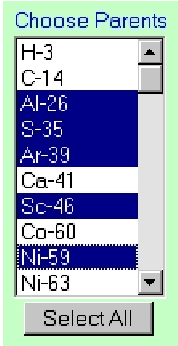


Figure 22. List Box For Parents

In the center section of the Intruder form shown in Figure 17 are the option buttons to choose the type of calculation. There are three types of calculations available that are numbered. The Case 2 calculation labeled "2. Specify times, input fraction remaining" corresponds to the spreadsheet analysis that has been used in the PA where fraction remaining comes from PORFLOW calculations, i.e. leaching is considered. The Case 1 calculation labeled "1. Specify times, compute fraction remaining" is like Case 2 but with no leaching so the fraction remaining is computed from the Bateman equation. The Case 3 calculation labeled "3. Transient calculation" uses the layer model to perform a transient calculation with no leaching. When one of these cases is selected, other options appear that are appropriate to the case. The following describes each of these cases and their options.

Case 1. Specify times, compute fraction remaining

When Case 1 is chosen, a section for specifying scenarios appears in the lower center and a section for specifying output appears below the parents list box as shown in Figure 23.

Each of the three scenarios has a checkbox that can be checked to include that scenario in the calculation. The time entries listed for calculation in the Bateman equation are the values from the disposal unit input file. The user can change these time entries if desired.

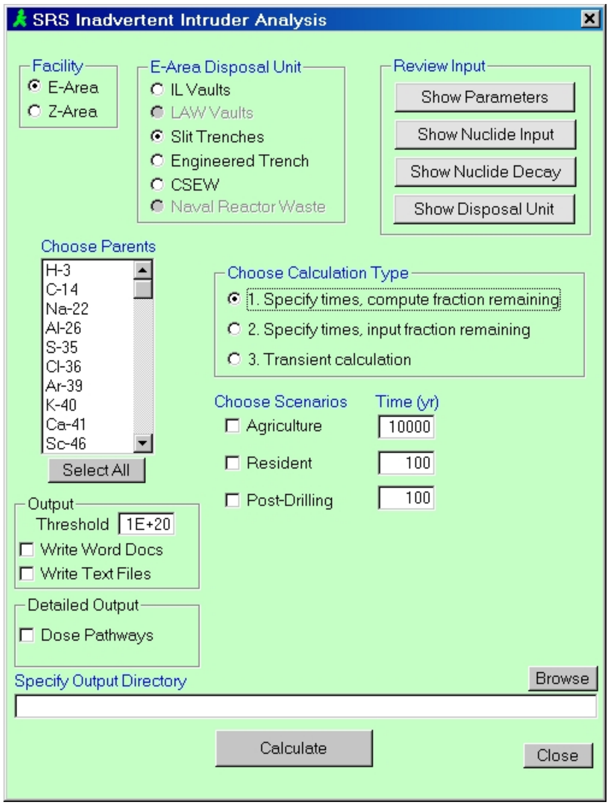


Figure 23. Form Appearance for Case 1

If the Resident scenario is chosen, then additional options appear as shown in Figure 24.

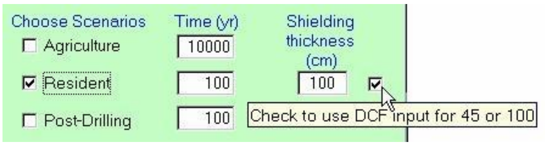


Figure 24. Additional Options for Resident Scenario for Case 1

The Resident scenario includes a shielding calculation and the shielding thickness must be specified. The listed entry for shielding thickness is the value from the disposal unit input file. The checkbox to the right of the shielding thickness does not have a label, but if the cursor is held over the checkbox, then the popup description displays as shown in Figure 24. If this box is not checked, then the DCF is obtained from a fit to the DCF as a function of thickness. If the box is checked, then exact input values are used for thickness of 45 or 100 cm.

Before calculating, we must specify a directory where output will be written. In Figure 23, the text box labeled "Specify Output Directory" has a browse button on the right. Clicking on this browse button brings up the browser dialog shown in Figure 25. The directory tree can be navigated to locate an existing directory. If desired, a new directory can be created within the chosen directory by entering the new directory name in the bottom text box. When the OK button is clicked, the directory path is entered in the main form in Figure 23.

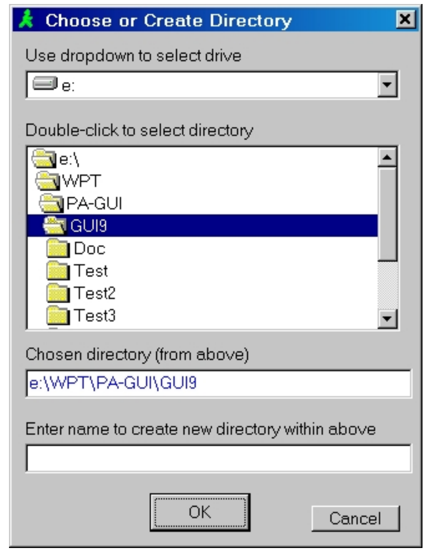


Figure 25. Browser Form for Output Directory

As described in Section 2.8.1 an Excel file named *Results_Case1.xls* is written to the output directory. Using the output checkboxes, the user can choose to additionally write the results as a Word document *Results_Case1.doc* and/or as text files such as *Results_Case1_ AG.txt*. The detailed output checkbox for Dose Pathways produces the Excel file *Dose_Pathways_Case1.xls*, which shows pathway contributions.

<u>Case 2. Specify times, input fraction remaining</u>

When Case 2 is chosen, the same choices appear as for Case 1 with one additional required input for the fraction remaining input file as shown at the lower middle of Figure 26. All other choices are identical to Case 1.

To locate the fraction remaining Excel input file, use the Browse button to bring up a browser dialog.

The checkbox "Use BranchFrac from File" should normally be used. If for some reason the branching fractions were not available, then a branching fraction will be computed from the decay chain calculation if this checkbox is unchecked.

As described in Section 2.8.2, the output files are very similar to those for Case 1 and the differences are given there.

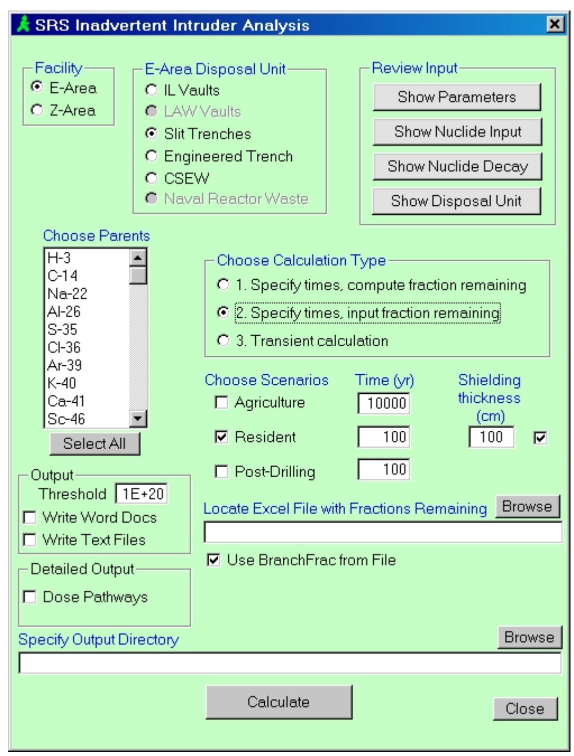


Figure 26. Form Appearance for Case 2

Case 3. Transient calculation

When Case 3 is chosen, the options for detailed output are different and there is an additional input section in the lower middle of the form as shown in Figure 27. Here the default values are entered for length of institutional control, the analysis end time, and the analysis time step size. The user can change these values if desired.

Note that a time step too large may result in missing the maximum value. A time step too small may cause the calculation to take a long time. The default value of 10 years seems to be a good compromise. A run with 1 year can be made to check the maximum. Time steps of less than 1 year are probably unnecessary.

If the agriculture or resident scenario is chosen, then there is an additional input for the digging depth for the foundation of a house as shown in Figure 27. The default value of 3 meters is given but this can be changed if desired.

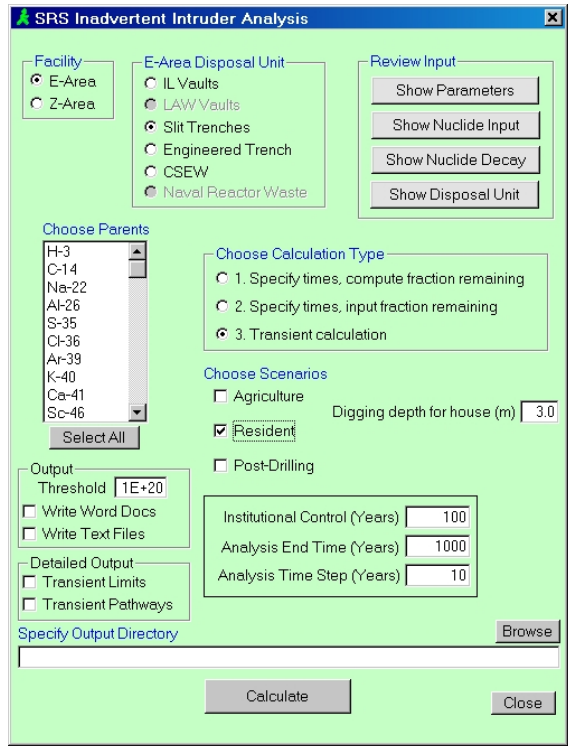
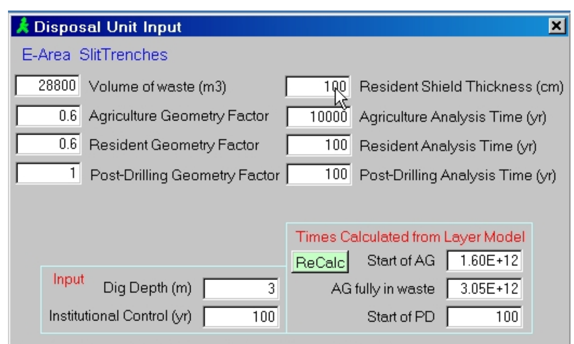


Figure 27. Form Appearance for Case 3

The transient calculation uses the layer model described in Section 2.7.2 to modify the cover thickness as a function of time. The start of the agriculture and post-drilling scenarios can be computed from this layer model. This is the function of the calculator that appears in the disposal unit input display shown in Figure 28. For the specified digging depth and the time for loss of institutional control, the start of the agriculture scenario is determined as the time that the remaining cover thickness equals the digging depth. Another time of interest is when the agriculture scenario is fully into the waste, i.e. all cover has eroded.



Layer	Thickness (m)	Description	Erosion Rate (mm/yr)	Degradation Time (yr)
1	0.9144	Soil cover (36")	1.4	0
2	0.3048	Erosion barrier (12")	0.0000000001	0
3	2.855	Soil backfill (112.4")	1.4	0

Figure 28. Disposal Unit Time Calculator

The post-drilling scenario starts after all impenetrable barriers have degraded. In the case shown, there are no impenetrable barriers, so the post-drilling scenario starts immediately at loss of institutional control. Note that the resident scenario always starts immediately at loss of institutional control, so there is no time delay computed for the resident scenario.

It is useful to know when the agriculture and post-drilling scenarios begin so that the analysis end time can be adjusted if necessary to include these scenarios. For scoping purposes, the digging depth and institutional control time can be changed in the calculator and the ReCalc button hit to recalculate the times. Note that the digging depth and institutional control time are not changed in the main form from scoping changes in the calculator.

When the Calculate button is clicked for Case 3, the start times for the agriculture and post-drilling scenarios are used to check if the overall analysis end time occurs before the scenario could start. If so, then a message appears informing the user that the scenario does not occur within the overall analysis time period.

Tips for Special Analyses

- If the user is running many cases for a subset of parents, then it may be useful to change the parents list in the input file *IntruderInput.xls* to be just the subset. Then this subset will appear in the list box and the user can click the Select All button rather than manually choosing the subset. The user should keep a copy of the full set in a column other than the first column. The first column of the Parents worksheet is what is read to fill the list box. Also note that output appears in the same order as the parent input list. For example, the user may want to alphabetize the parent list so that output appears in alphabetical order.

- If the user wants to vary input for a disposal unit to scope different cases, then he must make separate disposal unit input files for each case. The user should rename the standard input file *DisposalUnitInput.xls* to some other name so that the application will bring up a browser to choose the disposal unit input file. The user will need to restart the application each time to load a new disposal unit input file.

5. REFERENCES

Collard, L. B. 2004. Personal communication, supplied FORTRAN subroutine to calculate Bateman equation.

Cook, J. R. 2003. Computer file "CIG SA 6-23-03.xls", a sample Excel inadvertent intruder analysis calculation.

Eckerman, K. F. 1996. "CHAINS: Extended Precision Chain Code," computer program available from Oak Ridge National Laboratory website at http://homer.ornl.gov/vlab/VLcodeDF.html.

Foster, A. R and Wright, R. L. 1980. Basic Nuclear Engineering. Allyn and Bacon, Inc., Boston, MA.

Lee, P. L. 2004. *Inadvertent Intruder Analysis Input For Radiological Performance Assessments*. WSRC-TR-2004-00295, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

McDowell-Boyer, L., Yu, A. D., Cook, J. R., Kocher, D. C., Wilhite, E. L., Holmes-Burns, H., and Young, K. E. 2000. *Radiological Performance Assessment for the E-Area Low-Level Waste Facility*. WSRC-RP-94-218. Revision 1, Westinghouse Savannah River Company, Aiken, SC.

Appendix A. Code Listing of EDE Calculations

```
Public Function Vegetable_Ingestion(Plant_to_Soil_RadMassConc_Ratio As Double, _
                                    RadVolConc_Waste As Double, _
                                    Soil_Mixing_Dilution_Factor As Double, _
                                    Annual_ConsumedMass_Vegetables As Double, _
                                    DCF_Ingestion As Double, _
                                    BulkDensity_Soil As Double) As Double
  'Vegetable Ingestion Pathway
  'Returns annual EDE (rem/yr) from vegetable ingestion for given inputs
  '  Plant_to_Soil_RadMassConc_Ratio - plant-to-soil concentration ratio for radionuclide
                                       (uCi/kg vegetable per uCi/kg dry soil)
  '  RadVolConc_Waste - concentration of radionuclide in exhumed waste (uCi/m3)
  '  Soil_Mixing_Dilution_Factor - dilution factor for mixing of exhumed waste with garden soil
  '  Annual_ConsumedMass_Vegetables - annual consumption of vegetables (kg/yr)
  '  DCF_Ingestion - DCF for ingestion of radionuclide (rem/uCi)
  '  BulkDensity_Soil - bulk density of soil (kg/m3)

  Vegetable_Ingestion = Plant_to_Soil_RadMassConc_Ratio * _
                        RadVolConc_Waste * Soil_Mixing_Dilution_Factor * _
                        Annual_ConsumedMass_Vegetables * _
                        DCF_Ingestion / BulkDensity_Soil
End Function


Public Function Soil_Ingestion(RadVolConc_Waste As Double, _
                               Soil_Mixing_Dilution_Factor As Double, _
                               Annual_ConsumedMass_Soil As Double, _
                               DCF_Ingestion As Double, _
                               BulkDensity_Soil As Double) As Double
  'Soil Ingestion Pathway
  'Returns annual EDE (rem/yr) from soil ingestion for given inputs
  '  RadVolConc_Waste - concentration of radionuclide in exhumed waste (uCi/m3)
  '  Soil_Mixing_Dilution_Factor - dilution factor for mixing of exhumed waste with garden soil
  '  Annual_ConsumedMass_Soil - annual consumption of soil (kg/yr)
  '  DCF_Ingestion - DCF for ingestion of radionuclide (rem/uCi)
  '  BulkDensity_Soil - bulk density of soil (kg/m3)

  Soil_Ingestion = RadVolConc_Waste * Soil_Mixing_Dilution_Factor * _
                   Annual_ConsumedMass_Soil * DCF_Ingestion / BulkDensity_Soil
End Function
```

```
Public Function Garden_Exposure(RadVolConc_Waste As Double, _
                                Soil_Mixing_Dilution_Factor As Double, _
                                Year_Fraction_Garden_Exposure As Double, _
                                DCF_15cmSoil As Double) As Double
  'External Exposure to Soil Working in Garden
  'Returns annual EDE (rem/yr) from exposure working in garden for given inputs
  '  RadVolConc_Waste - concentration of radionuclide in exhumed waste (uCi/m3)
  '  Soil_Mixing_Dilution_Factor - dilution factor for mixing of exhumed waste with garden soil
  '  Year_Fraction_Garden_Exposure - fraction of year that exposure in garden occurs
  '  DCF_15cmSoil - DCF for uniform distribution in 15 cm of surface soil (rem/yr per uCi/m3)

  Garden_Exposure = RadVolConc_Waste * Soil_Mixing_Dilution_Factor * _
                    Year_Fraction_Garden_Exposure * DCF_15cmSoil
End Function



Public Function Home_AG_Exposure(RadVolConc_Waste As Double, _
                                 Year_Fraction_Home_Exposure As Double, _
                                 DCF_InfSoil_NoShield As Double, _
                                 Shielding_Factor_Home As Double) As Double
  'External Exposure Residing in Home for Agriculture
  'Returns annual EDE (rem/yr) from exposure residing in home for given inputs
  '  RadVolConc_Waste - concentration of radionuclide in exhumed waste (uCi/m3)
  '  Year_Fraction_Home_Exposure - fraction of year that exposure in home occurs
  '  DCF_InfSoil_NoShield - DCF for uniform distribution in infinite soil with no shielding
                           (rem/yr per uCi/m3)
  '  Shielding_Factor_Home - shielding factor for home (uniform for all radionuclides)

  Home_AG_Exposure = RadVolConc_Waste * Year_Fraction_Home_Exposure * _
                     DCF_InfSoil_NoShield * Shielding_Factor_Home
End Function



Public Function Garden_Inhalation(RadVolConc_Waste As Double, _
                                  Soil_Mixing_Dilution_Factor As Double, _
                                  AtmMassLoading_Soil_Garden As Double, _
                                  Year_Fraction_Garden_Exposure As Double, _
                                  Annual_AirVolIntake_Garden As Double, _
                                  DCF_Inhalation As Double, _
                                  BulkDensity_Soil As Double) As Double
  'Inhalation of Particles Working in Garden
  'Returns annual EDE (rem/yr) from soil inhalation in garden for given inputs
  '  RadVolConc_Waste - concentration of radionuclide in exhumed waste (uCi/m3)
  '  Soil_Mixing_Dilution_Factor - dilution factor for mixing of exhumed waste with garden soil
  '  AtmMassLoading_Soil_Garden - atmospheric mass loading of surface soil for garden (kg/m3)
```

```
  '  Year_Fraction_Garden_Exposure - fraction of year during which inhalation exposure in garden occurs
  '  Annual_AirVolIntake_Garden - annual air intake in garden (m3/yr)
  '  DCF_Inhalation - DCF for inhalation of radionuclide (rem/uCi)
  '  BulkDensity_Soil - bulk density of soil (kg/m3)

  Garden_Inhalation = RadVolConc_Waste * Soil_Mixing_Dilution_Factor * _
                      AtmMassLoading_Soil_Garden * _
                      Year_Fraction_Garden_Exposure * _
                      Annual_AirVolIntake_Garden * _
                      DCF_Inhalation / BulkDensity_Soil
End Function



Public Function Home_Inhalation(RadVolConc_Waste As Double, _
                                AtmMassLoading_Soil_Home As Double, _
                                Year_Fraction_Home_Exposure As Double, _
                                Annual_AirVolIntake_Home As Double, _
                                DCF_Inhalation As Double, _
                                BulkDensity_Soil As Double) As Double
  'Inhalation of Particles Residing in Home
  'Returns annual EDE (rem/yr) from soil inhalation in home for given inputs
  '  RadVolConc_Waste - concentration of radionuclide in exhumed waste (uCi/m3)
  '  AtmMassLoading_Soil_Home - atmospheric mass loading of surface soil for home (kg/m3)
  '  Year_Fraction_Home_Exposure - fraction of year during which inhalation exposure in home occurs
  '  Annual_AirVolIntake_Home - annual air intake in home (m3/yr)
  '  DCF_Inhalation - DCF for inhalation of radionuclide (rem/uCi)
  '  BulkDensity_Soil - bulk density of soil (kg/m3)

  Home_Inhalation = RadVolConc_Waste * _
                    AtmMassLoading_Soil_Home * _
                    Year_Fraction_Home_Exposure * _
                    Annual_AirVolIntake_Home * _
                    DCF_Inhalation / BulkDensity_Soil
End Function
```

```
Public Function Home_Res_Exposure(RadVolConc_Waste As Double, _
                                  Year_Fraction_Home_Exposure As Double, _
                                  DCF_InfSoil_100cmShield As Double, _
                                  Shielding_Factor_Home As Double) As Double
  'External Exposure Residing in Home for Resident
  'Returns annual EDE (rem/yr) from exposure residing in home for given inputs
  '  RadVolConc_Waste - concentration of radionuclide in exhumed waste (uCi/m3)
  '  Year_Fraction_Home_Exposure - fraction of year that exposure in home occurs
  '  DCF_InfSoil_100cmShield - DCF for uniform distribution in infinite soil with 100 cm shielding
                               (rem/yr per uCi/m3)
  '  Shielding_Factor_Home - shielding factor for home (uniform for all radionuclides)

  Home_Res_Exposure = RadVolConc_Waste * Year_Fraction_Home_Exposure * _
                      DCF_InfSoil_100cmShield * Shielding_Factor_Home
End Function



Public Function RadDose(Inventory As Double, _
                        WasteVolume As Double, _
                        SDCF As Double, _
                        GeometryFactor As Double, _
                        RadFractionRemaining As Double)
  'Returns dose for given nuclide in rem/yr for given inputs
  '  Inventory - rad waste inventory in uCi
  '  WasteVolume - volume of waste in disposal unit (m3)
  '  SDCF - scenario dose conversion factor for nuclide (rem/yr per uCi/m3)
  '         This is scenario EDE that is calculated for concentration of 1 uCi/m3
  '  GeometryFactor - geometrical correction factor
  '  RadFractionRemaining - fraction of initial inventory remaining for rad

  RadDose = (Inventory / WasteVolume) * SDCF * GeometryFactor * RadFractionRemaining

End Function
```

Appendix B. Design Check Instructions and Review

B.1 Instructions Provided for Design Check

Design Check Instructions for Inadvertent Intruder Analysis Application
(WSRC-TR-2004-00293)

A design check of the Intruder application should check that the application meets the functional requirements in Section 2.1 of WSRC-TR-2004-00293, which includes checking the verification of calculations in Section 3 of WSRC-TR-2004-00293. The following detailed instructions are intended as an aid to performing these checks using supplied input files that were used for the verification in Section 3.

The supplied computer files are located on computer l-koffman in Public\Intruder\DesignCheck and include the following folders and files.

```
\DesignCheck
     DisposalUnitInput.xls
     Intruder.exe
     \Check of CIG Spreadsheet
        CIG SA 6-23-03plee.xls
        FractionRemainingInput.xls
        IntruderInput_OrigCIGValues.xls
     \Check Transient
        IntruderInput.xls
     \Comparison to CHAINS
        IntruderInput_Chains.xls
        \ChainDecay
           dfact.exe
```

The Intruder application is started by double clicking Intruder.exe. The input file DisposalUnitInput.xls will automatically be used since it is in the same directory. The application will prompt for the intruder input Excel file.

1. Check of comparison to CIG spreadsheet calculation

The CIG spreadsheet calculation is in file `CIG SA 6-23-03plee.xls.` The corresponding intruder input file is `IntruderInput_OrigCIGValues.xls.`

a. Verify that the inputs on the Nuclide Input worksheet of the intruder input file in columns B, C, D, E, F, H (not G) agree with the CIG inputs in columns D, E, M, F, G, and I.
b. Verify that the fraction remaining input in file `FractionRemainingInput.xls` agrees with the corresponding CIG inputs in columns AF, AG, and AH. Note exceptions regarding inconsistent notation pointed out in Section 3.1 of WSRC-TR-2004-00293.
c. Run the Intruder application for the CSEW disposal unit using calculation type 2 to specify fractions remaining. Check all three scenarios, chose all parents, use the browser to select the fractions remaining input file, and use the browser to select an output directory.
d. Compare the results for the inventory limit in file `Results_Case2.xls` with the CIG results in columns AM, AP, and AS.

2. Check of decay chain calculation

An independent decay chain calculation program written by Eckerman is available from the Oak Ridge National Laboratory web site at http://homer.ornl.gov/vlab/vlcodeInst.html. The self extracting file `dfact.exe` is provided in the `ChainDecay` folder. Double click this file to extract the programs.

a. The CHAINS program is a DOS program, so start a Command Prompt window and change directory to where the programs were extracted. Then type CHAINS. You are prompted for the radionuclide – enter Am-243. You will see a listing of the decay chain with half-life and branching fractions f1 and f2 for daughters. Note that this information is also written to a text log file CHAINS.LOG. After you hit ENTER you will be prompted for the time in years for the decay calculation. Enter 100 and then 1000. The fraction of activity remaining is the column A(t)/Ao. These results are also written to the log file.
b. The intruder input file `IntruderInput_Chains.xls` has been modified to have the same half-lives and branching fractions as the CHAINS program for Am-243 so that a comparison of results can be made. Check that the half-lives and branching fractions in the log file from CHAINS agree with these values on the Nuclide Decay worksheet of `IntruderInput_Chains.xls`.
c. Run the Intruder application for the ILV disposal unit using calculation type 3 for a transient (this case produces detailed decay chain results). Choose only the parent Am-243 and choose the resident scenario. To force the results to occur at 100 years, choose the Institutional Control time as 100 and choose the Analysis End time as 100. The detailed results in output file `Components_Case3.xls` have the fraction of activity remaining in column B. Note that the number format can be changed to show 5 decimal places. Compare these values for 100 years to the ones in the CHAINS log file.
d. Run the Intruder application again for 1000 years by choosing the Institutional Control time as 1000 and choosing the Analysis End time as 1000. Compare these values for 1000 years to the ones in the CHAINS log file.

3. Check of transient layer thickness change with time

The transient calculation determines the bounding limit over the time period of the calculation. An important part of this calculation is the cover thickness above the waste as a function of time and the corresponding shielding thickness as a function of time. Check this calculation for the slit trench disposal unit.

a. Run the Intruder application for the slit trench disposal unit using the transient Case 3. Choose all parents, choose all three scenarios, check the box for Write Word Docs, and check the box under detailed output for Transient Limits. You should get a message that the agriculture scenario does not occur. In the output file `Transient_Dose_Case3.xls` look at worksheet Thickness. The column Res_Thickness is the cover thickness as a function of time and the column Res_ShieldThickness is the remaining thickness after digging a 3 meter basement for the house.
b. Use the transient layer model in the file `DisposalUnitInput.xls` to perform a hand calculation of the thickness change. If degradation time is nonzero, then this time must pass before erosion starts. Erosion removes the layer at a constant rate. Degradation of a subsequent layer does not start until it is uncovered. Use these rules to confirm that the calculation in step (a) is correct.
c. Run the Intruder application for the ILV disposal unit. Perform a hand calculation and confirm that the Intruder calculation is correct. Note that the vault roof and grout maintain a shielding thickness greater than one meter.

4. Check that Case 1 calculation agrees with an instant of time in transient Case 3 calculation

The verification for Case 3 uses Case 1 to check calculations at instants in time. For the slit trench calculation in step 3, choose some instant of time and note the shielding thickness

Res_ShieldThickness at this time. Now run the Intruder application for slit trenches using Case 1 for all parents with resident and post-drilling scenarios. For both scenarios, enter the time as the chosen instant of time from Case 3. For the shielding thickness, enter the Res_ShieldThickness value converted to cm (multiply by 100). Run the calculation and compare the dose result in `Results_Case1.xls` to the dose result at the instant of time in `Transient_Dose_Case3.xls` on worksheets Res_Dose and PD_Dose. For the comparison it is sufficient to spot check two or three nuclides.

5. Check that the results in Word output file `Results_Case3.doc` agrees with the results in the Excel output file `Results_Case3.xls` from the transient calculation in step 3 for slit trenches.

B.2 Summary of Design Check

Summary of Design Check for Inadvertent Intruder Analysis Application (WSRC-TR-2004-00293)

Overall, the report adequately addresses the functional requirements and provides the end users with a good guide. The specified functional requirements are outline as follows:

1) Perform consistent calculations via programmed subroutines or functions
2) Input values only one time and keep standard input under configuration control
3) Have a graphical user interface (GUI) that makes the application easy to use
4) Be able to recover the "CIG SA 6-23-03.xls" sample Excel calculation
5) Output results to Excel and output final tables directly to Word
6) Compute a no-leaching case at specified times using the Bateman equation
7) Provide a transient no-leaching calculation that models the soil covers and barriers as layers that degrade and erode with time

Requirements 1) and 2) were addressed in Section 2.2 *"Basic Approach."* Requirement 3) was discussed in Section 4 *"User Guide For The Intruder Application."* Requirement 4) was discussed in detail in Section 3.1 *"Comparison to CIG Spreadsheet Calculations."* Section 2.8 *"Output Files"* addressed Requirement 5). Requirements 6) and 7) were addressed in Sections 2.3 (*"Review of Scenarios"*), 2.6 (*"Types of Calculation"*), 2.7 (*"Input Files"*) and 2.8 (*"Output Files"*).

1. Check of comparison to CIG spreadsheet calculation

a. Inputs on the *Nuclide Input* worksheet of the intruder input file in columns B, C, D, E, F, H were spot checked and agree with corresponding columns (D, E, M, F, G, I) on the *Dose Estimates* worksheet of the CIG spreadsheet.
b. Values in columns E, F, G of the fraction remaining input spreadsheet *FractionRemainingInput.xls* were checked and agree with corresponding values in columns AF, AG, and AH on the *Dose Estimates* worksheet of the CIG spreadsheet.
c. Instruder application was run as instructed to obtain the results for the inventory limit (File *Results_Case2.xls*)
d. The results for the inventory limit in file *Results_Case2.xls* were compared with the CIG results. The percentage errors are given below:

Nuclide	AG Limits Error (%)	RES Limits Error (%)	PD Limits Error (%)
H-3			0.00E+00
C-14	-1.11E-04		-1.11E-04
Co-60		1.12E-14	
Ni-59	-1.79E-14		1.37E-14
Ni-63	0.00E+00		0.00E+00
Se-79	-1.90E-03		-1.91E-03
Rb-87	-9.35E-03		-9.36E-03

Sr-90	0.00E+00		0.00E+00
Zr-93	**-3.87E-01**		**-4.19E-01**
Nb-94	1.91E-14	0.00E+00	-3.37E-14
Mo-93	-1.48E-14		0.00E+00
Tc-99			-1.44E-03
Pd-107	-1.52E-14		0.00E+00
Cd-113m	-6.32E-04		-6.33E-04
Sn-121m	-1.55E-14		2.21E-14
Sn-126	1.93E-14	0.00E+00	1.11E-14
I-129			1.25E-14
Cs-135	1.15E-14		4.64E-14
Cs-137	2.50E-14	0.00E+00	2.04E-14
Sm-151	-1.22E-02		-1.33E-02
Eu-152	0.00E+00	-1.91E-14	1.88E-14
Eu-154		0.00E+00	-1.26E-14
Th-228	0.00E+00		
Th-230	0.00E+00	0.00E+00	-1.80E-14
Th-232	-7.14E-05	0.00E+00	-4.29E-03
U-232	0.00E+00	0.00E+00	1.95E-14
U-233	-5.26E-04	1.25E-14	-1.07E-03
U-234	-1.37E-14	0.00E+00	2.29E-14
U-235	-1.23E-02	-1.53E-02	-7.35E-04
U-236	0.00E+00		2.19E-14
U-238	-7.40E-08	0.00E+00	-1.87E-07
Np-237	0.00E+00	0.00E+00	0.00E+00
Pu-238	-1.16E-01		-8.80E-04
Pu-239	-1.62E-01		1.91E-14
Pu-240	-4.87E-04		-7.51E-04
Pu-241	-1.63E-03	0.00E+00	-2.02E-03
Pu-242	-4.33E-04		-6.89E-04
Pu-244	-1.81E-14	1.49E-14	0.00E+00
Am-241	-1.50E-02	0.00E+00	-2.13E-05
Am-242m	-3.12E-04		-5.95E-04
Am-243	-1.68E-14	1.29E-14	1.24E-14
Cm-242	2.81E-14		3.34E-14
Cm-243	1.54E-14	-1.77E-14	0.00E+00
Cm-244	-4.87E-04		-7.52E-04
Cm-245	-1.21E-03	0.00E+00	-6.10E-04
Cm-246	-6.39E-02		-5.89E-04
Cm-247	3.37E-14	-3.13E-02	0.00E+00
Cm-248	1.34E-02	**-8.26E+00**	1.19E-04
Bk-249	-1.13E-14	2.15E-14	3.17E-14
Cf-249	-2.45E-05	4.05E+02	-1.44E-05
Cf-250	-7.70E-02		-7.69E-02
Cf-251	0.00E+00		1.63E-14
Cf-252	**-3.09E+00**		**-3.09E+00**

Overall, the results of the Intruder Application run are in excellent agreement with the CIG results. The comparison shows large errors for Cm-248 (8.26% for the resident scenario) and Cf-252 (3.09%). These errors were addressed under Section 3.1 of the report.

2. Check of decay chain calculation

a. The CHAINS program was executed for Am-243 as instructed to obtain the *CHAINS.LOG* file that includes a listing of decay chain, half-lives and branching fractions. Activities and cumulative energies at 100 years and 1000 years are also listed.

b. Half-lives and branching fractions in the *CHAINS.LOG* file were checked against the corresponding values on the *Nuclide Decay* worksheet of IntruderInput_Chains.xls. Overall, values for half-lives are identical. The branching fractions are in good agreement within the range of round-off errors. For example, the *CHAINS.LOG* file shows that Ac-227 branches out to Th-227 and Fr-223 with branching fractions of 9.9E-1 and 1.4E-2, respectively. Note that these branching fractions do not add up to 1. On the *Nuclide Decay* worksheet of IntruderInput_Chains.xls, the chain for Ac-227 includes Fr-223 as branch 1 and Th-227 as branch 2 with branch fractions of 0.0138 and 0.9862, respectively. Although the branch order was different, that should not have any impact on the calculation. Similarly, in the *CHAINS.LOG* file, Bi-211 branches out to Tl-207 and Po-211 with branching fractions of 1 and 2.8E-3, respectively, compared to the corresponding branching fractions of 0.9972 and 0.0028 given in IntruderInput_Chains.xls

c. The Intruder program was run for the ILV disposal unit for 100 years as instructed.

d. The Intruder program was run for the ILV disposal unit for 1000 years as instructed. The results from c. and d. were compared to the results obtained from the CHAINS program. The comparison is shown in the following table which indicates that the values obtained from both programs are in excellent agreement.

Nuclide	100 years Error %	1000 years Error %
Am-243	-2.715E-05	4.604E-05
Np-239	-4.066E-05	2.362E-05
Pu-239	8.228E-05	-1.112E-04
U-235	-1.687E-04	1.846E-04
Th-231	-6.105E-05	9.536E-05
Pa-231	-5.951E-05	4.174E-05
Ac-227	-9.485E-05	-3.124E-05
Fr-223	3.887E-05	1.809E-04
Th-227	-3.194E-04	-3.189E-05
Ra-223	-2.897E-04	-1.352E-05
Rn-219	-3.076E-04	-1.358E-05
Po-215	-3.051E-04	-1.357E-05
Pb-211	-4.660E-04	-4.387E-05
Bi-211	-2.456E-04	-4.565E-05
Tl-207	-3.396E-04	-1.293E-05
Po-211	-2.320E-04	-1.430E-04

3. Check of transient layer thickness change with time

a. The Intruder program was run as instructed to generate the output file Transient_Dose_Case3.xls. The Res_Thickness column on the *Thickness* worksheet of this output file shows that the cover thickness approaches 3.1598m (i.e., the combining thickness of erosion barrier and soil backfill) at 760 years.

Res_Time (hr)	Res_Thickness (m)	Res_ShieldThickness (m)
100	4.07420E+00	1.07420E+00
110	4.06020E+00	1.06020E+00
120	4.04620E+00	1.04620E+00
130	4.03220E+00	1.03220E+00
140	4.01820E+00	1.01820E+00
150	4.00420E+00	1.00420E+00
.	.	.
.	.	.
.	.	.
700	3.23420E+00	2.34200E-01
710	3.22020E+00	2.20200E-01
720	3.20620E+00	2.06200E-01
730	3.19220E+00	1.92200E-01
740	3.17820E+00	1.78200E-01
750	3.16420E+00	1.64200E-01
760	3.15980E+00	1.59800E-01
770	3.15980E+00	1.59800E-01
780	3.15980E+00	1.59800E-01
790	3.15980E+00	1.59800E-01
800	3.15980E+00	1.59800E-01
.	.	.
.	.	.

b. From the Transient Layer Model on the *SlitTrenches* worksheet in the file DisposalUnitInput.xls, the erosion time of the soil cover layer is calculated as follows:

Erosion time = Thickness / Erosion rate
= (0.9144m)/(0.0014m/yr)
= 653.14 yr

Since soil erosion begins at 100 years, the cover thickness decreases to 3.1598m (erosion barrier + soil backfill) at 753.14 years. This confirms the Intruder result obtained under 3a.

c. The Intruder program was run as instructed to generate the output file Transient_Dose_Case3.xls. The Res_Thickness column on the *Thickness* worksheet of this output file shows that the cover thickness approaches 3.0582m (i.e., the combining thickness of erosion barrier, soil backfill, and vault roof + grout) at 760 years.

Res_Time (hr)	Res_Thickness (m)	Res_ShieldThickness (m)
100	3.97260E+00	1.11760E+00
110	3.95860E+00	1.11760E+00
120	3.94460E+00	1.11760E+00
130	3.93060E+00	1.11760E+00
140	3.91660E+00	1.11760E+00
150	3.90260E+00	1.11760E+00
.	.	.
.	.	.
.	.	.
720	3.10460E+00	1.11760E+00
730	3.09060E+00	1.11760E+00
740	3.07660E+00	1.11760E+00
750	3.06260E+00	1.11760E+00
760	3.05820E+00	1.11760E+00
770	3.05820E+00	1.11760E+00
780	3.05820E+00	1.11760E+00
790	3.05820E+00	1.11760E+00
800	3.05820E+00	1.11760E+00
.	.	.
.	.	.

From the Transient Layer Model on the *IL Vaults* worksheet in the file DisposalUnitInput.xls, the erosion time of the soil cover layer is calculated as follows:

Erosion time = Thickness / Erosion rate
= (0.9144m)/(0.0014m/yr)
= 653.14 yr

Since soil erosion begins at 100 years, the cover thickness decreases to 3.0582m (erosion barrier + soil backfill + vault roof + grout) at 753.14 years. This confirms the Intruder result.

4. Verify Case 3 by using Case 1 to check calculations at instants in time.

To verify Case 3, the result of the Intruder run for the slit trench disposal unit in 3a was selected at 500 years. The shielding thickness at this time is 51.42cm. The Intruder application was then run for slit trenches using Case 1 for all parents with resident and PD scenarios. The run time of 500 years and the 51.42cm shielding thickness were applied to this run. The dose result in *Results_Case1.xls* (Case 1) was compared to the dose result at 500 years in *Transient_Dose_Case3.xls* (Case 3). Five nuclides were spot checked for comparison. The calculated results are identical in both Cases. This verifies the transient calculation.

	Case 3		Case 1	
Nuclide	**Res**	**PD**	**Res**	**PD**
Al-26	1.90860E-03	6.40667E-05	1.90860E-03	6.40667E-05
K-40	9.83835E-05	2.00153E-04	9.83835E-05	2.00153E-04
Nb-94	3.21189E-04	3.69255E-05	3.21189E-04	3.69255E-05
Sn-126	2.77817E-04	4.92674E-05	2.77817E-04	4.92674E-05
Th-229	3.75791E-05	1.96871E-04	3.75791E-05	1.96871E-04

5. Check the results in Word output file

The results in Word output file *Results_Case3.doc* were spot checked against the results in the Excel output file *Results_Case3.xls* from the transient calculation in 3a for slit trenches. The comparison shows that the Excel results were correctly transcribed to the Word output file.

	Excel Output (Resident Scenario)			Word Output (Resident Scenario)		
	Max Time	Res Conc	Res Inv	Time of Limit	Concentration Limit	Inventory Limit
Nuclide	**(yr)**	**(uCi/m3)**	**(Ci/Volume)**	**(Year)**	**(uCi/m3)**	**(Ci/Volume)**
Na-22	100	9.90E+16	2.85E+15	100	9.90E+16	2.85E+15
Al-26	760	1.41E+02	4.06E+00	760	1.41E+02	4.06E+00
Co-60	100	7.29E+10	2.10E+09	100	7.29E+10	2.10E+09
Kr-85	100	3.46E+12	9.98E+10	100	3.46E+12	9.98E+10
Cf-249	760	1.32E+04	3.81E+02	760	1.32E+04	3.81E+02

	Excel Output (PD Scenario)			Word Output (PD Scenario)		
	Max Time	Res Conc	Res Inv	Time of Limit	Concentration Limit	Inventory Limit
Nuclide	**(yr)**	**(uCi/m3)**	**(Ci/Volume)**	**(Year)**	**(uCi/m3)**	**(Ci/Volume)**
C-14	100	6.72E+04	1.94E+03	100	6.72E+04	1.94E+03
Zr-93	250	3.22E+07	9.27E+05	250	3.22E+07	9.27E+05
Ra-226	130	2.42E+03	6.97E+01	130	2.42E+03	6.97E+01
Th-232	180	5.03E+03	1.45E+02	180	5.03E+03	1.45E+02
Cm-245	1000	2.60E+04	7.48E+02	1000	2.60E+04	7.48E+02