# Benchmark comparisons

# between the RESRAD and GENII dose assessment computer codes

by

Adriana Rindiani

A Thesis Submitted to the

Graduate Faculty in Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

Department: Mechanical Engineering
Major: Nuclear Engineering



Signatures have been redacted for privacy

Iowa State University
Ames, Iowa

1995

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## ACKNOWLEDGMENTS

Thanks to the good Lord that all my efforts in continuing my studies have come to fruition. I am really honored to have the opportunity to pursue my master's degree in the United States of America, especially at Iowa State University. I am so grateful that during my time in here, so many people came into my life and supported me in many different ways. Their efforts greatly reduce my homesick feelings for my family and my country.

I would like to express my thanks and deep appreciation to my Major Professor, Dr. Daniel B. Bullen, for sharing his knowledge in the radioactive waste field, for never giving up on me even when I was really stubborn, and for always supporting me in my studies.

I would also like to thank Dr. Eric B. Bartlett and Dr. Robert Horton, Jr. for their patience while serving on my Committee. I would also like to express my thanks to all of the people in the Nuclear Enginering Program for always offering help whenever needed.

Special thanks go to Iwan Santoso and Yudi U. Imarjoko for being so patient in teaching me to program using Turbo Pascal, and for helping me finish my research program. I would also like to thank John Hawkinson who always enlightened me in many ways and helped me out every time my computer crashed.

For my family, I am really thankful and appreciate all their support and prayers. Most of all, I thank Mr. P. Suratno and Mr. Mundi from the Indonesian Atomic Energy Control Bureau, and the STAID project in Indonesia for allowing me to complete my studies here.

# CHAPTER 1. INTRODUCTION

## Radioactive Waste

Nowadays, radioactive material is more widely used than ever. The demand for radioactive materials is continuing to increase. This demand requires that radioactive materials be processed from natural sources or reprocessed from irradiated materials. All of these processing steps result in the production of various forms of radioactive wastes. These radioactive wastes have different characteristics according to their chemical, physical, or radiologic properties.

Radioactive wastes are usually classified based on [9,11]:

1. The half life of the isotope, which classifies the radionuclide as short or long-lived;
2. The concentration of the radionuclides, which determines the classification level of the waste as low, medium, or high; and
3. The ability of the radioactive waste to generate heat, which is also dependent upon the concentration of the radionuclide.

Unlike any other waste, the handling of the radioactive waste posses unique challenges. To better control the handling of radioactive materials, the federal government has classified radioactive waste into several types, such as [11]:

1. High-level radioactive waste (HLRW) which includes spent nuclear fuel and the wastes produced in spent fuel reprocessing. This radioactive waste contains fission products and plutonium (Pu) isotopes. Because this waste is highly

radioactivity, it can generate significant quantities of heat. Since this class of waste requires massive shielding, it must be handled remotely.

2. Transuranic (TRU) waste results from weapons fabrication and spent reactor fuel reprocessing, and contains isotopes above uranium (U) in the periodic table. Compared to the HLRW, the TRU waste has less radioactivity and generates less heat. This waste still takes a long time to decay. The handling of this radioactive waste is similar to HLRW, but generally little or no shielding is required.

3. Low-level radioactive waste (LLRW) is all radioactive wastes other than those described in the previous two classifications. Almost all of the LLRW has low radioactivity and relatively short-lived radionuclides. This radioactive waste is usually produced from nuclear power production, industrial, institutional and government sources. Since these wastes generate little heat and have relatively low levels of radioactivity, little or no shielding is required.

The radioactive wastes, based on the above classifications, have to be handled very carefully due to their radiologic characteristics. The handling procedures are very different for every type of radioactive waste. For example, LLRW is buried in a shallow land burial site while HLRW is disposed in a deep geologic repository. When radioactive waste is stored, care must be taken to make sure that the container and the storage facility are properly designed for the class of radioactive waste to be disposed. During the storage of radioactive wastes, care must also be taken to monitor the potential release of radionuclides to the environment.

To predict the effects of such releases, special computer codes have been developed based on regulations from the federal government. These computer codes are used to calculate the release dose to the environment after a certain time and to evaluate the radiation dose to individual organs or the whole body for an individual or population exposed by a release from the disposal site.

## Role of Computer Codes in Radioactive Waste Management

Computer codes are very important in the management of radioactive wastes since they can be employed to calculate a number of important parameters. These parameters include the release dose to the environment and the effective dose to the human body. A number of pathways must be considered in the development of a dose assessment computer code, such as [3,13]:

1. Direct or external exposure;
2. Inhalation pathway; and
3. Ingestion pathway.

In addition, there are also some transport mechanisms which have to be considered in order to calculate the committed dose to the human body. These transport mechanisms include radionuclide transport through the air, surface water, ground water, and biotic transport.

Two computer codes that have been developed to calculate the release dose on the environment near a LLRW disposal site are the GENII (GENeration II) and the RESRAD (RESidual RADionuclides) programs. The GENII program is used to calculate potential radiation doses to human from radionuclides in the environment. The RESRAD program is used to calculate radiation dose to an on-site resident using site-specific residual radioactivity guidelines.

By using these two computer codes, people can calculate the release dose from the same LLRW storage facility. However, the results will be different for each calculation since each computer code employs a somewhat different approach. To permit a comparison between the RESRAD and GENII codes, the output of the RESRAD code must be modified using some of the formulas employed by the GENII program. This modification yields a release dose to specific organs of the human body, similar to the output of the GENII program.

## Objective

The primary objective of this research is to the development of an additional transport program module for the RESRAD code. This module will be derived from formulas employed in the GENII code to permit benchmark comparisons between these two codes. The results of this work may permit an evaluation of the conservatism of each code.

## Outline of Thesis

The first chapter of this thesis is the introduction, which includes a brief definition of radioactive waste and a description of the computer codes used in this research. This chapter also outlines the objective of the research. The second chapter is a literature review, which provides an overview of radiation and it's biological effects, LLRW, performance assessment (PA), regulations, and waste sites (WS). The third chapter discusses materials and methods. In the materials section, the GENII, RESRAD, and the transport program, and the scenario to be evaluated are discussed. In the methods section, the software employed is discussed, i.e., turbo PASCAL. In addition, the limitation in developing the transport program are discussed. The limitations include the dimensions, the pathway, and the food transfer factors for each isotope. The fourth chapter will present the results of the transport program developed for this research effort and the comparison with the GENII program. The last chapter presents the conclusions. This chapter will summarize the results of this research, and make suggestions for future work. A program listing and sample results for each computation are presented in the appendices.

# CHAPTER 2. LITERATURE REVIEW

## Radiation and Its Biological Effects

Radioactivity is defined as spontaneous nuclear transformation that results in the formation of a new element [6]. The nuclear transformation can occur by alpha emission, beta emission, positron emission, gamma emission, or electron capture.

The activity of every radioactive material is unique. It depends on the instability of the nucleus, which results from either high or low neutron to proton ratio in accordance with the mass-energy relationship. Radioactivity does not depend on the chemical and physical properties of a material.

### Radiation processes

**Alpha emission ($\alpha$)** An alpha particle, also known as helium ($_2He^4$), is produced from a heavy nucleus with a low neutron to proton ratio. The alpha particle consists of two neutrons and two protons. When a radionuclide emits an alpha particle, it will reduce the atomic number by two and the atomic mass number by four. For example in $_{92}U^{238}$, the radioactive decay reaction is

$$_{92}U^{238} \text{ ----->} \ _{90}Th^{234} + {_2He^4}$$

The energy of this alpha particle is monoenergetic. The neutron to proton ratio of the parent is 1.58 to 1, while that for the daughter is 1.6 to 1. Alpha emission will occur several times until the nucleus reaches stability. The summation of all of these radioactive emissions is called a radioactive decay chain.

Since the linear energy transfer from an alpha particle to tissues is very large, the dead outer layer of skin is thick enough to prevent an alpha particle from penetrating the skin. Alpha decay does not result in any harm if the radiation source is external. If the radiation source is inside the body, the alpha particle will penetrate living tissue and can cause significant damage to an organ or to the entire organism.

**Beta emission ($\beta^-$)** A beta particle is a single negative electrical charge ejected from the nucleus of a beta-unstable radionuclide. This particle, which has characteristics identical to those of an electron, has a very small mass (0.00055 atomic mass units). Beta decay occurs over a continuous energy distribution.

A beta particle has the ability to penetrate into living tissue to varying depths depending upon the energy of the particle. Because of this ability, the beta particle can cause significant radiologic effects. To protect the body from this hazard, protective clothing designed to provide shielding should be worn when working with beta emitting materials.

**Positron emission ($\beta^+$)** A positron is a beta particle with positive charge. This particle has the same characteristics as beta particle. Therefore, the handling of positron emitting materials is the same as for the beta particle.

**Gamma emission ($\gamma$)** Gamma photons are electrically neutral and are emitted from nuclei of excited atoms. Some gamma emissions occur in conjunction with other radioactive decay processes. Gamma photons are also produced from annihilation of electron-positron pairs. The annihilation process usually occurs near an isotope that emits positrons. Gamma radiation usually requires significant shielding for radiation protection.

**Electron capture ($e^-$)** When a radioisotope cannot attain stability by positron emission, it can capture an orbital electron and convert a proton to a neutron. The process is known as K-shell capture since electrons in the K shell are much closer to the nucleus. The formation of a neutron by capturing an orbital electron can be described as follows:

$${}_{-1}e^0 + {}_1H^1 \text{ -----> } {}_0n^1 + \nu$$

A neutrino ($\nu$) is always formed during electron capture. For energy to be conversed, this neutrino has an energy which is the difference between the actual kinetic energy and the observed kinetic energy of the system. Following the electron capture, low energy X-rays can also be produced. Therefore, shielding is also required for isotopes undergoing electron capture.

**Biological effects**

Particles and photons resulting from radioactive decay can penetrate into a material and result in two different reactions: non-ionizing and ionizing reactions. Non-ionizing radiation includes photons originating from lasers, micro-waves, radio-waves, and light sources. This radiation does not cause any changes in atomic structure, but it can cause some superficial damage to living tissues, such as sunburn. Ionizing radiation, in the form of photons, such as gamma rays and X-rays, or particles, such as alpha, beta, and positron, can cause direct damage to living tissue. This ionizing radiation causes an electron to be ejected from the atom and leaves the atom with an electrical charge. This charged atom is called an ion.

Ionizing radiation can cause some biological effects. These effects are classified into three categories:

1. Somatic effects: These effects will affect the entire body. These are further classified into two effects: prompt somatic effects which can be observed as soon as the body receives a large or acute dose, and delayed somatic effects which occur years after receiving radiation exposure;

2. Genetic effects: These effects may occur in the offspring of exposed individuals; and

3. Teratogenic effects: These effects occur due to exposure to the unborn child during the fetal or embryonic stages of development.

**Radiation effects** Radiation effects can be classified into stochastic and non-stochastic effects (Figure 2.1). A stochastic effect occurs with the same probability for a control population, as well as to those exposed to radiation. Stochastic effects do not depend on the radiation exposure. In health physics, stochastic effects are divided into two classes: cancer and genetic effects. The probability of these effects occurring is independent of the magnitude of the dose.

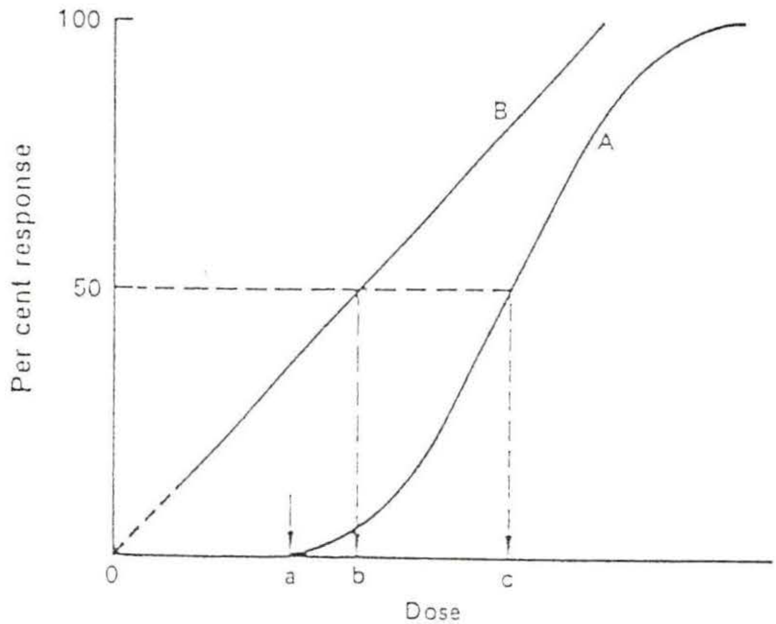


Figure 2.1 Non-stochastic (A) and stochastic (B) curves [6]

Non-stochastic effects are defined based on [2,11]:

a. A certain minimum dose must be exceeded before the particular effect is observed;

b. The magnitude of the effect increases with the size of the dose; and

c. There is a clear causal relationship between exposure to the noxious agent and the observed effect.

**Direct action** A direct action includes radiation effects that can be seen when the tissue is irradiated. Genetic mutation is included in this category. An atom in the DNA molecule is changed by dissociating due to the ionization or excitation caused by the radiation. This change prevents the DNA from correctly conveying genetic information to the next generation. This action occurs in the somatic cells, which reproduce at relatively high rates.

**Indirect action** A body consists primarily of water ($H_2O$). Under irradiation conditions, the water in the body will be ionized as

$$H_2O \text{ -----> } H_2O^+ + e^-$$

The positive ion will dissociate into

$$H_2O^+ \text{ -----> } H^+ + OH$$

and the electron will react with the water and produce

$$H_2O + e^- \text{ -----> } H_2O^-$$

The negatively charged water will dissociate directly into

$$H_2O^- \text{ -----> } OH^- + H$$

The free radicals, H, and OH in the body will react with a like radical or other molecules in solution. This reaction can create hydrogen peroxide ($H_2O_2$) or hydroperoxyl radicals ($HO_2$). Because of the toxicity of the molecules resulting from this reaction, and since the body contains a lot of water, excessive exposure to these conditions can be extremely detrimental to the health of the irradiated organism. All of these processes take a long time and the effect occurs not only in the portions of the body exposed to radiation, but throughout the entire body.

**Acute effects** Whole body radiation exposure will affect the individual organs and all of the systems of the body. Since not all organs are sensitive to radiation, the effects which occur depend on the magnitude of the dose. The effects are classified into three syndromes [2,6]: hemopoietic, gastrointestinal, and central nervous system. All of these syndromes can be seen in the exposed population through the following symptoms [6]:

1. nausea and vomiting;
2. malaise and fatigue;
3. increased body temperature; and
4. blood composition changes.

**Delayed effects** These effects occur when a person receives a single large exposure or continual low-level exposure of radiation. Due to either one of these exposure scenarios, tissues will change slowly. The result of this effect can be seen as genetic mutation, cancer, or cataracts.

# Low-level Radioactive Waste (LLRW)

## Classification of radioactive waste

Radioactive waste is classified into three types according to its physical properties:

1. Gaseous waste: This waste is produced at reprocessing plants and nuclear power plants. The most common radionuclides in this waste are $Kr^{85}$, $I^{131}$, $C^{14}$, and $H^{3}$. The gaseous waste is usually captured and contained to permit radioactive decay or released to the environment in very small quantities.

2. Liquid waste: This waste is produced at spent fuel reprocessing plants. It comes from the chemical extraction of uranium and plutonium from spent fuel. Besides the spent fuel reprocessing plant, hospitals also generate liquid waste. The liquid waste must be solidified before it is shipped to a disposal site.

3. Solid waste: This waste results from the mining and milling of U and Th ores, from spent fuel, and from contaminated equipment. The solid waste is usually compacted or incinerated and placed in containers before it is shipped to a disposal site.

LLRW is produced in solid and liquid forms. It is generated from commercial nuclear fuel cycle operations, institutions such as hospitals and universities, industrial users, decontamination and decommissioning of fuel cycle facilities, and defense-related activities (Table 2.1).

Table 2.1 Nuclear waste types and sources [14]

| Source | Nuclear waste types: Spent nuclear fuel (SNF) | High-level waste (HLW) | Transuranic waste (TRU) | Low-level waste (LLW) |
|---|---|---|---|---|
| Commercial nuclear fuel cycle operations | X | X | | X |
| Institutions (hospitals, universities, etc.) | X | | X | X |
| Industrial users | X | | X | X |
| Decontamination and decommissioning of fuel cycle | | | X | X |
| Defense-related activities | X | X | X | X |

**Classification of low-level radioactive waste**

LLRW is classified into 3 classes due to its radionuclide concentration as shown in Table 2.2 and 2.3 [9,14]:

1. Class A wastes: Defined as having concentrations of specific radionuclide less than the value listed in Tables 1 and 2 of 10 CFR 61;

2. Class B wastes: Contain radionuclide concentrations greater than Class A but less than Class C, as defined in Table 2 of 10 CFR 61; and

3. Class C wastes: Contain radionuclide concentrations greater than Class B but less than column 3 of Table 2 of 10 CFR 61.

Table 2.2 Table 1 of 10 CFR 61 [14]

| Radionuclide | Concentration (Ci/m$^3$) |
|---|---|
| $^{14}C$ | 8 |
| $^{14}C$ in activated metal | 80 |
| $^{59}Ni$ in activated metal | 220 |
| $^{94}Nb$ in activated metal | 0.2 |
| $^{99}Tc$ | 3 |
| $^{129}I$ | 0.08 |
| Alpha-emitting transuranic nuclides with half-life greater than 5 years | 100[a] |
| $^{241}Pu$ | 3,500[a] |
| $^{242}Cm$ | 20,000[a] |

[a]Units are nanocuries per gram.

Table 2.3 Table 2 of 10 CFR 61 [14]

| | Concentration (Ci/m$^3$) | | |
|---|---|---|---|
| Radionuclide | Col. 1 | Col. 2 | Col. 3 |
| All nuclides with less than 5-year half-life | 700 | [b] | [b] |
| $^{3}H$ | 40 | [b] | [b] |
| $^{60}Co$ | 700 | [b] | [b] |
| $^{63}Ni$ | 3.5 | 70 | 700 |
| $^{63}Ni$ in activated metal | 3.5 | 700 | 7000 |
| $^{90}Sr$ | 0.04 | 150 | 7000 |
| $^{137}Cs$ | 1 | 44 | 4600 |

[b]No estimated limits.

## Sources of the LLRW

**LLRW from nuclear power reactors** LLRW is generated from all processes in the nuclear power plant that relate to the radioactive contamination of equipment, cooling water, clothing, plastics, construction material, ion exchange resins and filters, and sludge from water purification evaporators. Typical radionuclides produced in these processes are $C^{14}$, $Co^{60}$, $Te^{99}$, $Ni^{59}$, etc.

**LLRW from industries** Typical radionuclides produced in industrial applications are $Co^{60}$, $C^{14}$, $P^{32}$, and $I^{125}$. One significant source of these isotopes is radio-pharmaceutical development.

**LLRW from institutions** LLRW can be produced from the research conducted in hospitals or universities. In medical research, the most common radionuclides used are $H^{3}$, $C^{14}$, $P^{32}$, and $S^{35}$. Many of these radionuclides are usually used in developing or testing new prescription drugs. In other research (academic), these radionuclides can be used in soil analysis, reactor experiments, and materials testing.

## Regulations Governing the Handling and Disposal of LLRW

In 1980, the US Congress enacted the LLW Policy Act that urged all states to form compacts to handle the LLRW generated in their region [14]. This act also required that LLRW disposal became the responsibility of each state. The progress of forming the state compacts was so slow that in 1985, the Congress enacted the Low-Level Waste Policy Amendments Act (LLWPAA) which delayed the requirement for compact formation and new disposal site operation until 1993 (Table 2.4 and Figure 2.2).

In addition to these Acts, there are other federal regulations addressing the processing, storing, and shipping of LLRW. These regulations have been promulgated by the US Department of Transportation (DOT), the Environmental Protection Agency (EPA), and the Nuclear Regulatory Commission (NRC). These regulations are part of the Code of Federal Regulations (CFR) under Title 49 for the DOT, Title 40 for the EPA, and Title 10 for the NRC.

**DOT regulations**

The DOT regulations were written as Title 49 of the CFR. These regulations include general regulation for hazardous and radioactive materials and their transport (Table 2.5).

**EPA regulation**

The EPA regulation relevant to LLRW handling is 40 CFR 190. This regulation addresses issues related to Nuclear Power Operation. This regulation also defines the classification of LLRW based on the activity of the radionuclides contained in the waste. An additional EPA regulation relevant to LLRW is 40 CFR 140, which sets the standards for clean drinking water. The maximum allowable radiation dose for drinking water is 4 mrem for the whole body.

Table 2.4 Interstate compacts based on the LLWPAA [14]

| Southeast | Northwest | Midwest | Central | Rocky Mountain | Northeast | Central Midwest |
|---|---|---|---|---|---|---|
| Alabama | Alaska | Indiana | Arkansas | Colorado | Connecticut | Illinois |
| Florida | Hawaii | Iowa | Kansas | Nevada | New Jersey | Kentucky |
| Georgia | Idaho | Michigan | Louisiana | New Mexico | | |
| Mississippi | Montana | Minnesota | Nebraska | Wyoming | | |
| N. Carolina | Oregon | Missouri | Oklahoma | | | |
| S. Carolina | Utah | Ohio | | | | |
| Tennessee | Washington | Wisconsin | | | | |
| Virginia | | | | | | |

Table 2.5 Title 49, Transportation Subchapter C-Hazardous materials regulations [14]

| | |
|---|---|
| 49 CFR 171 | General information, regulations, and definitions |
| 49 CFR 172 | Hazardous materials tables and hazardous materials communications regulations |
| 49 CFR 173 | Shippers—general requirements for shipments and packagings |
| 49 CFR 174 | Carriage by rail |
| 49 CFR 175 | Carriage by aircraft |
| 49 CFR 176 | Carriage by vessel |
| 49 CFR 177 | Carriage by public highway |
| 49 CFR 178 | Shipping container specifications |
| 49 CFR 179 | Specifications for tank cars |

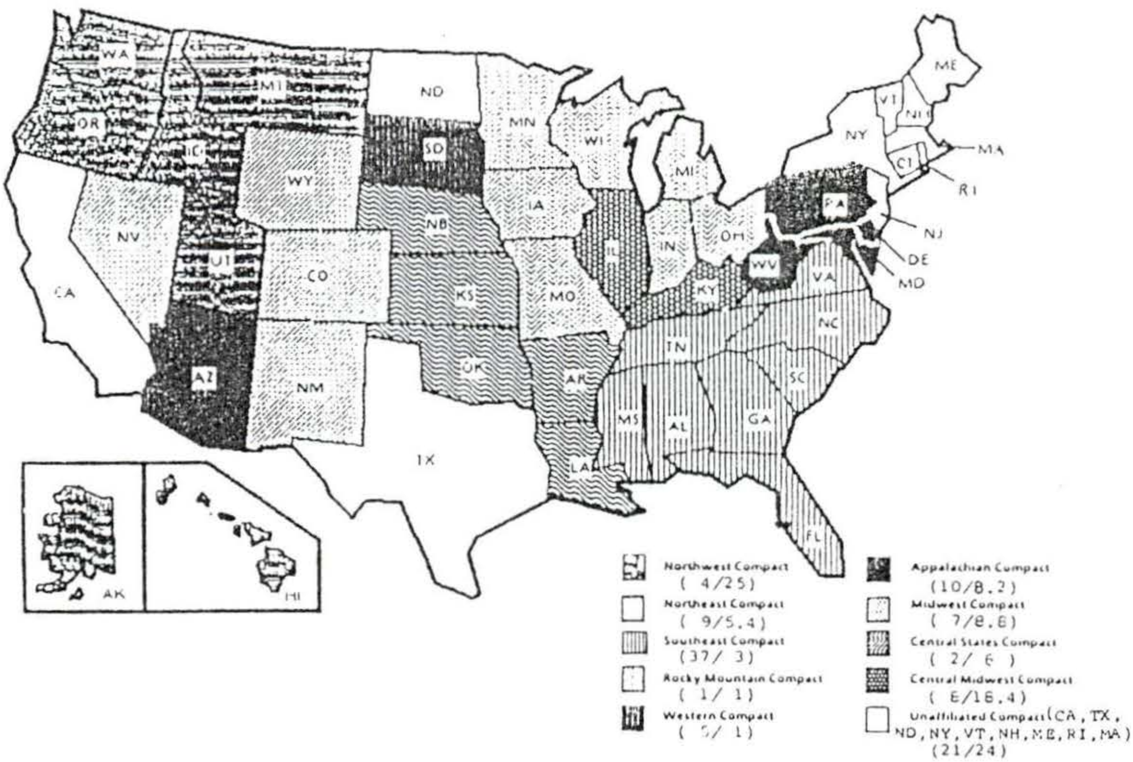


Figure 2.2 LLRW compacts as proposed on April 1987 [14]

**NRC regulations**

The NRC regulations addressing LLRW include [14]:

1. 10 CFR 20 This regulation defines concentration limits on effluents. Appendix B of this regulation limits the concentration of specific radionuclides in air and water;

2. 10 CFR 50 This regulation is used to set forth design objectives for equipment to control radioactivity in effluents;

3. 10 CFR 61 This regulation covers the licensing requirements for land disposal of low-level radioactive waste. Subpart C, Sections 61.41 and 61.42 regulates the requirements for LLRW disposal site performance as:

a. Radioactivity released to the general environment in ground water, air, soil, plants and animals must not result in an annual dose exceeding an equivalent of 25 mrem for the whole body, 75 mrem in the thyroid, and 25 mrem for any other organ;

b. Compliance with this regulation will be demonstrated with performance assessment calculations, including dose assessment;

4. 10 CFR 71 This regulation addresses all packaging, preparation for shipment, and transportation of radioactive materials, and provides the procedures and standards for NRC approval of packaging and shipping of radioactive materials.

**Performance Assessment Modeling**

Performance assessment (PA) modeling is widely used in the evaluation of radioactive waste disposal sites. PA is used to calculate the long term behavior of the disposal facility based on certain pathways and transport mechanisms as a function of time (Figure 2.3 and 2.4). The PA methodology developed for each LLRW facility is employed to evaluate the potential impacts to the general public from the operation and post-closure performance of the LLRW disposal facility.

The PA analysis completed in this study is based on the disturbed or inadvertent intruder scenario, as described in 10 CFR 61. For this analysis, radionuclides are assumed to be released to the environment and the resulting doses are determined. This methodology can also be used to determine the dose to the maximally exposed individual from the most significant pathway.

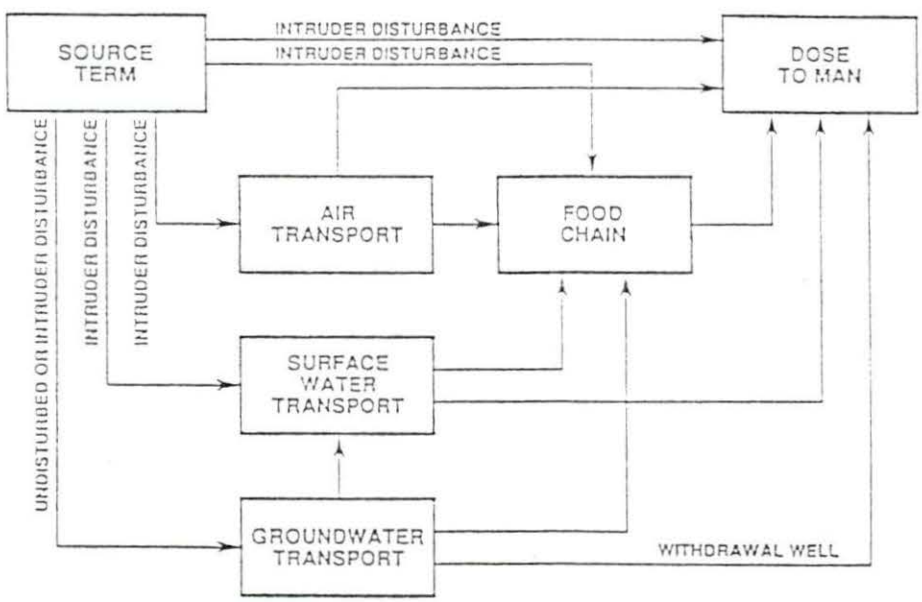


Figure 2.3 Pathways for undisturbed site [3,8]

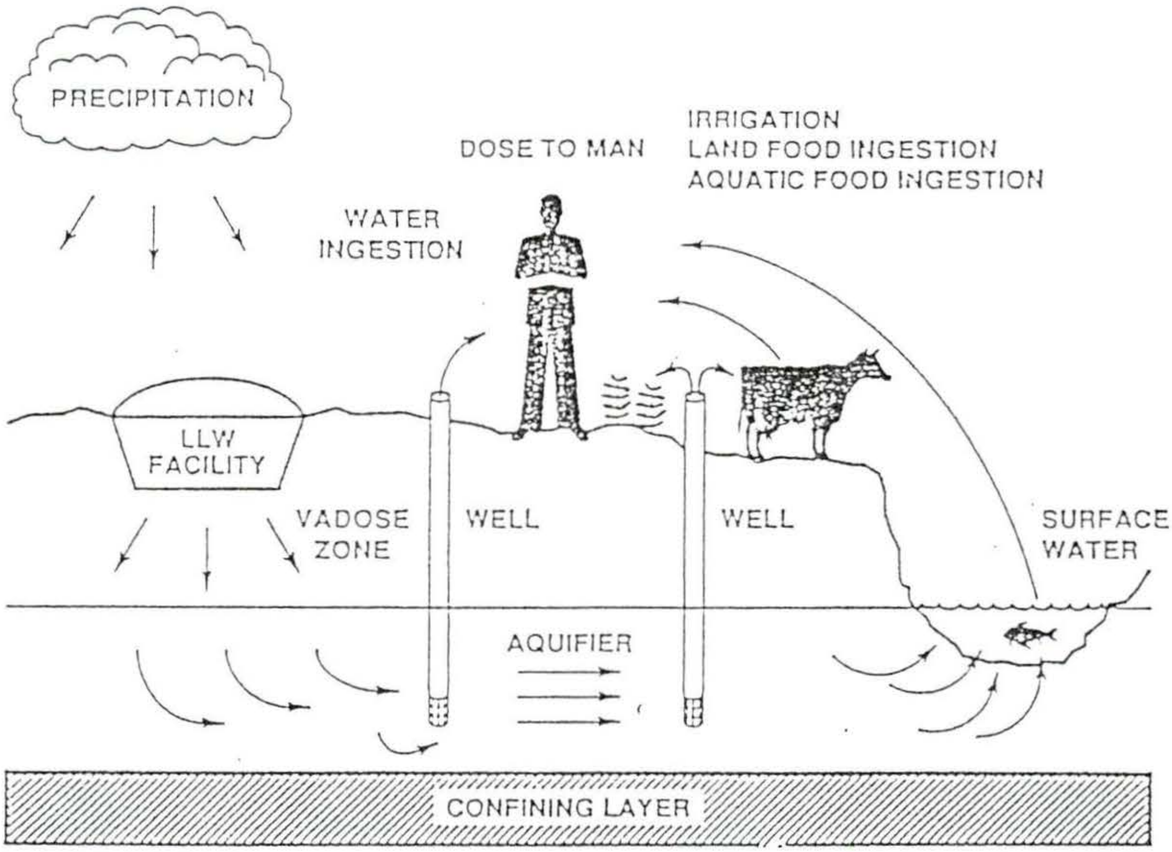


Figure 2.4 Transport pathways [3,8]

The pathways usually used in PA analysis are:

1. External exposure;
2. Inhalation; and
3. Ingestion that comes from drinking water and the food chain.

In using or developing a PA analysis model, the user must describe a scenario that will be modeled to determine the radionuclide release and the resulting dose to an exposed individual or population. This scenario development must address many issues, such as [12] identifying the source term for the radionuclide inventory, calculating the release rate of each radionuclide, calculating the transport of each radionuclide to the accessible environment, and determining the dose to the general public.

## Waste Sites

As a result of the LLWPAA, the US is divided into 9 compacts: Southeast, Northwest, Midwest, Central, Rocky Mountain, Northeast, Central Midwest, Appalachian, and Western. These compacts have the responsibility to dispose of radioactive waste generated by the member states in a disposal site located in a designated host state. 10 CFR 61 provides some requirements to be met during construction and operation of a near-surface disposal facility.

The near surface disposal facility is defined as the terminal emplacement site for radioactive wastes. These facilities are constructed on or near the earth's surface [10]. Because the position of the waste is on or near to the earth's surface (maximum depth is 30 meters), this waste site will be subjected to natural process such as erosion, flooding, plant and animal intrusion, etc. LLRW sites are built to contain only radioactive waste with relatively low concentration of radionuclides a majority of which usually exhibit short half-lives.

Near-surface disposal facilities can be classified into several types [10]. The first technology employed for LLRW disposal was shallow land burial. In these sites, the radioactive waste is placed in metal drums and concrete containers and is covered with one to three meters of soil or clay. Existing shallow land burial sites release relatively low radiation doses to the environment. Although this method is the least expensive among all methods for LLRW disposal, it has been outlawed in a majority of the new Compact host states.

The second method employs engineered structures in the form of vaults, which are placed above-ground or below-ground. The third method utilizes rock cavities or dry abandoned mines. The radioactive waste is emplaced in the bedrock, which is usually about 100 meters from the earth's surface. The final LLRW disposal method, which was initially employed to dispose liquid wastes, employed excavated basins and rock-filled trenches to serve as seepage basins. These basins were supposedly designed to limit the migration of liquid wastes until such time that a majority of the radionuclides had decayed. This technology, which was employed at a number of U. S. nuclear weapons fabrication facilities, is no longer utilized since it was rarely successful in adequately containing the liquid wastes.

# CHAPTER 3. MATERIALS AND METHODS

## Materials

### The GENII code

The GENII code was first developed by B. Napier at the Pacific Northwest Laboratory (PNL) in 1988. This code is currently used to calculate radiation doses from radionuclides released to the environment. The code was designed to complete the following tasks [13]:

1. To calculate radiation doses for acute releases, with options for annual dose, committed dose, and accumulated dose;

2. To calculate radiation doses for chronic releases, with the same options as above; and

3. To evaluate exposure pathways including direct exposure via water, soil, air, inhalation pathways, and ingestion pathways.

The GENII code was developed based on the methods recommended in the International Commission of Radiation Protection (ICRP) Publications No. 26 (1977) and No. 30 and their supplements (1979-1982). The code was then further adapted by Sandia National Laboratory (SNL) by incorporating the SUNS software shell to provide a workable personal computer interface and to permit stochastic evaluations. This new version of the code is known as GENII-S.

The GENII/GENII-S code is employed to evaluate various scenarios relevant to LLRW disposal including site-specific environmental conditions. The scenarios used are [12]:

1. Acute releases to air or water from ground level or elevated sources;
2. Chronic release to air or water from ground level or elevated sources; and
3. Initial contamination of soil or surfaces.

The evaluation of these scenarios with the GENII/GENII-S code permits the estimation of radiation doses to individuals or populations. The calculations can include the annual dose, dose commitments, or accumulated doses to the whole body or individual organs due to acute or chronic releases of radioactive materials.

The GENII/GENII-S code consists of seven linked computer codes and their associated data libraries (Figure 3.1). The first linked computer code is APPRENTICE which is used as a user interface to construct the input files for the GENII. The second code is ENVIN, which is used to setup the input. The third is ENV, which is used to calculate the environmental dose. EXTDF is then used to calculate the external dose factors. The DOSE program is used in dosimetry calculations yielding the total dose. The INTDF routine is used to calculate the

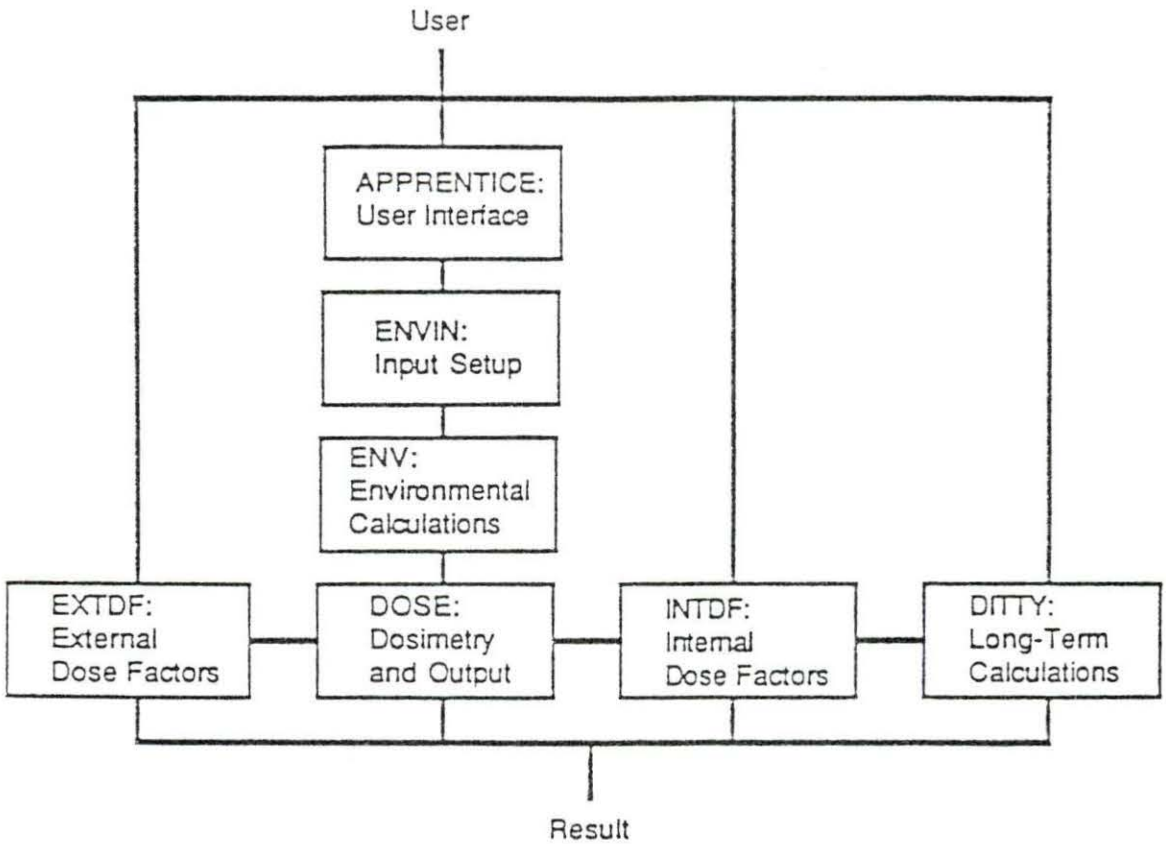


Figure 3.1 Current user/computer program interaction in the GENII Software Package [13]

internal dose factors. The final code is DITTY, which is used for long-term calculations. These seven computer codes are linked to provide dose calculation capabilities for a variety of exposure pathways and dose commitment scenarios.

The GENII/GENII-S code has a pull-down menu input format for construction of the input files. In order to operate this code, the user must understand the basic concepts associated with each scenario under consideration to permit identification of relevant input parameters. The input parameters employed are based on the scenario. These parameters are selected to model a pattern of human activity corresponding to actions, events, and processes that result in radiation exposure to individuals or groups [12]. A scenario can be either a far-field or a near-field scenario. A far-field scenario is used to determine the effect of the potential radionuclide release to a wide environment, i.e., to individuals or populations. A near-field scenario is employed to determine the effect of the potential radionuclide release to an individual as a result of initial contamination. These two scenarios will include a number of parameters, such as chronic or acute atmospheric releases and chronic or acute surface water releases for a far-field scenario, and initial surface or subsurface soil contamination, groundwater contamination and cumulative effects for a near-field scenario.

Besides these scenarios, the user must also select the relevant transport mechanisms and exposure pathways employed. Transport mechanisms are defined as the way the radionuclide is released into the environment and travels to the exposed population. These mechanisms can occur through air, surface water, ground water and biotic transport. Exposure pathways are the potential routes through which the radionuclide comes in contact with an individual or population group, such as external exposure, ingestion, and inhalation.

The output of the GENII/GENII-S code is a series of dose calculations that estimate the internal effective dose equivalents (IEDEs), external doses, and total effective dose equivalents (TEDEs). The IEDEs can be either committed effective dose equivalents or cumulative effective dose equivalents. The committed effective dose equivalent represents the doses from individual radionuclides to an individual or population in a one-year period after an intake (ingestion and inhalation). A cumulative effective dose equivalent is a dose expected for an individual or population after more than a one-year period of intake.

**The RESRAD code**

The RESRAD code was developed by the Argonne National Laboratory (ANL) in 1980s. This code has been adapted to operate on IBM Compatible personal computers. The code is used to determine the potential radiation dose to an on-site resident using site-specific residual radioactive guidelines. A guideline is defined as a radionuclide concentration or a level of radiation or radioactivity that, given appropriate use scenarios and site parameters, will reasonably ensure that individual dose limits and/or constraints will be achieved [8]. The guidelines include concentrations of residual radionuclides in soil, concentration of airborne radon decay products, concentrations of residual radionuclides in air and water, levels of external gamma radiation, and levels of radioactivity from surface contamination [8]. According to the soil guidelines, concentration of Ra-226, Ra-228, Th-230, and Th-232 must be less than 5 pCi/g for the first 15 cm below the soil surface, and less than 15 pCi/g for each additional 15 cm for a specific site to meet the RESRAD dose limits. The concentration of other radionuclides can then be derived using the RESRAD code.

This code can also be employed on the shallow land burial sites. The exposure pathways used in the RESRAD code usually include [8]:

1. Direct exposure to external radiation from the contaminated soil materials;

2. Internal dose from inhalation of airborne radionuclides, including radon progeny; and

3. Internal dose from ingestion of plant foods grown in the contaminated soil and irrigated with contaminated water, meat and milk from livestock fed with contaminated fodder and water, drinking water from a contaminated well or pond, fish from a contaminated pond, and contaminated soil ingestion.

These pathways are evaluated in a manner similar to pathways used in the GENII/GENII-S code. One limitation of the RESRAD code when compared to the GENII/GENII-S code, is that the RESRAD code does not employ any transport mechanism. This limitation makes the evaluation of radiation doses to specific organs impossible. Hence, it was necessary to develop a transport program for RESRAD.

**The transport program for the RESRAD code**

Since the GENII/GENII-S and the RESRAD codes are basically operated in a similar manner, it was determined that the RESRAD code could be modified to calculate the radiation dose to specific organs. In order to provide results which are compatible to the GENII/GENII-S results, a transport program for the RESRAD code was developed. This program employs transport formulas similar to those used in the GENII/GENII-S program. This new program permits a direct comparison between the results from the RESRAD and GENII/GENII-S codes.

The formulas used in this study are based on the ingestion pathway. The results yield the committed dose equivalent on bone surfaces and in the kidneys. Based on GENII/GENII-S, the transport formulas for this pathway are [13]:

$$I = U * C_p(t=T_h) * \{1 - \exp(-\lambda_r * T_f)\} / \lambda_r$$

where,

I : the total activity of a radionuclide ingested over a consumption period, $T_f$ (pCi)

U : the average ingestion rate of the crop over the ingestion period (kg/year)

$\lambda_r$ : the radiological decay constant ($year^{-1}$)

$= 0.693 / T_r$

$T_r$ : the biologic half-life of the radionuclide in the target organ (year), which is 300 days for the bone surface and 15 days in the kidneys for $U^{235}$ and $U^{238}$

$T_f$ : the duration of the uptake period (year)

$C_p(t=T_h)$ : the radionuclide concentration in the plant at harvest time (pCi/kg)

and $C_p(t=T_h)$ is calculated from :

$$C_p(t=T_h) = C_p(t=0) * \exp(-\lambda_e * T_h)$$

where,

$C_p(t{=}0)$ : the initial concentration of the radionuclide in the plant (pCi/kg)

$= r * C_s(t{=}0) * Tv_p / Y_p$

$C_s(t{=}0)$ : the initial soil surface concentration (i.e., at time t=0) (pCi/m$^3$)

r : fraction of initial deposition retained on the plant (dimensionless)

$Tv_p$ : translocation factor from plant surfaces to edible parts of the plant (dimensionless), currently assumed at 1.0 for leafy vegetables and forage crops, and 0.1 for all other vegetation

$Y_p$ : yield of crop type p (kg/m$^3$)

$\lambda_e$ : an effective removal constant (year$^{-1}$)

$= \lambda_r + \lambda_w$

$\lambda_w$ : the weathering removal rate, based on a half time of 14 days (year$^{-1}$)

$= 0.693 / (14 / 365) = 18.0675$ year$^{-1}$

$T_h$ : the harvest time (year)

Finally, the committed dose equivalent (CDE) is:

$$CDE = 3.7 * 10^3 * \text{CDE per unit activity} * I \text{ (mrem)}$$

where CDE per unit activity is a committed dose equivalent in target organs or tissues per intake of unit activity (Sv/Bq). Tabular data of CDE's for various radionuclides can be found in supplements of ICRP Publication No. 30 (1979-1982).

### Scenario

The scenario evaluated with the GENII/GENII-S code and the RESRAD code with the additional transport program is the same. This scenario represents a low-level radioactive waste disposal site of the shallow land burial type. This is a near-field scenario with chronic release of the radionuclides U-235 and U-238. The pathway used is ingestion of leafy vegetables, other vegetables, cereals/grains, and fruits. The dose calculated is a committed dose equivalent on the surface bone and in the kidneys for an individual.

## Methods

### The Turbo Pascal transport program

The Turbo Pascal computer language was used in the development of the transport program. This language contains a program heading which is used to name the program and the main program block which completes the calculation. The main program block is written between two keywords: begin and end.

The transport program was written using in Turbo Pascal and employed the results of the RESRAD program as input parameters. A calculation of the transport of each radionuclide to each target organ was the completed. The results of these calculations yielded the organ-specific dose for each isotope. These results can be directly compared to the GENII/GENII-S results.

**Limitations**

Calculations of this type can be extremely difficult when a number of radionuclides and pathways are considered. To simplify this task, the transport program was written to calculate only the committed dose equivalent for ${}_{92}U^{235}$ and ${}_{92}U^{238}$ on the bone surface and kidneys from the ingestion of leafy vegetables, all other vegetables, cereal/grains, and fruits. Having demonstrated the methodology, similar transport programs may be easily developed for other radionuclides and pathways.

The dimensions used as the input of the GENII and RESRAD codes are pCi/$m^3$ and pCi/g, respectively. For the transport program, the input parameter dimension is pCi/$m^3$. The dimensions of the output of the GENII code and the transport program are rem and mrem, respectively.

## CHAPTER 4. RESULTS

The committed effective dose equivalents (CEDE) for the bone surface and kidneys for a one year exposure and one year dose commitment of ${}_{92}U^{235}$ and ${}_{92}U^{238}$ are presented in Table 4.1 and 4.2 for the GENII code and the transport code developed in this research, respectively.

Table 4.1 The results from the GENII code

| Radionuclide | Bone Surface (mrem) | Kidneys (mrem) |
|---|---|---|
| U - 235 | $5.9 * 10^{-11}$ | $1.6 * 10^{-10}$ |
| U - 238 | $5.8 * 10^{-11}$ | $1.5 * 10^{-10}$ |

Table 4.2 The results from the transport program

| Radionuclide | Bone Surface (mrem) | Kidneys (mrem) |
|---|---|---|
| U - 235 | $9.19 * 10^{-5}$ | $6.68 * 10^{-8}$ |
| U - 238 | $9.19 * 10^{-5}$ | $6.37 * 10^{-8}$ |

The results presented in these tables suggest that there is limited agreement for the dose to the kidneys calculated by the GENII/GENII-S code and the transport code developed in this research effort. There is relatively poor agreement for the bone surface doses. These differences may be due to:

1. The initial concentration for the GENII code is in units of $pCi/m^3$. For the RESRAD code, the initial concentration is in units of pCi/g. The initial concentration for the RESRAD code was calculated by assuming that the concentration can be related by the density of the waste disposal material, i.e., assume that the contaminated materials and soils have the same bulk density ($2.4 * 10^6$ $g/m^3$). So, the calculation for the initial concentration for the RESRAD code becomes:

$$IC(RESRAD) = IC(GENII) / \rho_b$$

where,

IC(RESRAD) : the initial concentration for the RESRAD input (pCi/g)

IC(GENII) : the initial concentration for the GENII input ($pCi/m^3$)

$\rho_b$ : the bulk density ($g/m^3$)

2. For the transport program, again the initial soil concentration is required. The initial soil concentration is taken from an output file of RESRAD, named CONCENT.REP, for the time period desired. Here again, the units must be changed. For this parameter, the soil density ($1.6 * 10^6$ $g/m^3$) is used to convert from pCi/g to $pCi/m^3$. The equation for this concentration is

$$IC(ADD) = IC(OUTPUT) * \rho_s$$

where,

IC(ADD) : the initial soil surface concentration ($pCi/m^3$)

IC(OUTPUT) : the initial soil surface concentration from the RESRAD output (pCi/g)

$\rho_s$ : the soil surface density ($g/m^3$)

3. The formula used in the transport program is most likely too simplistic since it ignores several factors, such as food transfer factors (FTF), which are different for every radionuclide. In the GENII code, this factor is tabulated in FTRANS.DAT, which contains transfer factors relating concentrations of elements in soil to concentrations in farm products grown in that soil, and relating concentrations in animal feed to concentrations in animal products [12]. For all kinds of farm products, the FTFs vary from $10^1$ to $10^{-4}$. Proper incorporation of this parameter in the transport program should improve the results of these calculations. These improvements may yield results similar to those given by the GENII code.

# CHAPTER 5. CONCLUSIONS

A benchmark comparison of the outputs of the GENII code and the RESRAD code modified with a transport program has been completed. The results of these calculations suggest limited agreement for an exposure of ${}_{92}U^{235}$ and ${}_{92}U^{238}$ to the kidneys. Poor agreement was attained for similar calculations completed for exposure of the same uranium isotopes to the surface of bones. One significant factor that may explain the discrepancies between these calculations is the omission of relevant food transfer factors for these isotopes in the RESRAD code which was modified with the transport program developed in this research effort.

Future work in this area should address:

1. Additional radionuclides;
2. Additional exposure pathways;
3. Additional target organs; and
4. Incorporation of relevant food transfer factors.

## BIBLIOGRAPHY

[1] Bullen, Daniel B. Performance for a LLRW Disposal Facility in the Southeast Compact. Paper presented at a meeting of the Western New York Chapter, Health Physics Society, New York, NY, November, 1991.

[2] Bullen, Daniel B. Radiation Protection Engineering: Biological Effects of Radiation. Lecture notes for Nuc E 584, Iowa State University, 1993.

[3] Bullen, Daniel B. Radiation Protection Engineering: PA Methodologies for LLRW Disposal Sites. Lecture notes for Nuc E 584, Iowa State University, 1993.

[4] Bullen, Daniel B. Radiation Protection Engineering: Regulatory Requirements for Radioactive Waste. Lecture notes for Nuc E 584, Iowa State University, 1993.

[5] Bullen, Daniel B. Radioactive Waste Management: Regulatory Requirements for LLRW Disposal (10 CFR 61). Lecture notes for Nuc E 556X, Iowa State University, 1994.

[6] Cember, Herman. Introduction to Health Physics, 2nd ed.; McGraw-Hill: New York, 1983; pp 60-70, 177-194.

[7] Gershey, Edward L. In Low-level Radioactive Waste: From Cradle to Grave; Klein, Robert C.; Party, Esmeralda; Wilkerson, Amy; Van Nostrand Reinhold:

New York, 1990; pp 12-26, 35-46.

[8] Gilbert, T.L. In A Manual for Implementary Residual Radioactive Material Guidelines; Yu, C.; Yuan, Y. C.; Zielen, A. J., Ed.; Argonne National Laboratory: Argonne, 1989.

[9] An International Group of Experts The Management of Radioactive Waste; The Uranium Institute: London, 1991; pp 2-5.

[10] Kittel, J. Howard Radioactive Waste Management Handbook Vol. 1: Near-surface Land Disposal; Harwood Academic Publisher: New York, 1989; pp 1-23.

[11] The League of Women Voters The Nuclear Waste Primer: A Handbook for Citizens; Nick Lyons Books: New York, 1985; pp 8-9.

[12] Leigh, C. D. In User's Guide for GENII-S: A Code for Statistical and Deterministic Simulations of Radiation Doses to Humans from Radionuclides in the Environment; Thompson, B. M.; Campbell, J. E.; Longsine, D. E., Ed.; Sandia National Laboratory: Albuquerque, 1992.

[13] Napier, B. A. In GENII - The Hanford Environmental Radiation Dosimetry Software System Vo. I; Peloquin, R. A.; Strenge, D. L.; Ramsdell, J. V.; Pacific Northwest Laboratory: Richland, 1988.

[14] Tang, Y. S.; Saling, James H. Radioactive Waste Management; Hemisphere Publishing Corporation: New York, 1990; pp 1-18, 195-276.

[15] Yu, C. In Manual for Implementing Residual Radioactive Material Guidelines

Using RESRAD, Version 5.0; Argonne National Laboratory: Argonne, 1993.

[16] ICRP Publication 30: Limits for Intakes of Radionuclides by Workers; Pergamon Press: Oxford, 1978.

[17] Turbo Pascal Version 7.0: Language Guide; Borland International: Scotts Valley, 1983, pp 5-6.

# APPENDIX A

## THE TRANSPORT PROGRAM AND ITS OUTPUT

**Program List for the Transport Program**

```
Program Additional_Program_for_Resrad;

{N+}
uses crt;

Var
  Result,n,m                                  : integer;
  organ1,organ2                               : string[50];
  lambda_w,Th,Cst0,Tf                         : real;
  CDE_bone,CDE_kidney,CDE235_bone,CDE235_kidney,
  CDE238_bone,CDE238_kidney                   : array [1..2] of real;
  Tot_Upt,Cpt0                                : real;
  r,Y,Tvp,Uptake                              : array [1..4] of real;
  T_half_bone,T_half_kidney,lambda_bone,lambda_kidney,lambda_e_bone,
  lambda_e_kidney,CpTh_bone,CpTh_kidney,Intake_bone,Intake_kidney,
  organ                                       : array [1..2] of real;
  T,j,k                                       : integer;
  filevar                                     : text;

Procedure Initialization;

Begin
   for k := 1 to 4 do
     begin
        r[k]                  := 0;          (*dimensionless*)
        Y[k]                  := 0;          (*unit in kg/m3*)
        Tvp[k]                := 0;          (*dimensionless*)
        Uptake[k]             := 0;          (*unit in kg/yr*)
     end;
   for k := 1 to 2 do
     begin
        T_half_bone[k]        := 0;          (*unit in years*)
        T_half_kidney[k]      := 0;          (*unit in years*)
        lambda_bone[k]        := 0;          (*unit in year-1*)
        lambda_kidney[k]      := 0;          (*unit in year-1*)
        lambda_e_bone[k]      := 0;          (*unit in year-1*)
        lambda_e_kidney[k]    := 0;          (*unit in year-1*)
        Cpth_bone[k]          := 0;          (*unit in pCi/m3*)
        Cpth_kidney[k]        := 0;          (*unit in pCi/m3*)
```

```
            Intake_bone[k]           := 0;          (*unit in pCi*)
            Intake_kidney[k]         := 0;          (*unit in pCi*)
            organ[k]                 := 0;          (*target organ*)
      end;
End;

Procedure Dose_Calculation_on_Target_Organs_for_Ingestion_Pathway;

Begin
   assign(filevar,'c:\rindi\program\input.dat');
   reset(filevar);
   readln(filevar,m);
   for k := 1 to m do
      begin
         readln(filevar,r[k],Uptake[k],Y[k],Tvp[k]);
      end;
   close(filevar);
   Cpt0                         := 0;          (*units in pCi/kg*)
   Tot_Upt                      := 0;          (*units in kg/yr*)
   for k := 1 to m do
      begin
         Cpt0                   := Cpt0 + (Cst0 * r[k] * Tvp[k] / Y[k]);
         Tot_Upt                := Tot_Upt + Uptake[k];
      end;
   assign(filevar,'c:\rindi\program\organ.dat');
   reset(filevar);
   readln(filevar,n);
   for j := 1 to n do
      begin
         readln(filevar,organ[j],T_half_bone[j],T_half_kidney[j],
         CDE_bone[j],CDE_kidney[j]);
         lambda_bone[j]         := 0.693 / T_half_bone[j];
                                   (*units in year-1*)
         lambda_kidney[j]       := 0.693 / T_half_kidney[j];
                                   (*units in year-1*)
         lambda_e_bone[j]       := lambda_w + lambda_bone[j];
                                   (*units in year-1*)
         lambda_e_kidney[j]     := lambda_w + lambda_kidney[j];
                                   (*units in year-1*)
         CpTh_bone[j]           := Cpt0 * exp(-lambda_e_bone[j]*Th);
                                   (*units in pCi/kg*)
         CpTh_kidney[j]         := Cpt0 * exp(-lambda_e_kidney[j]*Th);
                                   (*units in pCi/kg*)
```

```
        Intake_bone[j]              := Tot_Upt * CpTh_bone[j] *
                                       (1 - exp(-lambda_bone[j] * Tf)) /
                                       lambda_bone[j];  (*units in pCi*)
        Intake_kidney[j]            := Tot_Upt * CpTh_kidney[j] *
                                       (1 - exp(-lambda_kidney[j] * Tf)) /
                                       lambda_kidney[j]; (*units in pCi*)
        if organ[j] = 1 then
         begin
            CDE235_bone[j]          := 3.7E+3 * Intake_bone[j] *
                                       CDE_bone[j];  (*units in mrem*)
            CDE235_kidney[j]        := 3.7E+3 * Intake_kidney[j] *
                                       CDE_kidney[j]; (*units in mrem*)
         end;

        if organ[j] = 2 then
         begin
            CDE238_bone[j]          := 3.7E+3 * Intake_bone[j] *
                                       CDE_bone[j];  (*units in mrem*)
            CDE238_kidney[j]        := 3.7E+3 * Intake_kidney[j] *
                                       CDE_kidney[j]; (*units in mrem*)
         end;
      end;
   close(filevar);
End;

Procedure Saving_to_disk;

Var
  filevar : text;

Begin
   assign(filevar,'c:\rindi\program\cde.out');
   rewrite(filevar);
   writeln(filevar,'Initial Soil Surface Concentration in pCi/m3 = ',Cst0);
   writeln(filevar,'Length of the Uptake Period in years         = ',Tf);
   writeln(filevar);
   writeln(filevar);
   writeln('Committed Dose Equivalent (mrem)');
   writeln('==========================');
   writeln;
   writeln('U-235 : ');
   if Result = 1 then
     begin
```

```
        write(organ1);
        write(CDE235_bone[1]);
        writeln;
        write(organ2);
        write(CDE235_kidney[1]);
        writeln;
        result := 2;
    end;
  writeln;
  writeln('U-238 : ');
  if Result = 2 then
    begin
        write(organ1);
        write(CDE238_bone[2]);
        writeln;
        write(organ2);
        write(CDE238_kidney[2]);
        result := 1;
      end;
  writeln(filevar,'Committed Dose Equivalent (mrem)');
  writeln(filevar,'================================');
  writeln(filevar);
  writeln(filevar,'U-235 : ');
  if Result = 1 then
    begin
        write(filevar,organ1);
        write(filevar,CDE235_bone[1]);
        writeln(filevar);
        write(filevar,organ2);
        write(filevar,CDE235_kidney[1]);
        writeln(filevar);
        result := 2;
    end;
  writeln(filevar);
  writeln(filevar,'U-238 : ');
  if Result = 2 then
    begin
        write(filevar,organ1);
        write(filevar,CDE238_bone[2]);
        writeln(filevar);
        write(filevar,organ2);
        write(filevar,CDE238_kidney[2]);
      end;
```

```
   close(filevar);
End;

Begin
   Initialization;
   n                  := 0;
   m                  := 0;
   Result             := 1;
   clrscr;
   organ1             := 'Bone Surface = ';
   organ2             := 'Kidneys      = ';
   lambda_w           := 18.0675;  (*units in year-1*)
   Th                 := 0.2466;   (*units in years*)
   write('Initial Soil Surface Concentration in pCi/m3 = ');
   read (Cst0);                    (*initial soil surface concentration in pCi/m3*)
   writeln;
   write('Length of the Uptake Period in years = ');
   read (Tf);                      (*length of uptake period in years*)
   writeln;
   Dose_Calculation_on_Target_Organs_for_Ingestion_Pathway;
   Saving_to_disk;
   writeln;
   writeln;
   writeln('Please press any key to continue !!!!!!!!');
   repeat until keypressed;
End.
```

C:\RINDI\PROGRAM\INPUT.DAT

```
4
2.0   15    1.5   1.0
4.0   140   4.0   0.1
2.0   64    2.0   1.0
0.6   80    0.8   1.0
```

C:\RINDI\PROGRAM\ORGAN.DAT

```
2
1     0.8219     0.0411     1.0E-6     4.3E-7
2     0.8219     0.0411     1.0E-6     4.1E-7
```

These two files are from the GENII manual and the ICRP Publication No. 30 (1979-1982). The original data are as follow:

Table A.1 Factors used for all kinds of vegetation

| | r | Uptake (kg/yr) | Yield (kg/m$^3$) | Translocation factor |
|---|---|---|---|---|
| Leafy veg. | 2.0 | 15 | 1.5 | 1.0 |
| Oth. veg. | 4.0 | 140 | 4.0 | 0.1 |
| Fruit | 2.0 | 64 | 2.0 | 1.0 |
| Cereals | 0.6 | 72 | 0.8 | 1.0 |

Table A.2 Data for U-235 and U-238

| | $T_{1/2}$ (year) | Organ | CDE/unit activity (Sv/Bq) |
|---|---|---|---|
| U - 235 | 0.8219 | Bone Surface | 1.0 E-6 |
| | 0.0411 | Kidneys | 4.3 E-7 |
| U - 238 | 0.8219 | Bone Surface | 1.0 E-6 |
| | 0.0411 | Kidneys | 4.1 E-7 |

C:\RINDI\PROGRAM\CDE.OUT

Initial Soil Surface Concentration in pCi/m3 = 4.2080000000E-03
Length of the Uptake Period in years = 1.0000000000E+00

Committed Dose Equivalent (mrem)
============================

U-235 :
Bone Surface = 9.1933561194E-05
Kidneys = 6.6812501518E-08

U-238 :
Bone Surface = 9.1933561194E-05
Kidneys = 6.3704943308E-08

# APPENDIX B

# THE GENII OUTPUT

```
--------------------------------------------------------------------------------
                     GENII  Dose Calculation Program
                       (Version 1.485 3-Dec-90)

Case title:   The ingestion pathway calculation for U-235 and U-238

Executed on:  12/09/94 at 14:49:36                                 Page A.  1
--------------------------------------------------------------------------------

          This is a near field (narrowly-focused, single site) scenario.
          Release is chronic
          Individual dose

          THE FOLLOWING TRANSPORT MODES ARE CONSIDERED
               Biotic Transport
               Waste Form Degradation

          THE FOLLOWING EXPOSURE PATHS ARE CONSIDERED:
               Terrestrial foods ingestion

          THE FOLLOWING TIMES ARE USED:
               Intake ends after (yr):                  1.0
               Dose calculations ends after (yr):       1.0

========== FILENAMES AND TITLES OF FILES/LIBRARIES USED ======================

 Input file name: \GENII\result.in
 GENII Default Parameter Values (28-Mar-90 RAP)
 Radionuclide Master Library   (11/28/90 RAP)
 Food Transfer Factor Library - (RAP  29-Aug-88) (UPDATED LEACHING FA
 External Dose Factors for GENII in person Sv/yr per Bq/m (8-May-90 R
 Internal Dose Increments, PNL Solubility Choices Rerun 12/3/90 PDR

==============================================================================

          -------- ----Release Terms------
          Release          Surface Buried
          Radio-   Air     Water   Source
          nuclide  pCi/yr  pCi/yr  pCi/m3
          -------- ------- ------- -------
          U 235    0.0E+00 0.0E+00 1.0E+00
          U 238    0.0E+00 0.0E+00 1.0E+00

========== NEAR-FIELD PARAMETERS =============================================
    0.0    Inventory disposed n years prior to beginning of intake period
      0    LOIC occurred n years prior to beginning of intake period
1.0E+00    Fraction of roots in upper soil (top 15 cm)
0.0E+00    Fraction of roots in deep soil
0.0E+00    Manual redistribution: deep soil/surface soil dilution factor

========== WASTE FORM AVAILABILITY ===========================================
5.0E-01    Waste form/package half life, yr
1.5E-01    Thickness of buried waste, m
1.5E-01    Depth of soil overburden, m

========== BIOTIC TRANSPORT OF BURIED SOURCE =================================
      1    Pre-Intake conditions: 1-Arid Non Ag,2-Humid Non Ag 3-Agriculture

========== TERRESTRIAL FOOD INGESTION ========================================
```

| FOOD TYPE | GROW TIME d | S * | --IRRIGATION-- RATE in/yr | TIME mo/yr | YIELD kg/m2 | PROD-UCTION kg/yr | --CONSUMPTION-- HOLDUP d | RATE kg/yr |
|---|---|---|---|---|---|---|---|---|
| Leaf Veg | 90.0 | 0 | 0.0 | 0.0 | 1.5 | | 14.0 | 1.5E+01 |
| Oth. Veg | 90.0 | 0 | 0.0 | 0.0 | 4.0 | | 14.0 | 1.4E+02 |
| Fruit | 90.0 | 0 | 0.0 | 0.0 | 2.0 | | 14.0 | 6.4E+01 |
| Cereals | 90.0 | 0 | 0.0 | 0.0 | 0.8 | | 180.0 | 7.2E+01 |

==============================================================================

Input prepared by: ______________________________ Date: ____________

Input checked by: ______________________________ Date: ____________

==============================================================================

GENII Dose Calculation Program
(Version 1.485 3-Dec-90)

Case title: The ingestion pathway calculation for U-235 and U-238

Executed on: 12/09/94 at 14:49:48 Page C. 1

| | |
|---|---|
| Release period: | 0.0 |
| Uptake/exposure period: | 1.0 |
| Dose commitment period: | 1.0 |
| Dose units: | Rem |

| Organ | Committed Dose Equivalent | Weighting Factors | Weighted Dose Equivalent |
|---|---|---|---|
| Gonads | 6.7E-15 | 2.5E-01 | 1.7E-15 |
| Breast | 2.3E-15 | 1.5E-01 | 3.5E-16 |
| R Marrow | 1.1E-14 | 1.2E-01 | 1.3E-15 |
| Lung | 1.9E-15 | 1.2E-01 | 2.3E-16 |
| Thyroid | 1.9E-15 | 3.0E-02 | 5.7E-17 |
| Bone Sur | 1.2E-13 | 3.0E-02 | 3.6E-15 |
| LL Int. | 2.3E-12 | 6.0E-02 | 1.4E-13 |
| UL Int. | 7.7E-13 | 6.0E-02 | 4.6E-14 |
| Kidneys | 3.1E-13 | 6.0E-02 | 1.9E-14 |
| S Int. | 1.4E-13 | 6.0E-02 | 8.1E-15 |
| Stomach | 5.3E-14 | 6.0E-02 | 3.2E-15 |
| Internal Effective Dose Equivalent | | | 2.2E-13 |
| External Dose | | | 0.0E+00 |
| Annual Effective Dose Equivalent | | | 2.2E-13 |

| | |
|---|---|
| Controlling Organ: | LL Int. |
| Controlling Pathway: | Ing |
| Controlling Radionuclide: | U 235 |
| Total Inhalation EDE: | 0.0E+00 |
| Total Ingestion EDE: | 2.2E-13 |

```
------------------------------------------------------------------------------
                        GENII  Dose Calculation Program
                         (Version 1.485 3-Dec-90)

Case title:   The ingestion pathway calculation for U-235 and U-238

Executed on:  12/09/94 at 14:49:48                                Page C.  2
------------------------------------------------------------------------------

Release period:                                                  0.0
Uptake/exposure period:                                          1.0
Dose commitment period:                                          1.0
Dose units:                                                  Rem



             Dose Commitment Year
                  1         2         3    ...
             ________________________________
Internal  :  |
Intake    :  |
Year:     3  |                    0.0E+00  ...
             |                       +
          2  |          0.0E+00   0.0E+00  ...                  Internal
             |             +         +                          Effective
          1  |  2.2E-13 + 0.0E+00 + 0.0E+00 + ...  =  2.2E-13   Dose
                                                                Equivalent
                  ||        ||        ||
Internal                                                        Cumulative
Annual          2.2E-13 + 0.0E+00 + 0.0E+00 + ...  =  2.2E-13   Internal
Dose                                                            Dose
                  +         +         +                  +
External
Annual          0.0E+00   0.0E+00   0.0E+00   ...     0.0E+00
Dose
                  ||        ||        ||                 ||
Annual                                                          Cumulative
Dose            2.2E-13 + 0.0E+00 + 0.0E+00 + ...  =  2.2E-13   Dose

                                                                Maximum
                                                      2.2E-13   Annual
                                                                Dose Occurred
                                                                In Year  1
______________________________________________________________________
```

GENII Dose Calculation Program
(Version 1.485 3-Dec-90)

Case title: The ingestion pathway calculation for U-235 and U-238

Executed on: 12/09/94 at 14:49:48 Page C. 3

| | |
|---|---|
| Release period: | 0.0 |
| Uptake/exposure period: | 1.0 |
| Dose commitment period: | 1.0 |
| Dose units: | Rem |

Committed Dose Equivalent by Exposure Pathway

| Pathway | Lung | Stomach | S Int. | UL Int. | LL Int. | Bone Su | R Marro | Testes |
|---|---|---|---|---|---|---|---|---|
| Leaf Veg | 7.2E-17 | 2.0E-15 | 5.0E-15 | 2.3E-14 | 8.5E-14 | 4.4E-15 | 3.9E-16 | 8.2E-17 |
| Oth. Veg | 1.4E-15 | 3.8E-14 | 9.6E-14 | 5.5E-13 | 1.6E-12 | 8.5E-14 | 7.6E-15 | 1.6E-15 |
| Fruit | 4.5E-16 | 1.2E-14 | 3.1E-14 | 1.8E-13 | 5.3E-13 | 2.7E-14 | 2.5E-15 | 5.1E-16 |
| Cereals | 3.7E-17 | 1.0E-15 | 2.6E-15 | 1.5E-14 | 4.5E-14 | 2.4E-15 | 2.1E-16 | 4.3E-17 |
| Total | 1.9E-15 | 5.3E-14 | 1.4E-13 | 7.7E-13 | 2.3E-12 | 1.2E-13 | 1.1E-14 | 2.2E-15 |

| Pathway | Ovaries | Muscle | Thyroid | Kidneys | Liver |
|---|---|---|---|---|---|
| Leaf Veg | 2.5E-16 | 8.6E-17 | 7.0E-17 | 1.1E-14 | 3.3E-18 |
| Oth. Veg | 4.8E-15 | 1.7E-15 | 1.4E-15 | 2.2E-13 | 6.4E-17 |
| Fruit | 1.5E-15 | 5.4E-16 | 4.4E-16 | 7.1E-14 | 2.1E-17 |
| Cereals | 1.3E-16 | 4.5E-17 | 3.6E-17 | 5.9E-15 | 4.7E-18 |
| Total | 6.7E-15 | 2.3E-15 | 1.9E-15 | 3.1E-13 | 9.3E-17 |

External Dose by Exposure Pathway

| Pathway | |
|---|---|
| Total | 0.0E+00 |

GENII Dose Calculation Program
(Version 1.485 3-Dec-90)

Case title: The ingestion pathway calculation for U-235 and U-238

Executed on: 12/09/94 at 14:49:48 

| | |
|---|---|
| Release period: | 0.0 |
| Uptake/exposure period: | 1.0 |
| Dose commitment period: | 1.0 |
| Dose units: | Rem |

Committed Dose Equivalent by Radionuclide

| Radionuclide | Lung | Stomach | S Int. | UL Int. | LL Int. | Bone Su | R Marro | Testes |
|---|---|---|---|---|---|---|---|---|
| U 235 | 1.0E-15 | 1.9E-14 | 4.8E-14 | 2.7E-13 | 8.7E-13 | 5.9E-14 | 5.6E-15 | 1.3E-15 |
| TH 231 | 2.2E-18 | 3.1E-15 | 7.4E-15 | 3.1E-14 | 5.5E-14 | 3.4E-17 | 8.4E-17 | 8.5E-18 |
| PA 231 | 1.6E-20 | 2.4E-18 | 6.1E-18 | 3.5E-17 | 1.1E-16 | 9.4E-16 | 7.3E-17 | 2.2E-20 |
| AC 227 | 8.6E-23 | 4.2E-22 | 1.3E-21 | 1.1E-20 | 6.5E-20 | 2.3E-17 | 1.8E-18 | 2.5E-19 |
| TH 227 | 6.7E-22 | 8.7E-21 | 2.1E-20 | 1.3E-19 | 4.7E-19 | 3.6E-19 | 2.9E-20 | 7.2E-22 |
| FR 223 | 2.7E-22 | 2.9E-22 | 2.7E-22 | 2.7E-22 | 2.7E-22 | 2.9E-21 | 3.6E-22 | 2.7E-22 |
| RA 223 | 1.8E-19 | 2.8E-19 | 3.9E-19 | 1.4E-18 | 3.7E-18 | 1.6E-17 | 1.2E-18 | 1.8E-19 |
| U 238 | 9.2E-16 | 1.6E-14 | 4.2E-14 | 2.4E-13 | 7.4E-13 | 5.8E-14 | 4.7E-15 | 9.3E-16 |
| TH 234 | 1.0E-17 | 1.5E-14 | 3.8E-14 | 2.3E-13 | 6.4E-13 | 3.0E-16 | 2.7E-16 | 3.5E-17 |
| PA 234 | 3.6E-19 | 1.9E-17 | 3.6E-17 | 7.8E-17 | 6.3E-17 | 6.8E-19 | 2.0E-18 | 6.1E-19 |
| Total | 1.9E-15 | 5.3E-14 | 1.4E-13 | 7.7E-13 | 2.3E-12 | 1.2E-13 | 1.1E-14 | 2.2E-15 |

| Radionuclide | Ovaries | Muscle | Thyroid | Kidneys | Liver |
|---|---|---|---|---|---|
| U 235 | 4.8E-15 | 1.3E-15 | 9.8E-16 | 1.6E-13 | 0.0E+00 |
| TH 231 | 3.4E-16 | 2.2E-17 | 1.4E-19 | 0.0E+00 | 1.6E-17 |
| PA 231 | 1.4E-19 | 2.6E-20 | 1.5E-20 | 1.4E-17 | 8.8E-18 |
| AC 227 | 2.6E-19 | 6.3E-23 | 2.9E-23 | 0.0E+00 | 6.2E-18 |
| TH 227 | 1.5E-21 | 7.2E-22 | 6.2E-22 | 0.0E+00 | 5.6E-21 |
| FR 223 | 2.8E-22 | 2.7E-22 | 2.7E-22 | 0.0E+00 | 0.0E+00 |
| RA 223 | 1.8E-19 | 1.8E-19 | 1.6E-19 | 0.0E+00 | 0.0E+00 |
| U 238 | 1.1E-15 | 9.2E-16 | 9.2E-16 | 1.5E-13 | 0.0E+00 |
| TH 234 | 4.3E-16 | 5.0E-17 | 4.3E-18 | 0.0E+00 | 6.1E-17 |
| PA 234 | 8.5E-18 | 1.3E-18 | 4.6E-20 | 2.1E-18 | 1.5E-18 |
| Total | 6.7E-15 | 2.3E-15 | 1.9E-15 | 3.1E-13 | 9.3E-17 |

GENII Dose Calculation Program
(Version 1.485 3-Dec-90)

Case title: The ingestion pathway calculation for U-235 and U-238

Executed on: 12/09/94 at 14:49:48 Page C. 5

Release period: 0.0
Uptake/exposure period: 1.0
Dose commitment period: 1.0
Dose units: Rem

| Radio-nuclide | Inhalation Effective Dose Equivalent | Ingestion Effective Dose Equivalent | External Dose | Internal Effective Dose Equivalent | Annual Effective Dose Equivalent |
|---|---|---|---|---|---|
| U 235 | 0.0E+00 | 8.6E-14 | 0.0E+00 | 8.6E-14 | 8.6E-14 |
| TH 231 | 0.0E+00 | 5.8E-15 | 0.0E+00 | 5.8E-15 | 5.8E-15 |
| PA 231 | 0.0E+00 | 4.7E-17 | 0.0E+00 | 4.7E-17 | 4.7E-17 |
| AC 227 | 0.0E+00 | 1.3E-18 | 0.0E+00 | 1.3E-18 | 1.3E-18 |
| TH 227 | 0.0E+00 | 5.3E-20 | 0.0E+00 | 5.3E-20 | 5.3E-20 |
| FR 223 | 0.0E+00 | 3.5E-22 | 0.0E+00 | 3.5E-22 | 3.5E-22 |
| RA 223 | 0.0E+00 | 1.1E-18 | 0.0E+00 | 1.1E-18 | 1.1E-18 |
| U 238 | 0.0E+00 | 7.4E-14 | 0.0E+00 | 7.4E-14 | 7.4E-14 |
| TH 234 | 0.0E+00 | 5.5E-14 | 0.0E+00 | 5.5E-14 | 5.5E-14 |
| PA 234 | 0.0E+00 | 1.5E-17 | 0.0E+00 | 1.5E-17 | 1.5E-17 |

# APPENDIX C

# THE RESRAD OUTPUT

Table of Contents

Part I: Mixture Sums and Single Radionuclide Guidelines





Dose Conversion Factor (and Related) Parameter Summary
File: DOSFAC.BIN

| 0<br>Menu | Parameter | Current<br>Value | Default | Parameter<br>Name |
|---|---|---|---|---|
| A-1 | Ground external gamma, volume DCF's, (mrem/yr)/(pCi/cm**3): | | | |
| A-1 | Ac-227+D , soil density = 1.0 g/cm**3 | 2.760E+00 | 2.760E+00 | DCF1( 1,1) |
| A-1 | Ac-227+D , soil density = 1.8 g/cm**3 | 1.520E+00 | 1.520E+00 | DCF1( 1,2) |
| A-1 | | | | |
| A-1 | Pa-231 , soil density = 1.0 g/cm**3 | 2.210E-01 | 2.210E-01 | DCF1( 2,1) |
| A-1 | Pa-231 , soil density = 1.8 g/cm**3 | 1.210E-01 | 1.210E-01 | DCF1( 2,2) |
| A-1 | | | | |
| A-1 | Pb-210+D , soil density = 1.0 g/cm**3 | 4.870E-03 | 4.870E-03 | DCF1( 3,1) |
| A-1 | Pb-210+D , soil density = 1.8 g/cm**3 | 2.310E-03 | 2.310E-03 | DCF1( 3,2) |
| A-1 | | | | |
| A-1 | Ra-226+D , soil density = 1.0 g/cm**3 | 1.550E+01 | 1.550E+01 | DCF1( 4,1) |
| A-1 | Ra-226+D , soil density = 1.8 g/cm**3 | 8.560E+00 | 8.560E+00 | DCF1( 4,2) |
| A-1 | | | | |
| A-1 | Th-230 , soil density = 1.0 g/cm**3 | 2.110E-03 | 2.110E-03 | DCF1( 5,1) |
| A-1 | Th-230 , soil density = 1.8 g/cm**3 | 1.030E-03 | 1.030E-03 | DCF1( 5,2) |

| | | | | |
|---|---|---|---|---|
| A-1 | | | | |
| A-1 | U-234 , soil density = 1.0 g/cm**3 | 1.580E-03 | 1.580E-03 | DCF1( 6,1) |
| A-1 | U-234 , soil density = 1.8 g/cm**3 | 6.970E-04 | 6.970E-04 | DCF1( 6,2) |
| A-1 | | | | |
| A-1 | U-235+D , soil density = 1.0 g/cm**3 | 8.940E-01 | 8.940E-01 | DCF1( 7,1) |
| A-1 | U-235+D , soil density = 1.8 g/cm**3 | 4.900E-01 | 4.900E-01 | DCF1( 7,2) |
| A-1 | | | | |
| A-1 | U-238+D , soil density = 1.0 g/cm**3 | 1.270E-01 | 1.270E-01 | DCF1( 8,1) |
| A-1 | U-238+D , soil density = 1.8 g/cm**3 | 6.970E-02 | 6.970E-02 | DCF1( 8,2) |
| | | | | |
| A-3 | Depth factors, ground external gamma, dimensionless: | | | |
| A-3 | Ac-227+D , soil density = 1.0 g/cm**3, thickness = .15 m | 7.900E-01 | 7.900E-01 | FD( 1,1,1) |
| A-3 | Ac-227+D , soil density = 1.0 g/cm**3, thickness = 0.5 m | 9.700E-01 | 9.700E-01 | FD( 1,2,1) |
| A-3 | Ac-227+D , soil density = 1.0 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 1,3,1) |
| A-3 | Ac-227+D , soil density = 1.8 g/cm**3, thickness = .15 m | 9.100E-01 | 9.100E-01 | FD( 1,1,2) |
| A-3 | Ac-227+D , soil density = 1.8 g/cm**3, thickness = 0.5 m | 1.000E+00 | 1.000E+00 | FD( 1,2,2) |
| A-3 | Ac-227+D , soil density = 1.8 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 1,3,2) |
| A-3 | | | | |
| A-3 | Pa-231 , soil density = 1.0 g/cm**3, thickness = .15 m | 7.900E-01 | 7.900E-01 | FD( 2,1,1) |
| A-3 | Pa-231 , soil density = 1.0 g/cm**3, thickness = 0.5 m | 1.000E+00 | 1.000E+00 | FD( 2,2,1) |
| A-3 | Pa-231 , soil density = 1.0 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 2,3,1) |
| A-3 | Pa-231 , soil density = 1.8 g/cm**3, thickness = .15 m | 9.200E-01 | 9.200E-01 | FD( 2,1,2) |
| A-3 | Pa-231 , soil density = 1.8 g/cm**3, thickness = 0.5 m | 1.000E+00 | 1.000E+00 | FD( 2,2,2) |
| A-3 | Pa-231 , soil density = 1.8 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 2,3,2) |
| A-3 | | | | |
| A-3 | Pb-210+D , soil density = 1.0 g/cm**3, thickness = .15 m | 8.800E-01 | 8.800E-01 | FD( 3,1,1) |
| A-3 | Pb-210+D , soil density = 1.0 g/cm**3, thickness = 0.5 m | 1.000E+00 | 1.000E+00 | FD( 3,2,1) |
| A-3 | Pb-210+D , soil density = 1.0 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 3,3,1) |
| A-3 | Pb-210+D , soil density = 1.8 g/cm**3, thickness = .15 m | 9.700E-01 | 9.700E-01 | FD( 3,1,2) |
| A-3 | Pb-210+D , soil density = 1.8 g/cm**3, thickness = 0.5 m | 1.000E+00 | 1.000E+00 | FD( 3,2,2) |
| A-3 | Pb-210+D , soil density = 1.8 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 3,3,2) |
| A-3 | | | | |



Dose Conversion Factor (and Related) Parameter Summary (continued)
File: DOSFAC.BIN

| 0<br>Menu | Parameter | Current<br>Value | Default | Parameter<br>Name |
|---|---|---|---|---|
| A-3 | Ra-226+D , soil density = 1.0 g/cm**3, thickness = .15 m | 6.300E-01 | 6.300E-01 | FD( 4,1,1) |
| A-3 | Ra-226+D , soil density = 1.0 g/cm**3, thickness = 0.5 m | 9.200E-01 | 9.200E-01 | FD( 4,2,1) |
| A-3 | Ra-226+D , soil density = 1.0 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 4,3,1) |
| A-3 | Ra-226+D , soil density = 1.8 g/cm**3, thickness = .15 m | 8.500E-01 | 8.500E-01 | FD( 4,1,2) |

| | | | | |
|---|---|---|---|---|
| A-3 | Ra-226+D , soil density = 1.8 g/cm**3, thickness = 0.5 m | 1.000E+00 | 1.000E+00 | FD( 4,2,2) |
| A-3 | Ra-226+D , soil density = 1.8 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 4,3,2) |
| A-3 | | | | |
| A-3 | Th-230 , soil density = 1.0 g/cm**3, thickness = .15 m | 9.300E-01 | 9.300E-01 | FD( 5,1,1) |
| A-3 | Th-230 , soil density = 1.0 g/cm**3, thickness = 0.5 m | 1.000E+00 | 1.000E+00 | FD( 5,2,1) |
| A-3 | Th-230 , soil density = 1.0 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 5,3,1) |
| A-3 | Th-230 , soil density = 1.8 g/cm**3, thickness = .15 m | 1.000E+00 | 1.000E+00 | FD( 5,1,2) |
| A-3 | Th-230 , soil density = 1.8 g/cm**3, thickness = 0.5 m | 1.000E+00 | 1.000E+00 | FD( 5,2,2) |
| A-3 | Th-230 , soil density = 1.8 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 5,3,2) |
| A-3 | | | | |
| A-3 | U-234 , soil density = 1.0 g/cm**3, thickness = .15 m | 9.000E-01 | 9.000E-01 | FD( 6,1,1) |
| A-3 | U-234 , soil density = 1.0 g/cm**3, thickness = 0.5 m | 1.000E+00 | 1.000E+00 | FD( 6,2,1) |
| A-3 | U-234 , soil density = 1.0 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 6,3,1) |
| A-3 | U-234 , soil density = 1.8 g/cm**3, thickness = .15 m | 1.000E+00 | 1.000E+00 | FD( 6,1,2) |
| A-3 | U-234 , soil density = 1.8 g/cm**3, thickness = 0.5 m | 1.000E+00 | 1.000E+00 | FD( 6,2,2) |
| A-3 | U-234 , soil density = 1.8 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 6,3,2) |
| A-3 | | | | |
| A-3 | U-235+D , soil density = 1.0 g/cm**3, thickness = .15 m | 8.700E-01 | 8.700E-01 | FD( 7,1,1) |
| A-3 | U-235+D , soil density = 1.0 g/cm**3, thickness = 0.5 m | 1.000E+00 | 1.000E+00 | FD( 7,2,1) |
| A-3 | U-235+D , soil density = 1.0 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 7,3,1) |
| A-3 | U-235+D , soil density = 1.8 g/cm**3, thickness = .15 m | 1.000E+00 | 1.000E+00 | FD( 7,1,2) |
| A-3 | U-235+D , soil density = 1.8 g/cm**3, thickness = 0.5 m | 1.000E+00 | 1.000E+00 | FD( 7,2,2) |
| A-3 | U-235+D , soil density = 1.8 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 7,3,2) |
| A-3 | | | | |
| A-3 | U-238+D , soil density = 1.0 g/cm**3, thickness = .15 m | 7.800E-01 | 7.800E-01 | FD( 8,1,1) |
| A-3 | U-238+D , soil density = 1.0 g/cm**3, thickness = 0.5 m | 1.000E+00 | 1.000E+00 | FD( 8,2,1) |
| A-3 | U-238+D , soil density = 1.0 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 8,3,1) |
| A-3 | U-238+D , soil density = 1.8 g/cm**3, thickness = .15 m | 8.800E-01 | 8.800E-01 | FD( 8,1,2) |
| A-3 | U-238+D , soil density = 1.8 g/cm**3, thickness = 0.5 m | 1.000E+00 | 1.000E+00 | FD( 8,2,2) |
| A-3 | U-238+D , soil density = 1.8 g/cm**3, thickness = 1.0 m | 1.000E+00 | 1.000E+00 | FD( 8,3,2) |
| | | | | |
| B-1 | Dose conversion factors for inhalation, mrem/pCi: | | | |
| B-1 | Ac-227+D | 6.700E+00 | 6.700E+00 | DCF2( 1) |
| B-1 | Pa-231 | 1.300E+00 | 1.300E+00 | DCF2( 2) |
| B-1 | Pb-210+D | 2.100E-02 | 2.100E-02 | DCF2( 3) |
| B-1 | Ra-226+D | 7.900E-03 | 7.900E-03 | DCF2( 4) |
| B-1 | Th-230 | 3.200E-01 | 3.200E-01 | DCF2( 5) |
| B-1 | U-234 | 1.300E-01 | 1.300E-01 | DCF2( 6) |
| B-1 | U-235+D | 1.200E-01 | 1.200E-01 | DCF2( 7) |
| B-1 | U-238+D | 1.200E-01 | 1.200E-01 | DCF2( 8) |
| | | | | |
| D-1 | Dose conversion factors for ingestion, mrem/pCi: | | | |
| D-1 | Ac-227+D | 1.500E-02 | 1.500E-02 | DCF3( 1) |
| D-1 | Pa-231 | 1.100E-02 | 1.100E-02 | DCF3( 2) |
| D-1 | Pb-210+D | 6.700E-03 | 6.700E-03 | DCF3( 3) |

| D-1 | Ra-226+D | 1.100E-03 | 1.100E-03 | DCF3( 4) |
|---|---|---|---|---|



Dose Conversion Factor (and Related) Parameter Summary (continued)
File: DOSFAC.BIN

| 0 Menu | Parameter | Current Value | Default | Parameter Name |
|---|---|---|---|---|
| D-1 | Th-230 | 5.300E-04 | 5.300E-04 | DCF3( 5) |
| D-1 | U-234 | 2.600E-04 | 2.600E-04 | DCF3( 6) |
| D-1 | U-235+D | 2.500E-04 | 2.500E-04 | DCF3( 7) |
| D-1 | U-238+D | 2.500E-04 | 2.500E-04 | DCF3( 8) |
| | | | | |
| D-34 | Food transfer factors: | | | |
| D-34 | Ac-227+D , plant/soil concentration ratio, dimensionless | 2.500E-03 | 2.500E-03 | RTF( 1,1) |
| D-34 | Ac-227+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d) | 2.000E-05 | 2.000E-05 | RTF( 1,2) |
| D-34 | Ac-227+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d) | 2.000E-05 | 2.000E-05 | RTF( 1,3) |
| D-34 | | | | |
| D-34 | Pa-231 , plant/soil concentration ratio, dimensionless | 1.000E-02 | 1.000E-02 | RTF( 2,1) |
| D-34 | Pa-231 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d) | 5.000E-03 | 5.000E-03 | RTF( 2,2) |
| D-34 | Pa-231 , milk/livestock-intake ratio, (pCi/L)/(pCi/d) | 5.000E-06 | 5.000E-06 | RTF( 2,3) |
| D-34 | | | | |
| D-34 | Pb-210+D , plant/soil concentration ratio, dimensionless | 1.000E-02 | 1.000E-02 | RTF( 3,1) |
| D-34 | Pb-210+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d) | 8.000E-04 | 8.000E-04 | RTF( 3,2) |
| D-34 | Pb-210+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d) | 3.000E-04 | 3.000E-04 | RTF( 3,3) |
| D-34 | | | | |
| D-34 | Ra-226+D , plant/soil concentration ratio, dimensionless | 4.000E-02 | 4.000E-02 | RTF( 4,1) |
| D-34 | Ra-226+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d) | 1.000E-03 | 1.000E-03 | RTF( 4,2) |
| D-34 | Ra-226+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d) | 1.000E-03 | 1.000E-03 | RTF( 4,3) |
| D-34 | | | | |
| D-34 | Th-230 , plant/soil concentration ratio, dimensionless | 1.000E-03 | 1.000E-03 | RTF( 5,1) |
| D-34 | Th-230 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d) | 1.000E-04 | 1.000E-04 | RTF( 5,2) |
| D-34 | Th-230 , milk/livestock-intake ratio, (pCi/L)/(pCi/d) | 5.000E-06 | 5.000E-06 | RTF( 5,3) |
| D-34 | | | | |
| D-34 | U-234 , plant/soil concentration ratio, dimensionless | 2.500E-03 | 2.500E-03 | RTF( 6,1) |
| D-34 | U-234 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d) | 3.400E-04 | 3.400E-04 | RTF( 6,2) |
| D-34 | U-234 , milk/livestock-intake ratio, (pCi/L)/(pCi/d) | 6.000E-04 | 6.000E-04 | RTF( 6,3) |
| D-34 | | | | |
| D-34 | U-235+D , plant/soil concentration ratio, dimensionless | 2.500E-03 | 2.500E-03 | RTF( 7,1) |
| D-34 | U-235+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d) | 3.400E-04 | 3.400E-04 | RTF( 7,2) |
| D-34 | U-235+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d) | 6.000E-04 | 6.000E-04 | RTF( 7,3) |
| D-34 | | | | |
| D-34 | U-238+D , plant/soil concentration ratio, dimensionless | 2.500E-03 | 2.500E-03 | RTF( 8,1) |

| | | | | |
|---|---|---|---|---|
| D-34 | U-238+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d) | 3.400E-04 | 3.400E-04 | RTF( 8,2) |
| D-34 | U-238+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d) | 6.000E-04 | 6.000E-04 | RTF( 8,3) |
| | | | | |
| D-5 | Bioaccumulation factors, fresh water, L/kg: | | | |
| D-5 | Ac-227+D , fish | 1.500E+01 | 1.500E+01 | BIOFAC( 1,1) |
| D-5 | Ac-227+D , crustacea and mollusks | 1.000E+03 | 1.000E+03 | BIOFAC( 1,2) |
| D-5 | | | | |
| D-5 | Pa-231 , fish | 1.000E+01 | 1.000E+01 | BIOFAC( 2,1) |
| D-5 | Pa-231 , crustacea and mollusks | 1.100E+02 | 1.100E+02 | BIOFAC( 2,2) |
| D-5 | | | | |
| D-5 | Pb-210+D , fish | 3.000E+02 | 3.000E+02 | BIOFAC( 3,1) |
| D-5 | Pb-210+D , crustacea and mollusks | 1.000E+02 | 1.000E+02 | BIOFAC( 3,2) |
| D-5 | | | | |
| D-5 | Ra-226+D , fish | 5.000E+01 | 5.000E+01 | BIOFAC( 4,1) |
| D-5 | Ra-226+D , crustacea and mollusks | 2.500E+02 | 2.500E+02 | BIOFAC( 4,2) |

1RESRAD, Version 5.19 T½ Limit = 0.5 year 12/08/94 17:28 Page 5
Summary : The ingestion pathway calculation for U-235 and U-238
File : RESULT1.DAT

Dose Conversion Factor (and Related) Parameter Summary (continued)
File: DOSFAC.BIN

| 0 Menu | Parameter | Current Value | Default | Parameter Name |
|---|---|---|---|---|
| D-5 | Th-230 , fish | 1.000E+02 | 1.000E+02 | BIOFAC( 5,1) |
| D-5 | Th-230 , crustacea and mollusks | 5.000E+02 | 5.000E+02 | BIOFAC( 5,2) |
| D-5 | | | | |
| D-5 | U-234 , fish | 1.000E+01 | 1.000E+01 | BIOFAC( 6,1) |
| D-5 | U-234 , crustacea and mollusks | 6.000E+01 | 6.000E+01 | BIOFAC( 6,2) |
| D-5 | | | | |
| D-5 | U-235+D , fish | 1.000E+01 | 1.000E+01 | BIOFAC( 7,1) |
| D-5 | U-235+D , crustacea and mollusks | 6.000E+01 | 6.000E+01 | BIOFAC( 7,2) |
| D-5 | | | | |
| D-5 | U-238+D , fish | 1.000E+01 | 1.000E+01 | BIOFAC( 8,1) |
| D-5 | U-238+D , crustacea and mollusks | 6.000E+01 | 6.000E+01 | BIOFAC( 8,2) |

1RESRAD, Version 5.19 T½ Limit = 0.5 year 12/08/94 17:28 Page 6
Summary : The ingestion pathway calculation for U-235 and U-238
File : RESULT1.DAT

Site-Specific Parameter Summary

| 0 Menu | Parameter | User Input | Default | Used by RESRAD (If different from user input) | Parameter Name |
|---|---|---|---|---|---|
| R011 | Area of contaminated zone (m**2) | 1.000E+04 | 1.000E+04 | --- | AREA |

| | | | | | |
|---|---|---|---|---|---|
| R011 | Thickness of contaminated zone (m) | 1.500E-01 | 2.000E+00 | --- | THICK0 |
| R011 | Length parallel to aquifer flow (m) | 1.000E+02 | 1.000E+02 | --- | LCZPAQ |
| R011 | Basic radiation dose limit (mrem/yr) | 3.000E+01 | 3.000E+01 | --- | BRDL |
| R011 | Time since placement of material (yr) | 0.000E+00 | 0.000E+00 | --- | TI |
| R011 | Times for calculations (yr) | 1.000E+00 | 1.000E+00 | --- | T( 2) |
| R011 | Times for calculations (yr) | 5.000E+01 | 3.000E+00 | --- | T( 3) |
| R011 | Times for calculations (yr) | not used | 1.000E+01 | --- | T( 4) |
| R011 | Times for calculations (yr) | not used | 3.000E+01 | --- | T( 5) |
| R011 | Times for calculations (yr) | not used | 1.000E+02 | --- | T( 6) |
| R011 | Times for calculations (yr) | not used | 3.000E+02 | --- | T( 7) |
| R011 | Times for calculations (yr) | not used | 1.000E+03 | --- | T( 8) |
| R011 | Times for calculations (yr) | not used | 3.000E+03 | --- | T( 9) |
| R011 | Times for calculations (yr) | not used | 1.000E+04 | --- | T(10) |
| | | | | | |
| R012 | Initial principal radionuclide (pCi/g): U-235 | 4.167E-07 | 0.000E+00 | --- | S1( 7) |
| R012 | Initial principal radionuclide (pCi/g): U-238 | 4.167E-07 | 0.000E+00 | --- | S1( 8) |
| R012 | Concentration in groundwater (pCi/L): U-235 | not used | 0.000E+00 | --- | W1( 7) |
| R012 | Concentration in groundwater (pCi/L): U-238 | not used | 0.000E+00 | --- | W1( 8) |
| | | | | | |
| R013 | Cover depth (m) | 1.500E-01 | 0.000E+00 | --- | COVER0 |
| R013 | Density of cover material (g/cm**3) | not used | 1.500E+00 | --- | DENSCV |
| R013 | Cover depth erosion rate (m/yr) | 1.000E-03 | 1.000E-03 | --- | VCV |
| R013 | Density of contaminated zone (g/cm**3) | 1.600E+00 | 1.500E+00 | --- | DENSCZ |
| R013 | Contaminated zone erosion rate (m/yr) | 1.000E-03 | 1.000E-03 | --- | VCZ |
| R013 | Contaminated zone total porosity | 4.000E-01 | 4.000E-01 | --- | TPCZ |
| R013 | Contaminated zone effective porosity | 2.000E-01 | 2.000E-01 | --- | EPCZ |
| R013 | Contaminated zone hydraulic conductivity (m/yr) | 1.000E+01 | 1.000E+01 | --- | HCCZ |
| R013 | Contaminated zone b parameter | 5.300E+00 | 5.300E+00 | --- | BCZ |
| R013 | Humidity in air (g/cm**3) | not used | 8.000E+00 | --- | HUMID |
| R013 | Evapotranspiration coefficient | 6.000E-01 | 5.000E-01 | --- | EVAPTR |
| R013 | Precipitation (m/yr) | 1.000E+00 | 1.000E+00 | --- | PRECIP |
| R013 | Irrigation (m/yr) | 0.000E+00 | 2.000E-01 | --- | RI |
| R013 | Irrigation mode | overhead | overhead | --- | IDITCH |
| R013 | Runoff coefficient | 2.000E-01 | 2.000E-01 | --- | RUNOFF |
| R013 | Watershed area for nearby stream or pond (m**2) | 1.000E+06 | 1.000E+06 | --- | WAREA |
| R013 | Accuracy for water/soil computations | 1.000E-03 | 1.000E-03 | --- | EPS |
| | | | | | |
| R014 | Density of saturated zone (g/cm**3) | 1.600E+00 | 1.500E+00 | --- | DENSAQ |
| R014 | Saturated zone total porosity | 4.000E-01 | 4.000E-01 | --- | TPSZ |
| R014 | Saturated zone effective porosity | 2.000E-01 | 2.000E-01 | --- | EPSZ |
| R014 | Saturated zone hydraulic conductivity (m/yr) | 1.000E+02 | 1.000E+02 | --- | HCSZ |
| R014 | Saturated zone hydraulic gradient | 2.000E-02 | 2.000E-02 | --- | HGWT |
| R014 | Saturated zone b parameter | 5.300E+00 | 5.300E+00 | --- | BSZ |
| R014 | Water table drop rate (m/yr) | 1.000E-03 | 1.000E-03 | --- | VWT |
| R014 | Well pump intake depth (m below water table) | 1.000E+01 | 1.000E+01 | --- | DWIBWT |

| | | | | | |
|---|---|---|---|---|---|
| R014 | Model: Nondispersion (ND) or Mass-Balance (MB) | ND | ND | --- | MODEL |
| R014 | Well pumping rate (m**3/yr) | 1.500E+02 | 2.500E+02 | --- | UW |
| R015 | Number of unsaturated zone strata | 1 | 1 | --- | NS |



Site-Specific Parameter Summary (continued)

| 0<br>Menu | Parameter | User<br>Input | Default | Used by RESRAD<br>(If different from user input) | Parameter<br>Name |
|---|---|---|---|---|---|
| R015 | Unsat. zone 1, thickness (m) | 2.000E+00 | 4.000E+00 | --- | H(1) |
| R015 | Unsat. zone 1, soil density (g/cm**3) | 1.800E+00 | 1.500E+00 | --- | DENSUZ(1) |
| R015 | Unsat. zone 1, total porosity | 4.200E-01 | 4.000E-01 | --- | TPUZ(1) |
| R015 | Unsat. zone 1, effective porosity | 2.300E-01 | 2.000E-01 | --- | EPUZ(1) |
| R015 | Unsat. zone 1, soil-specific b parameter | 7.000E+00 | 5.300E+00 | --- | BUZ(1) |
| R015 | Unsat. zone 1, hydraulic conductivity (m/yr) | 1.000E+02 | 1.000E+01 | --- | HCUZ(1) |
| | | | | | |
| R016 | Distribution coefficients for U-235 | | | | |
| R016 | Contaminated zone (cm**3/g) | 2.500E+01 | 5.000E+01 | --- | DCNUCC( 7) |
| R016 | Unsaturated zone 1 (cm**3/g) | 2.500E+01 | 5.000E+01 | --- | DCNUCU( 7,1) |
| R016 | Saturated zone (cm**3/g) | 2.500E+01 | 5.000E+01 | --- | DCNUCS( 7) |
| R016 | Leach rate (/yr) | 0.000E+00 | 0.000E+00 | 5.292E-02 | ALEACH( 7) |
| R016 | Solubility constant | 0.000E+00 | 0.000E+00 | not used | SOLUBK( 7) |
| | | | | | |
| R016 | Distribution coefficients for U-238 | | | | |
| R016 | Contaminated zone (cm**3/g) | 2.500E+01 | 5.000E+01 | --- | DCNUCC( 8) |
| R016 | Unsaturated zone 1 (cm**3/g) | 2.500E+01 | 5.000E+01 | --- | DCNUCU( 8,1) |
| R016 | Saturated zone (cm**3/g) | 2.500E+01 | 5.000E+01 | --- | DCNUCS( 8) |
| R016 | Leach rate (/yr) | 0.000E+00 | 0.000E+00 | 5.292E-02 | ALEACH( 8) |
| R016 | Solubility constant | 0.000E+00 | 0.000E+00 | not used | SOLUBK( 8) |
| | | | | | |
| R016 | Distribution coefficients for daughter Ac-227 | | | | |
| R016 | Contaminated zone (cm**3/g) | 2.000E+01 | 2.000E+01 | --- | DCNUCC( 1) |
| R016 | Unsaturated zone 1 (cm**3/g) | 2.000E+01 | 2.000E+01 | --- | DCNUCU( 1,1) |
| R016 | Saturated zone (cm**3/g) | 2.000E+01 | 2.000E+01 | --- | DCNUCS( 1) |
| R016 | Leach rate (/yr) | 0.000E+00 | 0.000E+00 | 6.603E-02 | ALEACH( 1) |
| R016 | Solubility constant | 0.000E+00 | 0.000E+00 | not used | SOLUBK( 1) |
| | | | | | |
| R016 | Distribution coefficients for daughter Pa-231 | | | | |
| R016 | Contaminated zone (cm**3/g) | 5.000E+01 | 5.000E+01 | --- | DCNUCC( 2) |
| R016 | Unsaturated zone 1 (cm**3/g) | 5.000E+01 | 5.000E+01 | --- | DCNUCU( 2,1) |
| R016 | Saturated zone (cm**3/g) | 5.000E+01 | 5.000E+01 | --- | DCNUCS( 2) |
| R016 | Leach rate (/yr) | 0.000E+00 | 0.000E+00 | 2.656E-02 | ALEACH( 2) |

| | | | | | |
|---|---|---|---|---|---|
| R016 | Solubility constant | 0.000E+00 | 0.000E+00 | not used | SOLUBK( 2) |
| | | | | | |
| R016 | Distribution coefficients for daughter Pb-210 | | | | |
| R016 | Contaminated zone (cm**3/g) | 1.000E+02 | 1.000E+02 | --- | DCNUCC( 3) |
| R016 | Unsaturated zone 1 (cm**3/g) | 1.000E+02 | 1.000E+02 | --- | DCNUCU( 3,1) |
| R016 | Saturated zone (cm**3/g) | 1.000E+02 | 1.000E+02 | --- | DCNUCS( 3) |
| R016 | Leach rate (/yr) | 0.000E+00 | 0.000E+00 | 1.331E-02 | ALEACH( 3) |
| R016 | Solubility constant | 0.000E+00 | 0.000E+00 | not used | SOLUBK( 3) |
| | | | | | |
| R016 | Distribution coefficients for daughter Ra-226 | | | | |
| R016 | Contaminated zone (cm**3/g) | 7.000E+01 | 7.000E+01 | --- | DCNUCC( 4) |
| R016 | Unsaturated zone 1 (cm**3/g) | 7.000E+01 | 7.000E+01 | --- | DCNUCU( 4,1) |
| R016 | Saturated zone (cm**3/g) | 7.000E+01 | 7.000E+01 | --- | DCNUCS( 4) |
| R016 | Leach rate (/yr) | 0.000E+00 | 0.000E+00 | 1.899E-02 | ALEACH( 4) |
| R016 | Solubility constant | 0.000E+00 | 0.000E+00 | not used | SOLUBK( 4) |



Site-Specific Parameter Summary (continued)

| 0<br>Menu | Parameter | User<br>Input | Default | Used by RESRAD<br>(If different from user input) | Parameter<br>Name |
|---|---|---|---|---|---|
| R016 | Distribution coefficients for daughter Th-230 | | | | |
| R016 | Contaminated zone (cm**3/g) | 6.000E+04 | 6.000E+04 | --- | DCNUCC( 5) |
| R016 | Unsaturated zone 1 (cm**3/g) | 6.000E+04 | 6.000E+04 | --- | DCNUCU( 5,1) |
| R016 | Saturated zone (cm**3/g) | 6.000E+04 | 6.000E+04 | --- | DCNUCS( 5) |
| R016 | Leach rate (/yr) | 0.000E+00 | 0.000E+00 | 2.222E-05 | ALEACH( 5) |
| R016 | Solubility constant | 0.000E+00 | 0.000E+00 | not used | SOLUBK( 5) |
| | | | | | |
| R016 | Distribution coefficients for daughter U-234 | | | | |
| R016 | Contaminated zone (cm**3/g) | 2.500E+01 | 5.000E+01 | --- | DCNUCC( 6) |
| R016 | Unsaturated zone 1 (cm**3/g) | 2.500E+01 | 5.000E+01 | --- | DCNUCU( 6,1) |
| R016 | Saturated zone (cm**3/g) | 2.500E+01 | 5.000E+01 | --- | DCNUCS( 6) |
| R016 | Leach rate (/yr) | 0.000E+00 | 0.000E+00 | 5.292E-02 | ALEACH( 6) |
| R016 | Solubility constant | 0.000E+00 | 0.000E+00 | not used | SOLUBK( 6) |
| | | | | | |
| R017 | Inhalation rate (m**3/yr) | not used | 8.400E+03 | --- | INHALR |
| R017 | Mass loading for inhalation (g/m**3) | not used | 2.000E-04 | --- | MLINH |
| R017 | Dilution length for airborne dust, inhalation (m) | 3.000E+00 | 3.000E+00 | --- | LM |
| R017 | Exposure duration | 3.000E+01 | 3.000E+01 | --- | ED |
| R017 | Shielding factor, inhalation | not used | 4.000E-01 | --- | SHF3 |
| R017 | Shielding factor, external gamma | not used | 7.000E-01 | --- | SHF1 |
| R017 | Fraction of time spent indoors | not used | 5.000E-01 | --- | FIND |
| R017 | Fraction of time spent outdoors (on site) | not used | 2.500E-01 | --- | FOTD |

| | | | | | |
|---|---|---|---|---|---|
| R017 | Shape factor, external gamma | not used | 1.000E+00 | --- | FS1 |
| R017 | Fractions of annular areas within AREA: | | | | |
| R017 | Outer annular radius (m) = √(1/π) | not used | 1.000E+00 | --- | FRACA( 1) |
| R017 | Outer annular radius (m) = √(10/π) | not used | 1.000E+00 | --- | FRACA( 2) |
| R017 | Outer annular radius (m) = √(20/π) | not used | 1.000E+00 | --- | FRACA( 3) |
| R017 | Outer annular radius (m) = √(50/π) | not used | 1.000E+00 | --- | FRACA( 4) |
| R017 | Outer annular radius (m) = √(100/π) | not used | 1.000E+00 | --- | FRACA( 5) |
| R017 | Outer annular radius (m) = √(200/π) | not used | 1.000E+00 | --- | FRACA( 6) |
| R017 | Outer annular radius (m) = √(500/π) | not used | 1.000E+00 | --- | FRACA( 7) |
| R017 | Outer annular radius (m) = √(1000/π) | not used | 1.000E+00 | --- | FRACA( 8) |
| R017 | Outer annular radius (m) = √(5000/π) | not used | 1.000E+00 | --- | FRACA( 9) |
| R017 | Outer annular radius (m) = √(1.E+04/π) | not used | 1.000E+00 | --- | FRACA(10) |
| R017 | Outer annular radius (m) = √(1.E+05/π) | not used | 0.000E+00 | --- | FRACA(11) |
| R017 | Outer annular radius (m) = √(1.E+06/π) | not used | 0.000E+00 | --- | FRACA(12) |
| | | | | | |
| R018 | Fruits, vegetables and grain consumption (kg/yr) | 2.760E+02 | 1.600E+02 | --- | DIET(1) |
| R018 | Leafy vegetable consumption (kg/yr) | 1.500E+01 | 1.400E+01 | --- | DIET(2) |
| R018 | Milk consumption (L/yr) | not used | 9.200E+01 | --- | DIET(3) |
| R018 | Meat and poultry consumption (kg/yr) | not used | 6.300E+01 | --- | DIET(4) |
| R018 | Fish consumption (kg/yr) | not used | 5.400E+00 | --- | DIET(5) |
| R018 | Other seafood consumption (kg/yr) | not used | 9.000E-01 | --- | DIET(6) |
| R018 | Soil ingestion rate (g/yr) | not used | 3.650E+01 | --- | SOIL |
| R018 | Drinking water intake (L/yr) | not used | 5.100E+02 | --- | DWI |
| R018 | Contamination fraction of drinking water | not used | 1.000E+00 | --- | FDW |
| R018 | Contamination fraction of household water | not used | 1.000E+00 | --- | FHHW |
| R018 | Contamination fraction of livestock water | not used | 1.000E+00 | --- | FLW |
| R018 | Contamination fraction of irrigation water | 1.000E+00 | 1.000E+00 | --- | FIRW |
| R018 | Contamination fraction of aquatic food | not used | 5.000E-01 | --- | FR9 |



Site-Specific Parameter Summary (continued)

| 0 Menu | Parameter | User Input | Default | Used by RESRAD (If different from user input) | Parameter Name |
|---|---|---|---|---|---|
| R018 | Contamination fraction of plant food | -1 | -1 | 0.500E+00 | FPLANT |
| R018 | Contamination fraction of meat | not used | -1 | --- | FMEAT |
| R018 | Contamination fraction of milk | not used | -1 | --- | FMILK |
| | | | | | |
| R019 | Livestock fodder intake for meat (kg/day) | not used | 6.800E+01 | --- | LFI5 |
| R019 | Livestock fodder intake for milk (kg/day) | not used | 5.500E+01 | --- | LFI6 |
| R019 | Livestock water intake for meat (L/day) | not used | 5.000E+01 | --- | LWI5 |
| R019 | Livestock water intake for milk (L/day) | not used | 1.600E+02 | --- | LWI6 |
| R019 | Livestock soil intake (kg/day) | not used | 5.000E-01 | --- | LSI |

| | | | | | |
|---|---|---|---|---|---|
| R019 | Mass loading for foliar deposition (g/m**3) | 1.000E-04 | 1.000E-04 | --- | MLFD |
| R019 | Depth of soil mixing layer (m) | 1.500E-01 | 1.500E-01 | --- | DM |
| R019 | Depth of roots (m) | 9.000E-01 | 9.000E-01 | --- | DROOT |
| R019 | Drinking water fraction from ground water | 1.000E+00 | 1.000E+00 | --- | FGWDW |
| R019 | Household water fraction from ground water | not used | 1.000E+00 | --- | FGWHH |
| R019 | Livestock water fraction from ground water | not used | 1.000E+00 | --- | FGWLW |
| R019 | Irrigation fraction from ground water | not used | 1.000E+00 | --- | FGWIR |
| | | | | | |
| C14 | C-12 concentration in water (g/cm**3) | not used | 2.000E-05 | --- | C12WTR |
| C14 | C-12 concentration in contaminated soil (g/g) | not used | 3.000E-02 | --- | C12CZ |
| C14 | Fraction of vegetation carbon from soil | not used | 2.000E-02 | --- | CSOIL |
| C14 | Fraction of vegetation carbon from air | not used | 9.800E-01 | --- | CAIR |
| C14 | C-14 evasion layer thickness in soil (m) | not used | 3.000E-01 | --- | DMC |
| C14 | C-14 evasion flux rate from soil (1/sec) | not used | 7.000E-07 | --- | EVSN |
| C14 | C-12 evasion flux rate from soil (1/sec) | not used | 1.000E-10 | --- | REVSN |
| C14 | Fraction of grain in beef cattle feed | not used | 8.000E-01 | --- | AVFG4 |
| C14 | Fraction of grain in milk cow feed | not used | 2.000E-01 | --- | AVFG5 |
| | | | | | |
| STOR | Storage times of contaminated foodstuffs (days): | | | | |
| STOR | Fruits, non-leafy vegetables, and grain | 1.400E+01 | 1.400E+01 | --- | STOR_T(1) |
| STOR | Leafy vegetables | 1.000E+00 | 1.000E+00 | --- | STOR_T(2) |
| STOR | Milk | not used | 1.000E+00 | --- | STOR_T(3) |
| STOR | Meat and poultry | not used | 2.000E+01 | --- | STOR_T(4) |
| STOR | Fish | not used | 7.000E+00 | --- | STOR_T(5) |
| STOR | Crustacea and mollusks | not used | 7.000E+00 | --- | STOR_T(6) |
| STOR | Well water | 1.000E+00 | 1.000E+00 | --- | STOR_T(7) |
| STOR | Surface water | 1.000E+00 | 1.000E+00 | --- | STOR_T(8) |
| STOR | Livestock fodder | not used | 4.500E+01 | --- | STOR_T(9) |
| | | | | | |
| R021 | Thickness of building foundation (m) | not used | 1.500E-01 | --- | FLOOR |
| R021 | Bulk density of building foundation (g/cm**3) | not used | 2.400E+00 | --- | DENSFL |
| R021 | Total porosity of the cover material | not used | 4.000E-01 | --- | TPCV |
| R021 | Total porosity of the building foundation | not used | 1.000E-01 | --- | TPFL |
| R021 | Volumetric water content of the cover material | not used | 5.000E-02 | --- | PH2OCV |
| R021 | Volumetric water content of the foundation | not used | 3.000E-02 | --- | PH2OFL |
| R021 | Diffusion coefficient for radon gas (m/sec): | | | | |
| R021 | in cover material | not used | 2.000E-06 | --- | DIFCV |
| R021 | in foundation material | not used | 3.000E-07 | --- | DIFFL |
| R021 | in contaminated zone soil | not used | 2.000E-06 | --- | DIFCZ |
| R021 | Radon vertical dimension of mixing (m) | not used | 2.000E+00 | --- | HMIX |
| R021 | Average annual wind speed (m/sec) | not used | 2.000E+00 | --- | WIND |
| R021 | Average building air exchange rate (1/hr) | not used | 5.000E-01 | --- | REXG |

Site-Specific Parameter Summary (continued)

| 0 Menu | Parameter | User Input | Default | Used by RESRAD (If different from user input) | Parameter Name |
|---|---|---|---|---|---|
| R021 | Height of the building (room) (m) | not used | 2.500E+00 | --- | HRM |
| R021 | Building interior area factor | not used | 0.000E+00 | --- | FAI |
| R021 | Building depth below ground surface (m) | not used | 1.000E+00 | --- | DMFL |
| R021 | Emanating power of Rn-222 gas | not used | 2.500E-01 | --- | EMANA(1) |
| R021 | Emanating power of Rn-220 gas | not used | 1.500E-01 | --- | EMANA(2) |

Summary of Pathway Selections

| Pathway | User Selection |
|---|---|
| 1 -- external gamma | suppressed |
| 2 -- inhalation (w/o radon) | suppressed |
| 3 -- plant ingestion | active |
| 4 -- meat ingestion | suppressed |
| 5 -- milk ingestion | suppressed |
| 6 -- aquatic foods | suppressed |
| 7 -- drinking water | suppressed |
| 8 -- soil ingestion | suppressed |
| 9 -- radon | suppressed |



| Contaminated Zone Dimensions | | Initial Soil Concentrations, pCi/g | |
|---|---|---|---|
| Area: | 10000.00 square meters | U-235 | 4.167E-07 |
| Thickness: | 0.15 meters | U-238 | 4.167E-07 |
| Cover Depth: | 0.15 meters | | |

0

Total Dose TDOSE(t), mrem/yr
Basic Radiation Dose Limit = 30 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t)

| t (years): | 0.000E+00 | 1.000E+00 | 5.000E+01 |
|---|---|---|---|
| TDOSE(t): | 1.263E-08 | 1.200E-08 | 1.095E-09 |
| M(t): | 4.210E-10 | 4.001E-10 | 3.650E-11 |

0Maximum TDOSE(t): 1.263E-08 mrem/yr at t = 0.000E+00 years



Summary : The ingestion pathway calculation for U-235 and U-238

File : RESULT1.DAT

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

0 Water Independent Pathways (Inhalation excludes radon)

| 0 Radio-Nuclide | Ground mrem/yr | Ground fract. | Inhalation mrem/yr | Inhalation fract. | Radon mrem/yr | Radon fract. | Plant mrem/yr | Plant fract. | Meat mrem/yr | Meat fract. | Milk mrem/yr | Milk fract. | Soil mrem/yr | Soil fract. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U-235 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 6.315E-09 | 0.5000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 |
| U-238 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 6.315E-09 | 0.5000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 |
| Total | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 1.263E-08 | 1.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 |

0

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

0 Water Dependent Pathways

| 0 Radio-Nuclide | Water mrem/yr | Water fract. | Fish mrem/yr | Fish fract. | Radon mrem/yr | Radon fract. | Plant mrem/yr | Plant fract. | Meat mrem/yr | Meat fract. | Milk mrem/yr | Milk fract. | All Pathways* mrem/yr | All Pathways* fract. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U-235 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 6.315E-09 | 0.5000 |
| U-238 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 6.315E-09 | 0.5000 |
| Total | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 1.263E-08 | 1.0000 |

0*Sum of all water independent and dependent pathways.



Summary : The ingestion pathway calculation for U-235 and U-238

File : RESULT1.DAT

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years

0 Water Independent Pathways (Inhalation excludes radon)

| 0 Radio-Nuclide | Ground mrem/yr | Ground fract. | Inhalation mrem/yr | Inhalation fract. | Radon mrem/yr | Radon fract. | Plant mrem/yr | Plant fract. | Meat mrem/yr | Meat fract. | Milk mrem/yr | Milk fract. | Soil mrem/yr | Soil fract. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U-235 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 6.013E-09 | 0.5010 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 |
| U-238 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 5.990E-09 | 0.4990 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 |
| Total | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 1.200E-08 | 1.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 |

0

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years

0 Water Dependent Pathways

| Radio-Nuclide | Water mrem/yr | Water fract. | Fish mrem/yr | Fish fract. | Radon mrem/yr | Radon fract. | Plant mrem/yr | Plant fract. | Meat mrem/yr | Meat fract. | Milk mrem/yr | Milk fract. | All Pathways* mrem/yr | All Pathways* fract. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U-235 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 6.013E-09 | 0.5010 |
| U-238 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 5.990E-09 | 0.4990 |
| Total | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 1.200E-08 | 1.0000 |

0*Sum of all water independent and dependent pathways.

1RESRAD, Version 5.19 T½ Limit = 0.5 year 12/08/94 17:28 Page 14
Summary : The ingestion pathway calculation for U-235 and U-238
File : RESULT1.DAT

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 5.000E+01 years

0 Water Independent Pathways (Inhalation excludes radon)

| Radio-Nuclide | Ground mrem/yr | Ground fract. | Inhalation mrem/yr | Inhalation fract. | Radon mrem/yr | Radon fract. | Plant mrem/yr | Plant fract. | Meat mrem/yr | Meat fract. | Milk mrem/yr | Milk fract. | Soil mrem/yr | Soil fract. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U-235 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 6.448E-10 | 0.5889 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 |
| U-238 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 4.502E-10 | 0.4111 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 |
| Total | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 1.095E-09 | 1.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 |

0

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 5.000E+01 years

0 Water Dependent Pathways

| Radio-Nuclide | Water mrem/yr | Water fract. | Fish mrem/yr | Fish fract. | Radon mrem/yr | Radon fract. | Plant mrem/yr | Plant fract. | Meat mrem/yr | Meat fract. | Milk mrem/yr | Milk fract. | All Pathways* mrem/yr | All Pathways* fract. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U-235 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 6.448E-10 | 0.5889 |
| U-238 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 4.502E-10 | 0.4111 |
| Total | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 0.000E+00 | 0.0000 | 1.095E-09 | 1.0000 |

0*Sum of all water independent and dependent pathways.

1RESRAD, Version 5.19 T½ Limit = 0.5 year 12/08/94 17:28 Page 15
Summary : The ingestion pathway calculation for U-235 and U-238
File : RESULT1.DAT

Dose/Source Ratios Summed Over All Pathways

Parent and Progeny Principal Radionuclide Contributions Indicated

| 0Parent (i) | Product (j) | Branch Fraction | DSR(j,t) (mrem/yr)/(pCi/g) t= 0.000E+00 | 1.000E+00 | 5.000E+01 |
|---|---|---|---|---|---|
| U-235 | U-235 | 1.000E+00 | 1.516E-02 | 1.438E-02 | 1.080E-03 |
| U-235 | Pa-231 | 1.000E+00 | 0.000E+00 | 5.466E-05 | 4.153E-04 |
| U-235 | Ac-227 | 1.000E+00 | 0.000E+00 | 3.749E-07 | 5.195E-05 |
| U-235 | ΣDSR(j) | | 1.516E-02 | 1.443E-02 | 1.548E-03 |
| 0U-238 | U-238 | 1.000E+00 | 1.516E-02 | 1.438E-02 | 1.080E-03 |
| U-238 | U-234 | 1.000E+00 | 0.000E+00 | 4.384E-08 | 1.591E-07 |
| U-238 | Th-230 | 1.000E+00 | 0.000E+00 | 1.869E-13 | 8.778E-11 |
| U-238 | Ra-226 | 1.000E+00 | 0.000E+00 | 1.907E-15 | 5.839E-11 |
| U-238 | Pb-210 | 1.000E+00 | 0.000E+00 | 3.557E-17 | 2.968E-11 |
| U-238 | ΣDSR(j) | | 1.516E-02 | 1.438E-02 | 1.081E-03 |

Branch Fraction is the cumulative factor for the j'th principal radionuclide daughter: CUMBRF(j) = BRF(1)*BRF(2)* ... BRF(j).
The DSR includes contributions from associated (half-life ≤ 0.5 yr) daughters.
0
Single Radionuclide Soil Guidelines G(i,t) in pCi/g
Basic Radiation Dose Limit = 30 mrem/yr

| 0Nuclide (i) | t= 0.000E+00 | 1.000E+00 | 5.000E+01 |
|---|---|---|---|
| U-235 | 1.979E+03 | 2.079E+03 | 1.938E+04 |
| U-238 | 1.979E+03 | 2.087E+03 | 2.776E+04 |

0

Summed Dose/Source Ratios DSR(i,t) in (mrem/yr)/(pCi/g)
and Single Radionuclide Soil Guidelines G(i,t) in pCi/g
at tmin = time of minimum single radionuclide soil guideline
and at tmax = time of maximum total dose = 0.000E+00 years

| 0Nuclide (i) | Initial pCi/g | tmin (years) | DSR(i,tmin) | G(i,tmin) (pCi/g) | DSR(i,tmax) | G(i,tmax) (pCi/g) |
|---|---|---|---|---|---|---|
| U-235 | 4.167E-07 | 0.000E+00 | 1.516E-02 | 1.979E+03 | 1.516E-02 | 1.979E+03 |
| U-238 | 4.167E-07 | 0.000E+00 | 1.516E-02 | 1.979E+03 | 1.516E-02 | 1.979E+03 |



Individual Nuclide Dose Summed Over All Pathways
Parent Nuclide and Branch Fraction Indicated
0Nuclide Parent BRF(i) DOSE(j,t), mrem/yr

| (j) | (i) | | t= 0.000E+00 | 1.000E+00 | 5.000E+01 |
|---|---|---|---|---|---|
| U-235 | U-235 | 1.000E+00 | 6.315E-09 | 5.990E-09 | 4.502E-10 |
| 0Pa-231 | U-235 | 1.000E+00 | 0.000E+00 | 2.278E-11 | 1.730E-10 |
| 0Ac-227 | U-235 | 1.000E+00 | 0.000E+00 | 1.562E-13 | 2.165E-11 |
| 0U-238 | U-238 | 1.000E+00 | 6.315E-09 | 5.990E-09 | 4.502E-10 |
| 0U-234 | U-238 | 1.000E+00 | 0.000E+00 | 1.827E-14 | 6.627E-14 |
| 0Th-230 | U-238 | 1.000E+00 | 0.000E+00 | 7.788E-20 | 3.657E-17 |
| 0Ra-226 | U-238 | 1.000E+00 | 0.000E+00 | 7.947E-22 | 2.433E-17 |
| 0Pb-210 | U-238 | 1.000E+00 | 0.000E+00 | 1.482E-23 | 1.237E-17 |

BRF(i) is the branch fraction of the parent nuclide.

Individual Nuclide Soil Concentration
Parent Nuclide and Branch Fraction Indicated

| 0Nuclide (j) | Parent (i) | BRF(i) | S(j,t), pCi/g<br>t= 0.000E+00 | 1.000E+00 | 5.000E+01 |
|---|---|---|---|---|---|
| U-235 | U-235 | 1.000E+00 | 4.167E-07 | 3.952E-07 | 2.955E-08 |
| 0Pa-231 | U-235 | 1.000E+00 | 0.000E+00 | 8.462E-12 | 6.478E-11 |
| 0Ac-227 | U-235 | 1.000E+00 | 0.000E+00 | 1.324E-13 | 2.341E-11 |
| 0U-238 | U-238 | 1.000E+00 | 4.167E-07 | 3.952E-07 | 2.955E-08 |
| 0U-234 | U-238 | 1.000E+00 | 0.000E+00 | 1.118E-12 | 4.180E-12 |
| 0Th-230 | U-238 | 1.000E+00 | 0.000E+00 | 5.122E-18 | 2.807E-15 |
| 0Ra-226 | U-238 | 1.000E+00 | 0.000E+00 | 7.426E-22 | 2.279E-17 |
| 0Pb-210 | U-238 | 1.000E+00 | 0.000E+00 | 5.755E-24 | 7.507E-18 |

BRF(i) is the branch fraction of the parent nuclide.

Table of Contents

Part IV: Concentration of Radionuclides





Concentration of radionuclides in different media
at t = 0.000E+00 years*

| Radio-Nuclide | Contaminated Zone | Surface Soil | Air Particulate | Well Water | Surface Water | Nonleafy Vegetable | Leafy Vegetable | Fodder | Meat | Milk | Fish | Crustacea |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pCi/g | pCi/g | pCi/m**3 | pCi/l | pCi/l | pCi/kg | pCi/kg | pCi/kg | pCi/kg | pCi/l | pCi/kg | pCi/kg |
| Ac-227 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Pa-231 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Pb-210 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ra-226 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Th-230 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| U-234 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| U-235 | 4.17E-07 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.74E-07 | 1.74E-07 | 1.74E-07 | 4.01E-09 | 5.73E-09 | 0.00E+00 | 0.00E+00 |
| U-238 | 4.17E-07 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.74E-07 | 1.74E-07 | 1.74E-07 | 4.01E-09 | 5.73E-09 | 0.00E+00 | 0.00E+00 |

*For all foodstuff media, concentrations are adjusted for storage time before use.
Concentrations in the media occurring in pathways that are suppressed are calculated using the current input parameters, i.e. using parameters appearing in the input screen when the pathways are active.
The Surface soil is the top layer of soil within the user specified mixing zone/depth.



Concentration of radionuclides in different media
at t = 1.000E+00 years*

| Radio-Nuclide | Contamina-ted Zone | Surface Soil | Air Par-ticulate | Well Water | Surface Water | Nonleafy Vegetable | Leafy Vegetable | Fodder | Meat | Milk | Fish | Crustacea |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pCi/g | pCi/g | pCi/m**3 | pCi/l | pCi/l | pCi/kg | pCi/kg | pCi/kg | pCi/kg | pCi/l | pCi/kg | pCi/kg |
| Ac-227 | 1.32E-13 | 8.82E-16 | 1.71E-19 | 0.00E+00 | 0.00E+00 | 7.24E-14 | 5.64E-14 | 1.11E-13 | 9.03E-15 | 1.31E-16 | 0.00E+00 | 0.00E+00 |
| Pa-231 | 8.46E-12 | 5.64E-14 | 1.10E-17 | 0.00E+00 | 0.00E+00 | 1.42E-11 | 1.41E-11 | 1.45E-11 | 5.09E-12 | 4.50E-15 | 0.00E+00 | 0.00E+00 |
| Pb-210 | 5.76E-24 | 3.84E-26 | 7.45E-30 | 0.00E+00 | 0.00E+00 | 1.55E-23 | 1.00E-23 | 2.86E-23 | 2.15E-24 | 5.01E-25 | 0.00E+00 | 0.00E+00 |
| Ra-226 | 7.43E-22 | 4.95E-24 | 9.61E-28 | 0.00E+00 | 0.00E+00 | 4.97E-21 | 4.95E-21 | 5.01E-21 | 3.43E-22 | 2.78E-22 | 0.00E+00 | 0.00E+00 |
| Th-230 | 5.12E-18 | 3.41E-20 | 6.63E-24 | 0.00E+00 | 0.00E+00 | 1.02E-18 | 8.66E-19 | 1.40E-18 | 1.80E-20 | 9.54E-22 | 0.00E+00 | 0.00E+00 |
| U-234 | 1.12E-12 | 7.45E-15 | 1.45E-18 | 0.00E+00 | 0.00E+00 | 4.84E-13 | 4.67E-13 | 5.23E-13 | 1.40E-14 | 1.96E-14 | 0.00E+00 | 0.00E+00 |
| U-235 | 3.95E-07 | 2.63E-09 | 5.12E-13 | 0.00E+00 | 0.00E+00 | 1.65E-07 | 1.65E-07 | 1.65E-07 | 4.26E-09 | 6.23E-09 | 0.00E+00 | 0.00E+00 |
| U-238 | 3.95E-07 | 2.63E-09 | 5.12E-13 | 0.00E+00 | 0.00E+00 | 1.65E-07 | 1.65E-07 | 1.65E-07 | 4.26E-09 | 6.23E-09 | 0.00E+00 | 0.00E+00 |

*For all foodstuff media, concentrations are adjusted for storage time before use.
Concentrations in the media occurring in pathways that are suppressed are calculated using the current input parameters, i.e. using parameters appearing in the input screen when the pathways are active.
The Surface soil is the top layer of soil within the user specified mixing zone/depth.


Concent : The ingestion pathway calculation for U-235 and U-238
File : RESULT1.DAT

Concentration of radionuclides in different media
at t = 5.000E+01 years*

| Radio-Nuclide | Contamina-ted Zone | Surface Soil | Air Par-ticulate | Well Water | Surface Water | Nonleafy Vegetable | Leafy Vegetable | Fodder | Meat | Milk | Fish | Crustacea |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pCi/g | pCi/g | pCi/m**3 | pCi/l | pCi/l | pCi/kg | pCi/kg | pCi/kg | pCi/kg | pCi/l | pCi/kg | pCi/kg |
| Ac-227 | 2.34E-11 | 7.80E-12 | 1.52E-15 | 0.00E+00 | 0.00E+00 | 9.92E-12 | 9.96E-12 | 1.04E-11 | 2.51E-13 | 8.94E-14 | 0.00E+00 | 0.00E+00 |
| Pa-231 | 6.48E-11 | 2.16E-11 | 4.19E-15 | 0.00E+00 | 0.00E+00 | 1.08E-10 | 1.09E-10 | 1.09E-10 | 9.09E-11 | 8.40E-14 | 0.00E+00 | 0.00E+00 |
| Pb-210 | 7.51E-18 | 2.50E-18 | 4.86E-22 | 0.00E+00 | 0.00E+00 | 1.27E-17 | 1.26E-17 | 1.31E-17 | 1.74E-18 | 5.93E-19 | 0.00E+00 | 0.00E+00 |
| Ra-226 | 2.28E-17 | 7.60E-18 | 1.48E-21 | 0.00E+00 | 0.00E+00 | 1.52E-16 | 1.52E-16 | 1.52E-16 | 1.41E-17 | 1.22E-17 | 0.00E+00 | 0.00E+00 |
| Th-230 | 2.81E-15 | 9.36E-16 | 1.82E-19 | 0.00E+00 | 0.00E+00 | 4.73E-16 | 4.92E-16 | 4.96E-16 | 5.03E-17 | 2.49E-18 | 0.00E+00 | 0.00E+00 |
| U-234 | 4.18E-12 | 1.39E-12 | 2.71E-16 | 0.00E+00 | 0.00E+00 | 1.75E-12 | 1.78E-12 | 1.78E-12 | 2.78E-13 | 4.77E-13 | 0.00E+00 | 0.00E+00 |
| U-235 | 2.96E-08 | 9.85E-09 | 1.91E-12 | 0.00E+00 | 0.00E+00 | 1.24E-08 | 1.26E-08 | 1.26E-08 | 1.97E-09 | 3.37E-09 | 0.00E+00 | 0.00E+00 |
| U-238 | 2.96E-08 | 9.85E-09 | 1.91E-12 | 0.00E+00 | 0.00E+00 | 1.24E-08 | 1.26E-08 | 1.26E-08 | 1.97E-09 | 3.37E-09 | 0.00E+00 | 0.00E+00 |

*For all foodstuff media, concentrations are adjusted for storage time before use.
Concentrations in the media occurring in pathways that are suppressed are calculated using the current input parameters, i.e. using parameters appearing in the input screen when the pathways are active.

The Surface soil is the top layer of soil within the user specified mixing zone/depth.
0C:\RES519\RESMAIN3.EXEexecution time =   22.68 seconds