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UPGRADE OF A FUSION ACCIDENT ANALYSIS CODE AND ITS APPLICATION TO A COMPARATIVE STUDY OF SEVEN FUSION REACTOR DESIGNS

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by

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ABSTRACT

Fusion energy has the potential to be a safe and environmentally favorable energy source. The importance of safety necessitates the existence of a computer code having the capability of assessing off–site impacts resulting from postulated fusion reactor accidents. The FUSCRAC3 computer code has been developed for this purpose. FUSCRAC3 calculates doses resulting from inhalation, groundshine, and cloudshine for 259 isotopes as well as doses resulting from ingestion for 145 isotopes. FUSCRAC3's data base includes the most up–to–date dose conversion factors for all four exposure pathways as well as the most current environmental transfer factors for the ingestion pathway.

This work presents a detailed description of the modifications made to the existing fusion reactor accident code, FUSCRAC2, in the development of the more advanced FUSCRAC3 computer code. Also included is a report of the validation procedures. Finally, the improved computer code was applied in two ways: 1) to provide a general data base presenting rem per curie data for each isotope, and 2) to assess the doses resulting from possible releases from the reactors evaluated in the ESECOM study. Regarding the latter application, it was found that the general trends established in the original study remained unchanged. However, it was determined that the inclusion of the ingestion pathway substantially affects the overall chronic dose. Isotopes of particular interest due to the ingestion contribution include H–3, Ca–45, Fe–55, and Po–210.

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1.0 INTRODUCTION

Fusion energy has the potential of offering many safety and environmental advantages over current energy resources. One of the key issues in assessing its environmental and safety characteristics is the analysis of off–site doses resulting from postulated fusion–reactor accidents. The appropriate tool for such an assessment is a computer code whose capabilities include modeling radioactive plume dispersion, radiation exposure pathways, biological behavior of radionuclides, and decay energies. FUSCRAC3 has these qualifications and can handle essentially all fusion–related isotopes.

FUSCRAC3 has its roots in the CRAC (Calculation of Reactor Accident Consequences) computer code. CRAC [1] was developed for the Reactor Safety Study, WASH–1400 [2]. Sandia National Laboratories made improvements on CRAC, accounting for emergency planning response as well as general risk assessment, and called their modified version CRAC2 [3].

Prior to CRAC2, FUSCRAC was created at MIT, based on CRAC, but which implemented a special model for tritium, as described in [4]. When the CRAC2 code became available, the appropriate changes were made to FUSCRAC, and FUSCRAC2 was created. No specific documentation existed for FUSCRAC2, since the model used was already specified in [4].

FUSCRAC2 contained a data base that was still largely geared toward fission. At the time this project was begun, FUSCRAC2 handled only 36 fusion–related isotopes. This posed great restrictions on the calculations of doses received as a result of the release of activated reactor materials. Hence, one of the major goals of this project was to expand the code's capabilities to 259 radioactive isotopes. Furthermore, the dose conversion factors for all four

radiation exposure pathways (inhalation, cloudshine, groundshine, and ingestion) needed to be updated to include the dose conversion factor data calculated by S. Fetter [5]. (A brief description of those files used in this thesis is found in Appendix A.) Also, an expanded set of environmental transfer factors computed by A. Rood for 144 isotopes [6] needed to be included into the chronic section of the input file of the computer code. The result of these modifications was FUSCRAC3.

Several steps were taken in order to insure the validity of the new code. These validation procedures are described in detail in Chapter 3.

It was then decided to establish a large data base consisting of rem/Ci data for each isotope for worst case conditions using the new code. This was done, and the results appear in Appendix D. The applicability of this data is very broad, ranging from optimization of structural materials to specific safety analyses for CIT (Compact Ignition Tokamak) and ITER (International Thermonuclear Experimental Reactor).

A specific application is presented in Chapter 4, Section 2. It was decided that a re–evaluation of the accident analysis study done by the Senior Committee on Environmental Safety and Economic Aspects of Magnetic Fusion Energy (ESECOM) [7] and [8] would be useful. Although it was expected that different numbers would be obtained from the FUSCRAC3 code due to differences between the code used in the ESECOM study and FUSCRAC3 (see 4.2.2), it was nonetheless desirable to determine whether the general trends found by the ESECOM study remained unchanged when FUSCRAC3 was applied.

The following chapters present the modifications made to FUSCRAC2 in order to create FUSCRAC3, the validation procedure used to ensure its accuracy,

and its application both in generating a "generic" data base and in its specific use for the ESECOM study.

2.0 FUSCRAC3 MODIFICATIONS

2.1 Data Base Modifications

FUSDOS3 is the dose conversion factor (DCF) file utilized by the computer code FUSCRAC3 to calculate doses. This data file contains information for three of the four radiation exposure pathways: namely, inhalation, cloudshine, and groundshine. The file was expanded to incorporate updated information for 259 isotopes, as computed by S. Fetter [5].

2.1.1 Inhalation Dose Conversion Factor Modifications

Fetter's data base contains internal dose conversion factors for 19 target organs and nine irradiation times for 259 radionuclides. FUSCRAC3 handles 11 of these 19 organs which are thought to be most sensitive to radiation exposure. These 11 organs are as follows: lung, bone marrow, stomach, small intestine, upper large intestine, lower large intestine, skeleton, thyroid, testes, ovaries, and whole body. Hence, information for some organs given by Fetter was not needed. In addition to dose conversion factors for specific organs, Fetter gives data for the whole body dose, the total body dose, and the effective dose equivalent. The whole body dose is defined as the dose to the entire body calculated as if all transformations were uniformly distributed throughout the body. The total body dose is the mass weighted average of the dose to each organ. The effective dose equivalent, or EDE, is the weighted average of the dose to certain organs, with the weights being determined by the probabilistic risk factors for the generation of fatal cancers associated with each organ. FUSCRAC3 uses the whole body dose conversion factors, because the whole body dose is specified in regulatory limits.

In calculating acute effects, one must consider the critical time period, which is defined as that time period over which the dose must be delivered in order for

an effect to be seen. In the CRAC2 [3] model, this critical time period is organ–dependent. For the whole body, tests, ovaries, and thyroid, the critical time period is two days. For the bone marrow, skeleton, and gastro–intestinal tract, it is seven days. And for the lungs, it is one year. It is important to note that other models may consider different time periods as being critical. For example, in FUSEDOSE [9], S. Fetter uses the whole body dose in the first seven days plus one half the dose in the next 23 days as his critical time period for determining acute effects to the whole body.

Fetter's data for the inhalation dose conversion factors was expressed as the total exposure (rem) from inhaling a given quantity of radioactivity (Ci) integrated over nine time periods after inhalation (and including the contribution from radioactive daughters). These nine time periods include four acute time periods (0–2 days, 0–7 days, 0–30 days, and 0–1 year), and five longer time periods (0–10 years, 0–20 years, 0–30 years, 0–40 years, and 0–50 years). FUSCRAC3 requires only seven time periods: 0–acute time period (organ dependent), 0–1 year, 1–10 years, 10–20 years, 20–30 years, 30–40 years, and 40–50 years. Hence, the proper time periods for each organ had to be selected from Fetter's data base, and the dose conversion factors from Fetter's data for the 0–10, 0–20, 0–30, 0–40, and 0–50 year time periods had to be subtracted successively to generate 1–10, 10–20, 20–30, 30–40, and 40–50 year time period information required for FUSCRAC3.

The above modifications were carried out in three steps using simple computer codes. The first code, STEP1, selected the data for the 11 organs of interest to FUSCRAC3, and created a temporary data file called "first." STEP2, the second computer code, selected the appropriate acute time period for each

organ as well as the 0–1, 0–10, 0–20, 0–30, 0–40, and 0–50 year information and stored the data in a temporary file called "second." Finally, the adjustment from the cumulative time period format of Fetter's data to the differential format of FUSCRAC3 was made in STEP5, which is the computer code that creates FUSDOS3. (See 2.1.4.) All of the above–mentioned codes are found in Appendix B.

2.1.2 Cloudshine Dose Conversion Factor Modifications

For cloudshine exposure, Fetter provides a dose rate conversion factor (rem/s per Ci/m^2) for 21 target organs and 259 radioactive isotopes. FUSCRAC3 requires a dose rate conversion factor (also in rem/s per Ci/m^2) for its 11 organs of interest. Hence, the STEP3 computer code was written in order to select the appropriate data from Fetter's files and then to create a temporary cloudshine data file called "third." (Again, see Appendix B.)

2.1.3 Groundshine Dose Conversion Factor Modifications

For groundshine exposure, Fetter provided a dose rate conversion factor (rem/s per Ci/m^2). FUSCRAC3 requires three numbers, one of them being a dose rate conversion factor (in rem/yr per Ci/m^2). In addition to this number, FUSCRAC3 requires two additional numbers for its early effects calculations: the integrated groundshine dose conversion factors for the first eight hours and for the first seven days. FUSCRAC3 uses these two numbers combined with a user–input time period over which the prompt groundshine exposure is to take place. This user input time period should lie between eight hours and seven days, because the code uses an interpolation routine based on the integrated groundshine at 8 hours and at 7 days. It is recommended that a time period of 7 days be chosen. That way, a conservative prompt groundshine dose is calculated. Furthermore, for

all organs except lung, this would not adversely affect the "prompt" dose period, which, for all organs except the lung, is either 2 or 7 days.

Because a decaying nuclide may form a radioactive daughter (and grand–daughter), the dose due to the decay of these species must be included in the total integrated groundshine dose conversion factors, because FUSCRAC3 does not keep track of decay products once the isotope has been deposited on the ground. Furthermore, a decaying nuclide may have more than one decay pathway associated with it. Thus, for each isotope, one must keep track of decay pathways and their associated probabilities, as well as of the buildup of radioactive daughters and granddaughters over the time period of interest, in order to correctly calculate the integrated dose conversion factors.

The first step in these groundshine calculations involved the creation of an extensive data file called hflife2, using information from [9] and [10]. For each of the 259 isotopes, hflife2 lists the isotope's halflife, number of branches (up to 2), branching percent, number of radioactive daughters in each branch (up to 2, the second daughter being equivalent to a granddaughter), and the daughter(s) halflife(s).

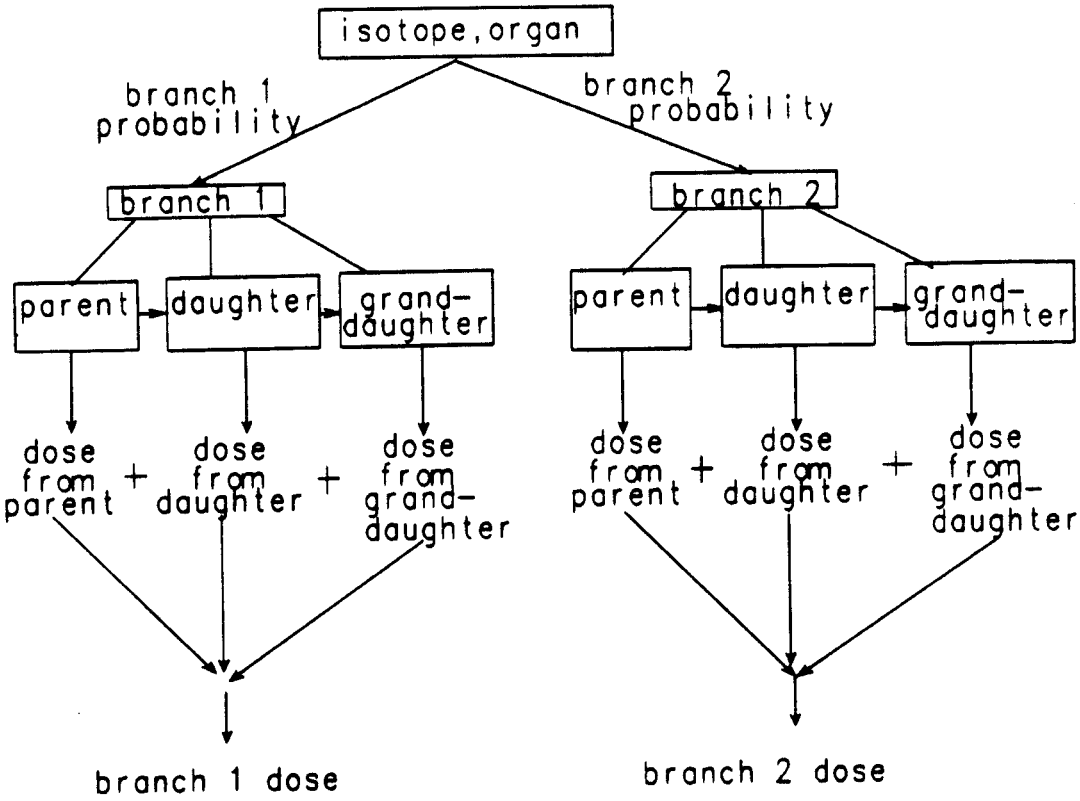
The next step was the writing of a computer code (STEP4GD) which would implement the data from hflife2 in order to calculate the integrated doses. The logic of the calculations is presented in the flowchart in Figure 2.1.

The following numerical methods were incorporated into the code to insure accuracy:

1) $\exp(-\lambda t)$ was written as $1/\exp(\lambda t)$ in order to prevent smearing, or catastrophic cancellation, as λt gets large. (λ is the decay constant, and it equals ln2/half–life)

FIGURE 2.1

LOGIC OF INTEGRATED GROUNDSHINE DCF CALCULATIONS



Total dose = branch 1 probability * branch 1 dose +
branch 2 probability * branch 2 dose

2) The expression $\frac{1}{\lambda}\left[1 - e^{-\lambda t}\right]$ can cause problems if the difference is close to 0 i.e., if λ is small, or, in other words, if the half–life is large). Even on large computers, 0 is often returned instead of 10^{-5} or 10^{-6}, etc. This can cause significant numerical errors because the difference is being divided by λ, which is a very small number. Thus, letting $x = e^{-\lambda t}$, one rewrites (1–x) in the following way:

$$(1-x) = \frac{(1-x)(1+x)}{(1+x)} = \frac{1-x^2}{(1+x)} = \frac{\left[1-x^2\right]\left[1+x^2\right]}{\left[1+x\right]\left[1+x^2\right]} \qquad (2.1)$$

$$= \frac{1-x^4}{\left[x^3+x^2+x+1\right]}$$

One could keep going, but this is far enough.

Since x is always less than one, x^4 will be even less than x. Hence, the difference between 1 and x^4 is greater than the difference between 1 and x, and should be great enough to return to a non–0 value.

It was determined that there is still a problem for one isotope, even with the improved expression from Equation (2.1). That isotope is La–138 which has a half–life of 3.47×10^{18} seconds, or approximately 110 G yr. The computer still returns a 0 value for the eight–hour time period (a calculator does also). However, the computer does return a non–zero answer for the difference expression for the seven–day time period, and because λ is so small, the dose is significant (on the order of 10^3 rem/Ci/m^2).

Because La–138 is not an important fusion isotope in general, the expression in Equation (1) was kept. If it is desired in the future, it may be possible to

get a more accurate dose for the eight-hour time period by expanding the numerical expression further:

$$\frac{\left[1-x^4\right]}{\left[x^3+x^2+x+1\right]} \cdot \frac{\left[1+x^4\right]}{\left[1+x^4\right]} = \frac{1-x^8}{x^7+x^6+x^5+x^4+x^3+x^2+x+1} \qquad (2.2)$$

Incorporation of this expression into STEP4GD would require much care, and would also generate a more lengthy and more involved code.

The doses resulting from the parent isotope, its daughter(s), (up to two corresponding to the two possible branches) and its granddaughter(s) (up to two corresponding to the two possible branches) are calculated by the code using the following equations (Note: "p" refers to parent; "D_1" and "1" refer to daughter; "D_2" and "2" refer to granddaughter):

Dose Due to Parent:

$$P = P_o e^{-\lambda_p t} \quad P_o = \frac{atoms}{m^2} \qquad (2.3a)$$

$$P\lambda_p = P_o e^{-\lambda_p t} \cdot \lambda_p = Ci/m^2 \qquad (2.3b)$$

$$G_p = \frac{rem/s}{Ci/m^2} \qquad (2.3c)$$

$$P_o \lambda_p e^{-\lambda_p t} \cdot G_p = rem/s \qquad (2.3d)$$

$$\frac{rem/s}{Ci/m^2} = G_p e^{-\lambda_p t} \qquad (2.3e)$$

Integrated dose: $$\int_o^t G_p e^{-\lambda_p t} = \boxed{\frac{G_p}{\lambda_p}\left[1 - e^{-\lambda_p t}\right] \; rem/Ci/m^2} \qquad (2.3f)$$

Dose Due to Daughter of Parent

$$\frac{dD_1}{dt} + \lambda_{D_1} D_1 = \lambda_p P = P_o \lambda_p e^{-\lambda_p t} \tag{2.4a}$$

Solution of this equation:

$$D_1 e^{\lambda_{D_1} t} = \frac{P_o \lambda_p \, e^{\left[\lambda_{D_1} - \lambda_p\right] t}}{\left[\lambda_{D_1} - \lambda_p\right]} + C \tag{2.4b}$$

Initial condition: At $t=0$, $D_1 = 0$

$$\text{Therefore, } C = \frac{-P_o \lambda_p}{\left[\lambda_{D_1} - \lambda_p\right]} \tag{2.4c}$$

$$\text{Thus, } D_1(t) = \frac{P_o \lambda_p}{\left[\lambda_{D_1} - \lambda_p\right]} e^{-\lambda p t} - \frac{P_o \lambda_p \, e^{-\lambda_{D_1} t}}{\left[\lambda_{D_1} - \lambda_p\right]} \tag{2.4d}$$

$$= \frac{P_o \lambda_p}{\left[\lambda_{D_1} - \lambda_p\right]} \left[e^{-\lambda_p t} - e^{-\lambda_{D_1} t}\right] \frac{atoms}{m^2}$$

And

$$D_1 \lambda_{D_1} = \frac{P_o \lambda_p \lambda_{D_1}}{\left[\lambda_{D_1} - \lambda_p\right]} \left[e^{-\lambda_p t} - e^{-\lambda_{D_1} t}\right] \frac{Ci_{daughter1}}{m^2} \tag{2.4e}$$

So

$$\frac{(Ci/m^2)_{daughter1}}{(Ci/m^2)_{Parent\ deposited}} = \frac{D_1 \lambda_{D_1}}{P_o \lambda_p} \tag{2.4f}$$

$$= \frac{\lambda_{D_1}}{\left[\lambda_{D_1} - \lambda_p\right]} \left[e^{-\lambda_p t} - e^{-\lambda_{D_1} t}\right]$$

And

$$\frac{G_{D_1} \cdot \lambda_{D_1}}{\left[\lambda_{D_1} - \lambda_p\right]} \left[e^{-\lambda_p t} - e^{-\lambda_{D_1} t}\right] \tag{2.4g}$$

$$= \frac{rem/s}{(Ci/m^2)_{daughter1}} \cdot \frac{(Ci/m^2)_{daughter1}}{(Ci/m^2)_{parent}} = \frac{rem/s}{(Ci/m^2)_{parent}}$$

Thus, integrating, one finds:

$$\int_0^{t=8hrs,7days} dt \frac{G_{D_1}\lambda_{D_1}}{\left[\lambda_{D_1}-\lambda_p\right]} e^{-\lambda_p t} - \frac{G_{D_1}\lambda_{D_1}}{\left[\lambda_{D_1}-\lambda_p\right]} e^{-\lambda_{D_1} t} \quad (2.4h)$$

$$= \boxed{\frac{G_{D_1}\lambda_{D_1}}{\lambda_p\left[\lambda_{D_1}-\lambda_p\right]}\left[1-e^{-\lambda_p t}\right] - \frac{G_{D_1}}{\left[\lambda_{D_1}-\lambda_p\right]}\left[1-e^{-\lambda_{D_1} t}\right]}$$

Dose due to Granddaughter of Parent:

$$\frac{dD_2}{dt} = D_1\lambda_{D_1} - D_2\lambda_{D_2} \quad (2.5a)$$

$$\frac{dD_2}{dt} + D_2\lambda_{D_2} = D_1\lambda_{D_1} = \frac{P_o\lambda_p\lambda_{D_1}}{\left[\lambda_{D_1}-\lambda_p\right]}\left[e^{-\lambda_p t} - e^{-\lambda_{D_1} t}\right] \quad (2.5b)$$

Solving:

$$D_2 e^{\lambda_{D_2} t} = \frac{P_o\lambda_p\lambda_{D_1}}{\left[\lambda_{D_1}-\lambda_p\right]}\left[\frac{e^{\left[\lambda_{D_2}-\lambda_p\right]t}}{\left[\lambda_{D_2}-\lambda_p\right]} - \frac{e^{\left[\lambda_{D_2}-\lambda_{D_1}\right]t}}{\left[\lambda_{D_2}-\lambda_{D_1}\right]}\right] + C \quad (2.5c)$$

Initial condition: At $t=0$, $D_2=0$.

$$\text{Therefore, } C = \frac{P_o\lambda_p\lambda_{D_1}}{\left[\lambda_{D_2}-\lambda_{D_1}\right]\left[\lambda_{D_2}-\lambda_p\right]} \quad (2.5d)$$

$$\text{Thus, } D_2(t) = P_o\lambda_p\left[\frac{\lambda_{D_1} e^{-\lambda_p t}}{\left[\lambda_{D_1}-\lambda_p\right]\left[\lambda_{D_2}-\lambda_p\right]}\right. \quad (2.5e)$$

$$\left. - \frac{\lambda_{D_1} e^{-\lambda_{D_1} t}}{\left[\lambda_{D_2}-\lambda_{D_1}\right]\left[\lambda_{D_1}-\lambda_p\right]} + \frac{\lambda_{D_1} e^{-\lambda_{D_2} t}}{\left[\lambda_{D_2}-\lambda_{D_1}\right]\left[\lambda_{D_2}-\lambda_p\right]}\right] \frac{atoms}{m^2}$$

Thus:

$$D_2\lambda_2 = P_o\lambda_p\lambda_2 \left[\frac{\lambda_{D_1} e^{-\lambda_p t}}{[\lambda_{D_1} - \lambda_p][\lambda_{D_2} - \lambda_p]} \right. \tag{2.5f}$$

$$\left. - \frac{\lambda_{D_1} e^{-\lambda_{D_1} t}}{[\lambda_{D_2} - \lambda_{D_1}][\lambda_{D_1} - \lambda_p]} + \frac{\lambda_{D_1} e^{-\lambda_2 t}}{[\lambda_{D_2} - \lambda_{D_1}][\lambda_{D_2} - \lambda_p]} \right]$$

So,

$$\frac{D_2\ \lambda_2}{P_o\ \lambda_p} = \frac{Ci/m^2{}_{daughter2}}{Ci/m^2{}_{parent}} \tag{2.5g}$$

$$= \lambda_2 \left[\frac{\lambda_{D_1} e^{-\lambda_p t}}{[\lambda_{D_1} - \lambda_p][\lambda_{D_2} - \lambda_p]} - \frac{\lambda_{D_1} e^{-\lambda_{D_1} t}}{[\lambda_{D_2} - \lambda_{D_1}][\lambda_{D_1} - \lambda_p]} \right.$$

$$\left. + \frac{\lambda_{D_1} e^{-\lambda_2 t}}{[\lambda_{D_2} - \lambda_{D_1}][\lambda_{D_2} - \lambda_p]} \right]$$

Finally, integrating yields:

$$G_{D_2} \cdot \left[\int_o^t \frac{\lambda_{D_2}\ \lambda_{D_1} e^{-\lambda pt}}{[\lambda_{D_1} - \lambda\ p][\lambda_{D_2} - \lambda_p]} - \frac{\lambda_{D_2}\ \lambda_{D_1} e^{-\lambda_1 t}}{[\lambda_{D_2} - \lambda\ D_1][\lambda_{D_1} - \lambda_p]} + \right.$$

$$\left. \frac{\lambda_{D_2}\lambda_{D_1} e^{-\lambda_{D_2} t}}{[\lambda_{D_2} - \lambda_{D_1}][\lambda_{D_2} - \lambda_p]}\ dt \right]$$

$$= \boxed{G_{D_2}\left[\frac{\lambda_{D_2}\lambda_{D_1}}{\lambda_p\left[\lambda_{D_1}-\lambda_p\right]\left[\lambda_{D_2}-\lambda_p\right]}\left[1-e^{-\lambda_p t}\right] - \frac{\lambda_{D_2}}{\left[\lambda_{D_2}-\lambda_{D_1}\right]\left[\lambda_{D_1}-\lambda_p\right]}\left[1-e^{-\lambda_{D_1} t}\right] + \frac{\lambda_{D_1}}{\left[\lambda_{D_2}-\lambda_{D_1}\right]\left[\lambda_{D_2}-\lambda_p\right]}\left[1-e^{-\lambda_{D_2} t}\right]\right]} \quad (2.5h)$$

See Appendix B for a listing of the STEP4GD computer code. (A list of variable names is also included in Appendix B.) The groundshine dose conversion factor information generated by STEP4GD was placed in a file called "fourth."

2.1.4 Creation of FUSDOS3

The final step in the creation of the updated dose conversion factor file for FUSCRAC3 was to combine the data from "second" (inhalation), "third" (cloudshine), and "fourth" (groundshine) data files. This was accomplished by the computer code STEP5 listed in Appendix B, which wrote to "fdtr1", which, after validation, became "fusdos3."

2.2 Input File (FUS.I) Modifications

2.2.1 Chronic Dose Section

The chronic section of the input file is broken up into six pathways. The first pathway accounts for resuspension of inhaled nuclides and concerns all 259 radionuclides. The sixth pathway involves the chronic groundshine dose and also concerns all 259 radionuclides. Pathways 2 through 5 represent the ingestion exposure pathway. Pathway 2 deals with the direct ingestion of crops; pathway 3

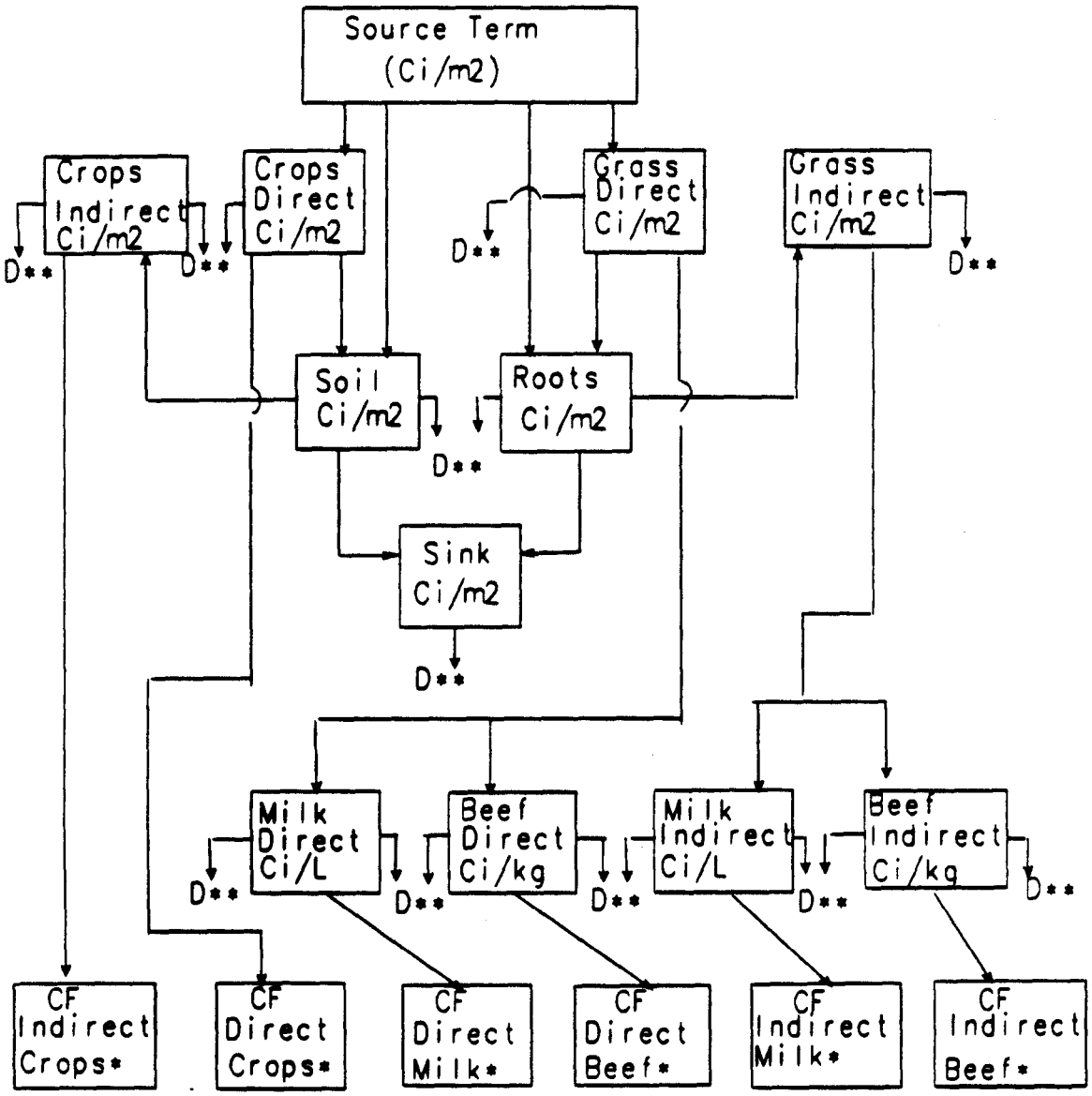
involves the direct ingestion of milk; pathway 4 concerns the direct ingestion of beef; and pathway 5 deals with two modes of indirect ingestion: indirect ingestion of crops, and the sum of indirect ingestion of beef and of milk.

In order to model the ingestion exposure pathway, one must model the transfer of radionuclides in the food chain, and hence, one must have an environmental transfer factor data base, as provided by A. Rood in [6]. These factors relate the quantity of a radionuclide ingested from crops, beef, and milk to the concentration of radioactivity on the ground after plume passage (Ci ingested/Ci deposited/m^2). Only 145 of the 259 radionuclides were considered important in the food chain model. The others were considered unimportant because they were gaseous, or they were too short–lived (half–life $\lesssim$ 10 minutes), or they were metabolically insignificant. The environmental transfer factors for the 144 of the 145 isotopes were provided by A. Rood [6]. The factors for tritium were provided by S. Piet [4]. For a flowchart representation of Rood's environmental transfer model, see Figure 2.2.

As is seen in Figure 2.2, the direct pathway considers radioactivity that directly falls onto crops and grass. Radioactivity can then be ingested by man eating contaminated crops, or by eating contaminated beef or milk obtained from cows that fed on contaminated grass. The indirect ingestion pathway considers radioactivity that first enters the soil and is then indirectly passed into crops or grass by root uptake. Rood [6] determined the direct and indirect transfer factors for two time periods: 0–1 year and 0–infinity. This latter time period actually has a cutoff point when the quantity of radioactivity that would be ingested becomes negligible because of losses to the soil sink or to radioactive decay. For the direct pathway, the transfer factors for the two time periods are the same

FIGURE 2.2

FLOWCHART OF ROOD'S ENVIRONMENTAL TRANSFER FACTOR MODEL



* CF is the conversion factor in units of: Ci ingested/Ci deposited/m2, and is equivalent in meaning to the environmental transfer factor.

** D refers to losses due to radioactive decay.

since this pathway represents crops and grass during the first growing season. For the indirect pathways, the two values are different, but are close for short–lived isotopes. The zero to infinity values were chosen for FUSCRAC3.

Tritium is different from all other isotopes. Plants immersed in air with tritiated water vapor exchange water with the air humidity quickly. As a result, the direct ingestion exposure pathway for tritium is related to the air concentration during plume passage rather than to the integrated ground concentration, and the environmental transfer factors for direct ingestion are thus inversely proportional to both the absolute humidity (g/m^3) and the deposition velocity (m/sec). For direct pathways, tritium is lost through transpiration from the plant, with a half–life of about one day. This value has been hard–wired into the code and is used in calculating an effective half life. For the indirect pathways, tritium is lost to the soil sink at a slow rate of 4%/year, which corresponds to a half–life of 6,325 days. This value was hard–wired into the FUSCRAC3 code by S. Piet [11], and it is combined with the radiological half–life for tritium to determine an effective half–life for the indirect pathways. Furthermore, indirect ingestion dominates direct ingestion for tritium because root uptake of ground water is faster and more efficient than uptake of ground contamination. This has also been accounted for. It was also discovered by S. Piet and S. Brereton that there was an error in the assumed value of the soil moisture content used to determine the indirect transfer factors for tritium [11]. The value, 105 ml/m^3, corresponded to a moisture content of only 0.0105% on a volume basis. In recent tritium release experiments, soil moisture content was measured in the range from 12–25% on a volume basis. Hence, the indirect factors were recalculated by Piet and Brereton and yielded numbers that were

three orders of magnitude lower. These numbers have been incorporated into the chronic section of the input file. For further details on the tritium model, one should consult [4] and [11].

In addition to the environmental transfer factors provided by [4] and [6], Fetter [5] provided the ingestion dose conversion factors for 19 organs, expressed in rem/Ci inhaled, integrated over nine time periods (0–2 days, 0–7 days, 0–30 days, 0–1 year, 0–10 years, 0–20 years, 0–30 years, 0–40 years, and 0–50 years). FUS.I requires six time periods, the first being the time period for integrating exposure after an isotope is ingested. It is recommended that this value be set to 0–50 years. The next five time periods are 0–10 years, 10–20 years, 20–30 years, 30–40 years, 40–50 years. The STEP6 computer code was written to extract the necessary information for the 11 isotopes from Fetter's ingestion dose conversion factor files, and also to generate differential time–period information presented by Fetter. STEP6 created a temporary file called "ingest".

Each of the six exposure pathways in the chronic section of FUS.I also asks for a time period (in days) and a radiation limit (in rem) to be used for an interdiction test. The code actually only tests for interdiction for direct ingestion and for groundshine [11]. It is recommended that a time period of 50 years (18250 days) be used which corresponds to the "0–∞" integrated environmental transfer factors [6], Furthermore, it is recommended that a high radiation limit (250 rem) be used to avoid interdiction. That way, the dose reported would be the most conservative dose incurred (i.e., without any food destruction).

The SETUP computer code combined the information from "ingest" and Rood's data files to generate the new chronic section of the input file. (See

Appendix B for listings of STEP6 and SETUP.) Tritium values were entered by hand, using [4].

2.2.2 Isotope Section

The input file was expanded to contain release information and half–lives of 259 isotopes. There is one important fact that a FUSCRAC3 user must be aware of regarding the isotope section of the input file. The isotope section of FUS.I asks for the name of the parent of the isotope if the parent is radioactive. However, some isotopes have more than one parent, and FUSCRAC3 cannot handle more than one parent. For those isotopes with more than one parent, the parent with the shorter half–life was chosen for all cases except one (the parent of Ta–179 was chosen to be W–179 instead of W–179m). Table 2.1 presents a list of those isotopes with more than one parent. If a user should decide to use parent 2 from the list instead of parent 1 for whatever reasons (structural components, for example), he just needs to go into the isotope section of the input file and replace the current parent with the new parent.

2.3 Modifications Made to the Main Code (FUSCRAC3)

2.3.1 Array Expansion

The major modification to the code itself was the enlargement of existing arrays to contain the larger amount of information. Arrays concerning isotopes were expanded from 54 to 259 while arrays concerning organs were changed from either 13 to 11 or eight to 11. However, many organ arrays set at eight were kept at eight, because that number reflects the limit on the number of effects in the acute and latent categories, which is hard–wired into the code itself.

2.3.2 Creation of FUSFET.O Output Files

Table 2.1. ISOTOPES WITH MORE THAN ONE PARENT

Isotope	Parent 1	Parent 2
sc–44	sc–44m	ti–44
y–90	y–90m	sr–90
y–91	y–91m	sr–91
nb–93m	mo–93	zr–93
nb–95	nb–95m	zr–95
nb–97	nb–97m	zr–97
nb–91	mo–91	nb–91m
tc–99	tc–99m	mo–99
te–129	sb–129	te–129m
i–129	te–129	te–129m
i–131	te–131	te–131m
sm–146	pm–146	gd–150
ta–182	ta–182m	hf–182
ta–179	w–179	w–179m
re–188	re–188m	w–188

Because FUSCRAC3 was to be used to generate rem/Ci data for all 259 isotopes for a pessimistic fusion reactor accident scenario (see Chapter 4), it was desirable to add to the code the ability to create a separate output file for each isotope consisting only of the applicable data. The information needed was as follows: 1) acute effects, latent effects from early exposure, and latent effects from chronic exposure at 1 km; 2) latent effects from early exposure and latent effects from chronic exposure at 10 km; 3) total number of cancers from early and chronic exposure (total latent/total); 4) total number of cancers calculated as if the whole body were a single organ, instead of treating it as a sum of individual organs with their organ–specific dose factors, as in 3); and 5) total whole body man rem.

Appendix C contains a partial code listing where additions were made to create the output file, FUSFET.O. The additions are indicated with an asterisk.

3.0 VALIDATION

3.1 Checking of Data Manipulation

Because much of the modifications described in Chapter 2 involved extensive data file manipulation and modification, several validation checks were made to insure that the data was processed properly.

3.1.1 Inhalation and Cloudshine

After the data file "first" was created, spot checks were performed on several isotopes against the original Fetter files [5] to verify that the dose conversion factor for a specific organ and isotope ended up where expected. After the data file "second" was generated, similar spot checks were again conducted by comparing "second" to the original Fetter files. Similar checks were made for "third," the data file for cloudshine.

3.1.2 Groundshine

Hand calculations were performed for several isotopes to confirm that the computer code, STEP4GD, was calculating the eight–hour and seven–day integrated groundshine dose conversion factors correctly. Hand calculations were performed for H–3, whose dose is due only to itself; Mg–28, whose dose results from its daughter (Al–28) and itself; Ar–42, whose dose results only from its daughter (K–42) because Ar–42 is a noble gas and hence has zero deposition velocity; and Sr–91, which has two branches, the first branch yielding two daughters (y–91m and y–91), and the second branch resulting in one daughter (y–91). Furthermore, each calculation checked a different organ: marrow for h–3; stomach for Mg–28; testes for Ar–42; and lung for Sr–91. All hand calculations agreed with the code–generated values within three significant figures.

3.1.3 Final FUSDOS3 File

Once all of the dose conversion factor data had been entered into the FUSDOS3 dose conversion file, spot checks performed on several isotopes and organs to ensure that the data was in the correct location.

3.1.4 Ingestion

Spot checks were performed on several isotopes in the ingestion section of the input file. For every isotope checked, every environmental transfer factor was checked against the original Rood files [6], and every dose conversion factor for every organ was checked against the original Fetter files [5].

3.2 Code Validation via Comparison of FUSCRAC3 with FUSCRAC2

The basic principle behind the code validation procedure was that the dose calculated by FUSCRAC3 resulting from a single isotope for a single exposure pathway should be equal to the dose calculated by FUSCRAC2 multiplied by the ratio of the new dose conversion factor to the old dose conversion factor for that isotope pathway.

For each isotope that was checked, the following procedure was implemented:

1) Six computer runs were generated as follows:
   - i) Inhalation pathway only: All groundshine and cloudshine dose conversion factors were set to zero in the FUSDOS3 file and all ingestion concentration factors were set to zero (actually, they were set to 10^{-9} to avoid division by zero errors). Inhalation–only runs were generated by FUSCRAC3 and FUSCRAC2.
   - ii) Groundshine pathway only: All inhalation and cloudshine dose conversion factors were set to zero in the FUSDOS3 file, and all

ingestion concentration factors were set to zero (10^{-9}). Groundshine–only runs were generated by FUSCRAC3 and FUSCRAC2.

iii) Complete runs: Runs were generated by FUSCRAC3 and FUSCRAC2, in which all pathways were included.

2) Acute Effects Validation

i) Inhalation: The complete runs (iii) from FUSCRAC3 and FUSCRAC2 were used, because the output file breaks down the total acute dose into the contribution from each of the acute pathways (inhalation, groundshine, and cloudshine). The ratio of the FUSCRAC3 inhalation dose to the FUSCRAC2 inhalation dose should equal:

$$\text{Ratio} = \frac{\text{new DCF for } t_{acute}}{\text{old DCF for } t_{acute}}$$

where t_{acute} is the time period for acute exposure, as discussed in 2.1.1 (t_{acute} = 2 days for thyroid, whole body, ovaries, and testes; 7 days for marrow, skeleton, stomach wall, small intestine, upper large intestine, and lower large intestine; and 1 year for the lung). Calculations were performed for H–3, Mn–54, Fe–55, Fe–59, and y–91 for every organ. All inhalation results from the codes compared well (within 2%). (Remember that FUSCRAC2 only handled 36 isotopes.)

ii) Groundshine: groundshine doses were compared in a similar manner to those of inhalation. The results compared well (within 2%) when the ratio of dose rate conversion factors (rem/yr per

Ci/m^2) was applied. The comparisons were made using the same isotopes as those listed under the inhalation section.

iii) Cloudshine: Cloudshine doses were compared in a similar manner to those of the groundshine. Comparisons using the ratio of dose rate conversion factors (rem/s per Ci/m^3) yielded excellent agreement (within 2%).

3) Latent Effects from Early Exposure Validation

i) Inhalation: The "inhalation only" computer runs were used for this comparison. It was found that the ratio of FUSCRAC3 doses to FUSCRAC2 doses equaled the ratio of the 0–50 year inhalation dose conversion factors (within 2%). The same isotopes used in the acute validation were compared (H–3, Mn–54, Fee–55, Fe–59, y–91).

Initially there was thought to be a problem with the Fe–55 latent dose to the thyroid because it was found that the ratio of doses from FUSCRAC3 and FUSCRAC2 did not equal the ratio of the 0–50 year inhalation dose conversion factors. Several checks were carried out to ensure that the data was indeed being read and manipulated correctly, and that the code itself was functioning correctly. Careful scrutiny of the code itself revealed special treatment of the thyroid in the latent effects subroutine: only the 0–1 dose conversion factor for latent effects due to initial exposure is used. The original authors of CRAC2 [3] implemented this special thyroid treatment because of the type of health effect that occurs with the thyroid . This problem was

not seen for the other isotopes because most, if not all, of the dose contributing to latent effects occurs within the first year for those isotopes. However, for Fe–55, the 1–10 year DCF is about one and a half times greater than the 0–1 year value. When the ratio of 0–1 year DCF's was used, excellent agreement (within 2%) was found.

ii) Groundshine: This validation utilized the "groundshine–only" computer runs. Again, excellent results were achieved (within 2%) when the ratio of seven–day integrated groundshine dose conversion factors was applied.

iii) Cloudshine: Cloudshine calculations were not performed because the cloudshine dose contribution to latent effects is negligible.

iv) The sum of the "inhalation–only" dose to an organ and the "groundshine–only" dose to that organ should equal the total initial dose to that organ in the complete run. (A slight difference is allowed, accounting for the exclusion of cloudshine.) It was found that the sum did indeed equal the total for every organ for every isotope listed above (within 2%).

4) Latent effects from Chronic Exposure

The latent effects from chronic exposure were checked by setting the inhalation, ground, and cloud dose conversion factors to zero for the isotope being checked. The environmental transfer factors were set to one, and the ingestion dose conversion factors for all but the pathway of interest were set to zero. The total dose would then be from that one particular ingestion pathway only. The ratio of the doses from

FUSCRAC3 and FUSCRAC2 were found to agree with the ratio of the ingestion dose conversion factors (within a few percent) for H–3, Fe–55, and Co–60. (All four ingestion pathways were checked.)

3.3 Additional Validation: Comparison of FUSCRAC3 with FUSCRAC2 for a Specific Accident Scenario

Comparison runs were conducted using the Loss of Coolant Accident (LOCA) data presented in Brereton's Ph.D. thesis [12]. The deuterium–tritium design was chosen, with the plasma beta equal to 10%.

The relevant release characteristics are presented in Table 3.1, as are the isotopes which were released.

3.3.1 Differences in the Chronic Dose Calculations

FUSCRAC2 had the capability of handling only four of the released isotopes in its chronic section: Cr–51, Mn–56, Fe–55, and Ni–57. In addition to these four isotopes, FUSCRAC3 also handles the following isotopes in its chronic section: P–32, P–33, V–48, V–49, Cr–49, Mn–52, Mn–52m, Mn–54, Fe–59, Ni–59, Ni–63, Ni–65, Mo–93, Mo–93m, Mo–99, Mo–101, W–181, W–185, and W–187. Also, FUSCRAC2 contained ingestion dose conversion factors for the whole body only, whereas FUSCRAC3 contains ingestion dose conversion factors for all eleven organs. Hence, it was expected that FUSCRAC3 would calculate a much larger contribution to the total latent effects due to ingestion.

It was instructive to compare the whole body ingestion dose conversion factors and the environmental transfer factors for each ingestion pathway for those four isotopes that FUSCRAC2 could handle. Table 3.2 presents a summary of such a comparison. It is seen that the biggest difference in environmental transfer factors occurs in the crops' direct and indirect values. In each case, the

Table 3.1. RELEASE CHARACTERISTICS OF THE LOSS OF COOLANT ACCIDENT SCENARIO [12]

Type of reactor: Deuterium–Tritium
Plasma beta: 10%
Pasquill stability class: D
Windspeed: 5 m/s
Release height: 0 m
Population density: 260 mi^2 (100 km^2)
Immediate release; 10 hour duration
Building height: 50 m; building length: 100 m

Isotopes released:

p–32*	cr–51	fe–55	mo–93m*
p–33*	cr–55*x	fe–59†	mo–99†
ti–51*x	mn–52*	ni–57	mo–101*
v–48*	mo–52m*	ni–59*	w–181*
v–49†	mn–54†	ni–63†	w–185*
v–52*	mn–56	ni–65*	w–187*
v–53*	mn–57*x	mo–91*x	
cr–49†	fe–53*x	mo–93†	

*FUSCRAC2 does not handle this isotope; FUSCRAC3 does.

†FUSCRAC2 handles this isotope for acute exposure and latent effects from initial exposure calculations, but the input file for FUSCRAC2 does not include this isotope in any of the six exposure pathways in the chronic section. This isotope is handled by FUSCRAC3 in all six chronic exposure pathways.

xFUSCRAC3 calculates the resuspension and groundshine contributions to the chronic dose for this isotope, but it does not calculate any ingestion dose for this isotope.

Table 3.2. COMPARISON OF VALUES USED IN CALCULATING THE INGESTION DOSE FOR THE FOUR ISOTOPES COMMON TO BOTH FUSCRAC3 AND FUSCRAC2 FOR THE LOCA [12]

Isotope	Whole body ingestion dose conversion factor ratio FUSCRAC3/ FUSCRAC2	CF* direct crop ratio FUSCRAC3/ FUSCRAC2	CF* direct beef ratio FUSCRAC3/ FUSCRAC2	CF* direct milk ratio FUSCRAC3/ FUSCRAC2	CF* indirect crop ratio FUSCRAC3/ FUSCRAC2	CF* indirect beef + milk ratio FUSCRAC3/ FUSCRAC2
Cr–51	0.07	9.6	1.0	1.2	9.5	0.99
Mn–56	1.0	9.6	1.0	1.0	9.6	1.0
Fe–55	1.1	9.6	1.0	1.0	9.6	1.0
Ni–57	0.6	9.6	1.0	1.0	9.6	1.0

*CF stands for concentration factor and is equivalent in meaning to the environmental transfer factor (Ci ingested/Ci deposited/m^2).

new FUSCRAC value (i.e., the value calculated by A. Rood in [6]) is approximately 9.6 times higher than the old FUSCRAC2 value. In fact, on page 14 of his report [6], A. Rood states, "FUSCRAC CF crop values were higher by a factor of about 10 when compared with the corresponding FUSECAL CF values" (where CF stands for the concentration factor and is equivalent in meaning to the environmental transfer factor). It is believed that Rood meant "lower", not "higher", in his statement, because the tables on pages 15 through 22 of his report reveal that each FUSECAL CF crop direct and indirect value (which was used in the updated FUSCRAC3) is approximately ten times greater than the corresponding FUSCRAC2 value.

Table 3.2 also shows a significant difference in the whole body ingestion dose conversion factors for Cr–51. The FUSCRAC3 value is approximately 1/14 the FUSCRAC2 value. Also, there are no other large differences in the other environmental transfer factors (i.e., beef and milk).

The comparisons in the results from FUSCRAC3 and FUSCRAC2 were made on three levels: acute effects, latent effects from early exposure, and latent effects from chronic exposure.

3.3.2 Acute Effects

The inhalation, groundshine, and cloudshine doses calculated by FUSCRAC3 were greater than those calculated by FUSCRAC2 for every organ in the acute section (i.e., lower large intestine, marrow, lung, and whole body). The most dramatic difference occurred in the inhalation dose, where FUSCRAC3 calculated a dose which was 315 times higher for the marrow, 53 times higher for the lower large intestine, 6.9 times higher for the lung, and 66 times higher for the whole body. The results are simply explained by the fact that FUSCRAC3 handles so

many more isotopes than FUSCRAC2. For those isotopes which both FUSCRAC3 and FUSCRAC2 handle, the air concentrations calculated by each code were the same. However, there were so many more isotopes in the air that FUSCRAC2 could not handle. Of particular importance because of the magnitude of their activity at the time of release were: P–32 with a half–life of 14 days and an inventory of 6100 Ci; P–33 with a 25–day half–life and an inventory of 63 Ci; W–181 with a half–life of 122 days and an inventory of 290 Ci; W–185 with a 75–day half–life and 372 Ci inventory; and W–187 with a one–day half–life and 79 Ci inventory (none of these isotopes could be handled by FUSCRAC2).

Analysis of the above inventories leads to an explanation of why the lung inhalation dose showed a relative increase from FUSCRAC2 to FUSCRAC3 which was much smaller than that exhibited by the other organs. The acute time period for the lung is one year. All of the above–mentioned isotopes have half–lives of less than one year, and hence, most of their contribution to the dose to the lung will occur in the first 30–80 days. Fe–55, on the other hand, has a half–life of 985 days, so it is a significant contributor to the dose over the entire time period. However, the inhalation dose conversion factor to the lung for Fe–55 in FUSCRAC3 is roughly one–half the inhalation dose conversion factor to the lung in FUSCRAC2. And because Fe–55 has an inventory of 680 Ci at the time of release, it is certainly one of the more important isotopes. Therefore, one can conclude that the reduction by one–half of the Fe–55 inhalation dose conversion factor to the lung counteracts all of the additional isotopes considered by FUSCRAC3 by a large amount, resulting in an overall lung inhalation dose increase on the order of only a factor of 7.

On the other hand, the bone marrow has an acute time period of seven days. Hence, the major isotopes contributing to its dose are P–32, P–33, and W–187. P–32 has as its largest dose conversion factor the marrow dose conversion factor, and since P–32 also has the largest activity at the time of release (by far), this explains why the marrow dose given by FUSCRAC3 is 315 times higher than that given by FUSCRAC2.

3.3.3 Latent Effects from Initial Exposure

FUSCRAC3 computed doses which were larger than those computed by FUSCRAC2 for all effects: 12 times higher for leukemia; 2 times higher for lung cancer; 4 times higher for gastro–intestinal cancer; 1.3 times higher for thyroid cancer; 12 times higher for bone cancer; and 3 times higher for cancer to the whole body.

The increase is due, of course, to the capability of FUSCRAC3 to handle all of the isotopes. The reason that the increase is not very large is again because of Fe–55. This time, it is the seven–day integrated groundshine dose conversion factors which are lower in FUSCRAC3 than they are in FUSCRAC2. In fact, for each organ, the groundshine dose conversion factor for Fe–55 in FUSCRAC3 is up to 100 times less than the corresponding dose conversion factor in FUSCRAC2.

3.3.4 Latent Effects from Chronic Exposure

Once again, FUSCRAC3 computed doses which were larger than those computed by FUSCRAC2 for all effects: 19 times higher for leukemia; 2 times higher for lung cancer; 11 times higher for gastro–intestinal cancer; and 8 times higher for cancer to the whole body. (Due to a printer malfunction, the dose increases were not recorded for the thyroid and bone cancers.)

This increase was expected as a result of the differences in the chronic sections described in 3.3.1. It is believed that the reason for the smaller increase in the number of lung cancers is because for P–32, P–33, W–181, W–185, and W–187, the lung ingestion dose conversion factor is so much lower than it is for all other organs considered. Therefore, the increase in the number of isotopes evaluated by FUSCRAC3 does not largely affect the lung ingestion dose.

3.3.5 Conclusion

The fact that the comparison between the doses calculated by FUSCRAC3 and those calculated by FUSCRAC2 for a specific accident scenario yielded results which were expected and which were easily explained by the inherent differences between the two codes lends further credibility to the FUSCRAC3 computer code.

4.0 APPLICATIONS

4.1 Generation of Rem/Ci Data for 259 Isotopes

It was desirable to generate dose information on a Rem/Ci basis for each of the 259 isotopes. One run was generated for each isotope using a 1 curie release of that isotope and setting the inventories of all other isotopes to 0. Hence, the doses calculated by the code yielded rem/Ci data for each isotope. The release characteristics were chosen to simulate the study done by Fetter using his FUSEDOSE code [9] for the Committee on Environmental Safety and Economic Aspects of Magnetic Fusion Energy (ESECOM) [7, 8]. It was intended that the rem/Ci data for each isotope would then be used for a comparison study between the results predicted by FUSEDOSE and those predicted by FUSCRAC3 (see 4.2).

The release characteristics are specified in Table 4.1. They represent pessimistic, worst–case assumptions. The fact that Fetter's code does not distinguish between finite duration release times (i.e., there is no plume wandering factor in FUSEDOSE) justifies the choice of a puff release (duration of release equal to 3 minutes). The worst case accident scenario modeled by ESECOM was a lithium fire lasting 10 hours, but setting the duration of release to 10 hours would yield less conservative numbers, because FUSCRAC3 does consider plume wandering, or spreading. Also, since a puff release is often chosen due to its conservative aspects, the choice allows for a more universal application of the results.

4.1.1 Spatial Mesh

The spatial mesh used is given in Table 4.2. Note that, for the ESECOM study, the regions of interest were 2 and 8, where the midpoints of these intervals were 1 km and 10 km, respectively. (Actually, these distances are often chosen, so once again, the universality of the results is preserved.)

Table 4.1. RELEASE CHARACTERISTICS

Worst case weather parameters:

Wind speed = 1 m/s
Pasquill stability class = F
Deposition velocity = 0.001 m/s for H–3
0.0 m/s for noble gases
0.01 m/s for all other isotopes
Inversion height = 250 m

Conservative release parameters
Waiting period after shutdown before release = 0.0 hours
Duration of release = 0.05 hours (3 minutes, minimum allowed by FUSCRAC3)

Conservative site assumptions

Site boundary = 1 km
Ground level release
Initial plume dimensions:
Sigma–y = 100 m
Sigma–z = 50 m
Percentage of land for crop farming = 15%
Percentage of land for milk/meat production = 15%

No mitigative actions
No evacuation
No long–term population relocation
No interdiction of food
Groundshine shielding factor during plume passage = 0.7 (on a scale of 0.0 to 1.0, 1.0 meaning no shielding; 0.7 accounts for surface roughness of the ground)
Groundshine shielding factor for chronic dose = 0.33 (accounts for the fact that people will be outdoors for approximately 8 hours in a 24–hour day)

Table 4.2. SPATIAL MESH USED IN THIS STUDY

Region	Outer Radius (m)	Average Radius (m)	Area (m^2)	Outer Radius (mi)	Average Radius (mi)	Area (mi^2)
1	9.90e+02	4.95e+02	1.92e+05	6.15e–01	3.08e–01	7.43e–02
2	1.01e+03	1.00e+03	7.85e+03	6.28e–01	6.21e–01	3.03e–03
3	1.99e+03	1.50e+03	5.77e+05	1.24e+00	9.32e–01	2.23e–01
4	2.01e+03	2.00e+03	1.57e+04	1.25e+00	1.24e+00	6.07e–03
5	4.99e+03	3.50e+03	4.10e+06	3.10e+00	2.17e+00	1.58e+00
6	5.01e+03	5.00e+03	3.93e+04	3.11e+00	3.11e+00	1.52e–02
7	9.99e+03	7.50e+03	1.47e+07	6.21e+00	4.66e+00	5.67e+00
8	1.00e+04	1.00e+04	7.96e+04	6.22e+00	6.21e+00	3.08e–02
9	2.00e+04	1.50e+04	5.89e+07	1.24e+01	9.32e+00	2.27e+01
10	3.00e+04	2.50e+04	9.82e+07	1.86e+01	1.55e+01	3.79e+01
11	4.00e+04	3.50e+04	1.37e+08	2.49e+01	2.17e+01	5.31e+01
12	5.00e+04	4.50e+04	1.77e+08	3.11e+01	2.80e+01	6.83e+01
13	6.00e+04	5.50e+04	2.16e+08	3.73e+01	3.42e+01	8.34e+01
14	7.00e+04	6.50e+04	2.55e+08	4.35e+01	4.04e+01	9.86e+01
15	8.00e+04	7.50e+04	2.95e+08	4.97e+01	4.66e+01	1.14e+02

This spatial mesh is not the most conservative choice, because the mesh close to the site is not fine enough (i.e., spatial interval one covers 0.0 to 0.99 km). A more conservative spatial mesh would have used a finer mesh. This was done by Steven Piet in some runs he did on his own. Table 4.3 shows his spatial mesh. Thus, as a check, his spatial mesh was used (and all other inputs were kept the same) for two isotopes for comparison. One Ci of Po–210 was released, and two output files were created, one using the existing spatial mesh, and one using Piet's spatial mesh. It was found that the doses in the two output files showed differences of less than 1%. A similar comparison was made for 1 Ci of H–3, and again, differences were less than 1%. It was thus concluded that the spatial mesh presented in Table 4.2 is satisfactory.

4.2.2 Isotope Section

The limitation in the isotope section of the input file as discussed in 2.2.2 was taken into account. That is, when runs were executed for the 14 parent isotopes listed in the "PARENT2" column of Table 2.1, those isotopes replaced the corresponding isotope listed in the "PARENT1" column so that daughter build–up effects for those 14 isotopes were included.

4.2.3 Data Output

As was discussed in Section 2.3.2, FUSCRAC3 had the capability of generating an output file for each of the 259 isotopes containing information of interest to this study, as follows:

1) acute effects from early exposure, reflecting the prompt dose to the whole body, bone marrow, lung, and lower large intestine at 1 km, where the prompt dose is defined as that dose delivered to a particular organ from cloudshine during plume passage, seven days of groundshine,

Table 4.3. SPATIAL MESH USED BY S. PIET

Region	Outer Radius (m)	Average Radius (m)	Area (m^2)	Outer Radius (mi)	Average Radius (mi)	Area (mi^2)
1	1.25e+02	6.25e+01	3.07e+03	7.77e–02	3.88e–02	1.19e–03
2	3.75e+02	2.50e+02	2.45e+04	2.31e–01	1.55e–01	9.48e–03
3	6.25e+02	5.00e+02	4.91e+04	3.88e–01	3.11e–01	1.90e–02
4	8.75e+02	7.50e+02	7.36e+04	5.44e–01	4.66e–01	2.84e–02
5	9.90e+02	9.33e+02	4.22e+04	6.15e–01	5.79e–01	1.63e–02
6	1.01e+03	1.00e+03	7.79e+03	6.28e–01	6.21e–01	3.01e–03
7	1.99e+03	1.50e+03	5.77e+05	1.24e+00	9.32e–01	2.23e–01
8	2.01e+03	2.00e+03	1.57e+04	1.25e+00	1.24e+00	6.07e–03
9	4.99e+03	3.50e+03	4.10e+06	3.10e+00	2.17e+00	1.58e+00
10	5.01e+03	5.00e+03	3.93e+04	3.11e+00	3.11e+00	1.52e–02
11	9.99e+03	7.50e+03	1.47e+07	6.21e+00	4.66e+00	5.67e+00
12	1.00e+04	1.00e+04	7.96e+04	6.22e+00	6.21e+00	3.08e–02
13	2.00e+04	1.50e+04	5.89e+07	1.24e+01	9.32e+00	2.27e+01
14	3.00e+04	2.50e+04	9.82e+07	1.86e+01	1.55e+01	3.79e+01
15	4.00e+04	3.50e+04	1.37e+08	2.49e+01	2.17e+01	5.31e+01
16	5.00e+04	4.50e+04	1.77e+08	3.11e+01	2.80e+01	6.83e+01
17	6.00e+04	5.50e+04	2.16e+08	3.73e+01	3.42e+01	8.34e+01
18	7.00e+04	6.50e+04	2.55e+08	4.35e+01	4.04e+01	9.86e+01
19	8.00e+04	7.50e+04	2.95e+08	4.97e+01	4.66e+01	1.14e+02

and the dose commitment over the organ–dependent acute time period (as defined in Section 2.1.1) from inhalation during plume passage (Recall from Section 2.1.1 that the critical time period is two days for the whole body, seven days for the bone marrow and lower large intestine, and one year for the lung.). Note also that the duration of plume passage equals the duration of release, which is three minutes.

2) Latent effects from initial exposure to the whole body at 1 km; the early dose, or dose from initial exposure, is that dose delivered from cloudshine during plume passage, seven days of groundshine, plus the 50–year dose commitment from radioactivity inhaled during plume passage; this differs from the prompt dose because the inhalation commitment is over a longer period of time.

3) Latent effects from chronic exposure to the whole body at 1 km, where the chronic dose was broken down into the resuspension, ingestion, and groundshine exposure pathways, and the time period of exposure was 50 years.

4) Latent effects from initial exposure to the whole body at 10 km (see 2) above).

5) Latent effects from chronic exposure to the whole body at 10 km (see 3) above).

6) Total number of cancers from both initial and chronic exposure, where the body is treated as a sum of individual organs and calculations are based on organ–specific dose factors and dose responses.

7) Total number of cancers from both initial and chronic exposure, where the body is treated as a single organ and the whole body dose conversion factors and dose response are used.

8) Total whole body man rem, due to both initial plus chronic exposure to the whole body—this is a population dose.

Numbers 6), 7) and 8) were chosen for reasons of universal applicability. They were not actually used for the specific application discussed in 4.2, but such data is often very useful in safety studies.

Cosmos files were created on the Cray machine, which ran 10 isotopes sequentially, thus creating output files containing the necessary information for each of the 10 isotopes per file. (A sample output file for Po–210 is found in Appendix C.) These files were downloaded onto an IBM PC. The files containing Fetter's FUSEDOSE results for the ESECOM study (see Section 4.2) were also downloaded from the Cray, and the data in the files was manipulated into a rem/Ci format. The information from the FUSCRAC3 runs and from the FUSEDOSE runs was then combined in several steps involving much data file manipulation, and the final result was the table listed in Appendix D.

The whole body chronic dose at 1 km and at 10 km listed in Appendix D refers to the whole body dose due to both initial exposure and chronic exposure. In other words, each of the three columns under the whole body chronic dose at 1 km reflects the addition of number 2) in the above description to the three pathways in number 3). Similarly, the columns under the whole body chronic

dose at 10 km reflect the addition of numbers 4) and 5). This definition of the chronic dose as the total dose from initial exposure plus chronic exposure is consistent with Fetter's definition of chronic dose (see Section 4.2). (Detailed definitions of each of the columns is presented in Appendix D.)

In analyzing the data in Appendix D, it was noted that for some extremely long–lived isotopes (half–lives greater than 10^{10} years), the prompt and 50–year chronic doses were relatively low, but that the man–rem (calculated over a time period from 0 to 80–plus years) was extremely high (10^5 to 10^9). This is explained by the fact that in calculating the chronic dose, FUSCRAC3 truncates at 50 years for groundshine, but does not for resuspension. Thus, it is possible for an isotope to have a low (or zero) dose contribution from ingestion and groundshine while having a high dose over the 50 to 80–plus year time period from resuspension, thus yielding a large man–rem value. Examples of these isotopes include: In–115 with zero contribution from groundshine and ingestion, and an inhalation dose (due to resuspension) on the order of 10^{-4} rem/Ci over the first 50 years, and an inhalation dose (due to resuspension) on the order to 10^6 for the 50–80+ year time period; and Sm–147, with zero groundshine and ingestion, an inhalation dose on the order of 10^{-1} over the zero to 50–year time period, and an inhalation dose on the order of 10^6 over the 50–80+ year time period. These isotopes are usually not of interest to fusion, but if one were to utilize the man–rem data for these extremely long–lived isotopes, one should have a physical understanding of the large man–rem values.

Because the data in Appendix D was generated based on generic worst–case assumptions and because the data is presented in rem/Ci format, it has many possible applications. One simply multiplies the rem/Ci number for the time

period (acute or latent) and distance (1 or 10 km) of interest by the number of curies of the isotope being released, and one obtains a conservative dose estimate.

4.2 Applications to the ESECOM Study

4.2.1 Background

The senior committee on Environmental, Safety, and Economic Aspects for Magnetic Fusion Energy (ESECOM) was organized in late 1985 in order to assess fusion energy's prospects for presenting economic, environmental, and safety characteristics that are attractive compared to those of existing energy sources. Details of the committee's procedures and findings can be found in [7] and [8]. The application of FUSCRAC3's data focused on the accident analysis section of the ESECOM study.

The ESECOM study reviewed seven fusion reference cases:

1) a deuterium–tritium tokamak reactor with a vanadium–alloy structure and a liquid lithium coolant/breeder; denoted in tables as Case 1 and/or V–Li/TOK
2) a helium–cooled variant of the case 1 tokamak, with a reduced activation ferritic steel (RAF) structure and a solid breeder Li_2O; denoted in tables as case 2 and/or RAF–He/TOK
3) a high–power density reversed field pinch (RFP) machine with RAF structure, a water–cooled copper–alloy first wall and limiter, and self–cooled lithium–lead breeder; denoted in tables as case 3 and/or RAF–PbLi/RFP
4) a high–power density RFP with a vanadium–lithium blanket; denoted as case 4 and/or V–Li/RFP

5) a low–activation tokamak with silicon carbide (SiC) structure, helium coolant, and Li_2O breeder; denoted as case 5 and/or SiC–He/TOK

6) a pool–type tokamak with vanadium/alloy structure and molten salt (FLIBE) coolant/breeder; denoted as case 6 and/or V–Flibe/TOK

7) an advanced fuel, deuterium–helium 3 fuel cycle with direct conversion of microwave synchrotron radiation; water cooled tokamak; denoted as case 7 (or case 8 by ESECOM) and/or V–D^3He/TOK

The fusion elements were categorized into five relative mobility classes based on limited experimental data and on melting points and boiling points of the elements and their oxides. The categories are presented in Table VII of [7], which is reproduced here as Table 4.4.

Given the radioactive inventories (these were calculated by the committee) and the mobility classes found in Table 4.4, the ESECOM committee then used FUSEDOSE to calculate the off–site doses resulting form a release of 100% of the radioactive inventory in each mobility category for each design. The inventories were broken up into two categories for each isotope: the first wall inventory and the inventory in the balance of the fusion core, referred to as BOFC. The BOFC represented the blanket, the manifold/reflector, the shield, and the magnets (if magnet activation was significant). All of the tritium in the blanket was counted as if it were in the first wall.

Two different doses were calculated by FUSEDOSE:

1) The "critical" dose was defined to be the dose delivered in the first seven days after exposure plus one–half the dose delivered in the eighth through the thirtieth days. Three exposure pathways were considered: cloudshine and groundshine during plume passage, and inhalation of radioactive material

Table 4.4. CATEGORIZATION OF RADIOACTIVE ISOTOPES BY MOBILITY UNDER ACCIDENT CONDITIONS

	CATEGORY DEFINITION	ELEMENTS
I	Elements gaseous or extremely volatile under thermochemical conditions of normal operation	H, C*, N, Ar
II	Elements somewhat volatile under thermo–chemical conditions of normal operation	Mg, P, Cl, Ca, Ag, Cd, Re, Hg
III	Elements somewhat to highly volatile under conditions likely to be encountered in an accident	Na, Mn, As, Sr, Mo, Cu, Ni, Tc, Tl, Po, Pb
IV	Elements somewhat volatile under conditions that may be encountered in severe accidents	K, Co, V, Pd, In, Sb, W, Te
V	Elements resistant to volatilization even under extreme accident conditions	Be, Al, Si, Sc, Ti, Fe, Y, Zr, Nb, Sn, La, Hf, Ta, Bi, Cr

*from activation of air

Temperature ranges are defined as follows:

normal operation	$T < 800K$
likely to be encountered in an accident	$800K < T < 1200K$
may be encountered in severe accidents	$1200K < T < 1800K$

It is assumed that the elements may come into contact with oxygen under accident conditions, so formation of volatile oxides has been taken into account.

Many of the categorizations are based on experimental data for V–15Cr–5Ti and HT–9 ferritic steel. Relative mobilities in different alloys will not necessarily be the same in all cases.

during plume passage, where the duration of plume passage equalled the duration of release, which was chosen to be 10 hours. The internal irradiation was assumed to continue after the plume had passed; the external irradiation was assumed to end with the end of the plume passage. A groundshine shielding factor of 0.7 accounting for surface roughness was used, which is consistent with FUSCRAC3. Furthermore, because FUSEDOSE cannot account for plume spreading (see Section 4.1), a duration of release equal to 10 hours caused no loss of conservation due to plume wandering.

2) The "chronic" dose was defined as the dose from ground contamination and resuspension over a 50–year exposure period plus the 50–year dose commitment resulting from initial exposure. A groundshine shielding factor was implemented to account for surface roughness and the individual's being indoors part of the time. This number was not documented, but a conversation with Fetter revealed that the choice of shielding factor $\simeq 0.33$ was probably made (consistent with FUSCRAC3). Fetter's "chronic" dose does *not* account for the ingestion pathway.

The committee then calculated what it called "threshold–dose release fractions", or TDRFs, for each design. A TDRF is defined as that fraction of the inventory (FIRST WALL or BOFC) that, if released under pessimistic conditions, would lead to a dose exceeding an established threshold. TDRFs were calculated for two different thresholds:

1) The "critical dose threshold" was defined as a "critical" whole body dose commitment of 200 rem delivered by passage of the plume to an individual located in the open at a distance of 1 km from the release. The choice of 200 rem corresponds to the smallest whole–body dose

with a perceptible chance of causing an early fatality in a sensitive individual.

2) The "chronic" dose threshold was defined as a 50–year whole–body dose of 25 rem from ground contamination and resuspension at a distance of 10 kilometers from the release.

The higher the TDRF, the better; a TDRF exceeding unity would mean that release of 100% of the first wall/BOFC inventory would be insufficient to produce the threshold dose. The results of the ESECOM accident analysis dose calculations are reproduced in Tables 4.5, 4.6, and 4.7 from documents [7] and [8].

It was determined that it would be instructive to re–do the dose calculations performed by ESECOM using FUSCRAC3. There are some major differences in the models used by FUSEDOSE and FUSCRAC3, and two of these differences enhance the desirability of re–examining the results: 1) FUSEDOSE contains the "old" dose conversion factors and FUSCRAC3 contains the most up–to–date numbers; hence, FUSCRAC3 should produce results reflecting the more accurate dose conversion factors; and 2) FUSEDOSE does not account for the ingestion exposure pathway; therefore, an examination of the impact of ingestion on the overall chronic dose should be made using FUSCRAC3.

The information in Appendix D was used to calculate the doses from a 100% release of the inventory of every isotope in every mobility category in every design. *No* assumptions were made about the insignificance of certain isotopes; every isotope was examined. The format of the ESECOM study described above was followed, and the results are presented in Tables 4.8 and 4.9. The organ chosen for both acute and latent effects was the whole body, since this was what was chosen by ESECOM. The inventories for all isotopes except H–3 were

TABLE 4.5: DOSE-THRESHOLD RELEASE FRACTIONS BY COMPONENT AND MOBILITY CATEGORY (ESECOM RESULTS)

Case and Mobility Categories	Inventories (MCi)		Release Fraction That Would Produce			
			200-rem Critical Dose from Plume at 1 km		25-rem 50-yr Ground Dose at 10 km	
	First Wall	BOFC	First Wall	BOFC	First Wall	BOFC
Case 1: V-Li/TOK						
I	5	0.077	52	7100	15	260
I-II	10	6.0	6.3	5.0	0.78	0.82
I-III	10	560	5.1	0.027	0.55	0.00011
I-IV	95	670	3.7	0.027	0.021	0.00010
I-V	540	2400	0.036	0.015	0.0016	0.00009
Case 2: RAF-He/TOK						
I	1.7	0.040	160	2×10^4	56	4400
I-II	7.1	16	5.7	2.3	2.3	0.86
I-III	390	450	0.036	0.032	0.00011	0.00011
I-IV	510	670	0.035	0.028	0.00011	0.00010
I-V	1200	1300	0.033	0.027	0.00011	0.00010
Case 3: RAF-PbLi/RFP						
I	0.51	0.032	510	4×10^3	180	2200
I-II	21	20	1.9	0.63	0.70	0.076
I-III	120	480	0.031	0.011	0.00086	0.00019
I-IV	220	1300	0.028	0.011	0.00013	0.00017
I-V	2500	1600	0.028	0.010	0.00013	0.00010
Case 4: V-Li/RFP						
I	5.0	0.07	51	2×10^4	18	350
I-II	6.5	6.3	17	4	2.4	0.17
I-III	6.5	940	14	0.012	1.9	0.00010
I-IV	38	1100	8.1	0.011	0.031	0.00008
I-V	180	4600	0.099	0.0084	0.0047	0.00008
Case 5: SiC-He/TOK						
I	1.7	2.1	160	220	56	77
I-II	8.2	14	86	17	55	12
I-III	8.3	15	41	3.1	8.4	0.095
I-IV	8.0	230	41	0.13	2.9	0.016
I-V	800	1500	21	0.13	2.9	0.016
Case 6: V-Flibe/TOK						
I	0.17	0.01	1600	1×10^5	560	5700
I-II	1.1	0.96	41	38	4.7	4.8
I-III	1.1	1.2	32	22	3.0	0.32
I-IV	17	16	19	14	0.90	0.060
I-V	110	220	0.20	0.21	0.0096	0.008
Case 8: V-D^3He/TOK						
I	0.50	0.006	500	8×10^5	180	2×10^5
I-II	0.81	0.038	100	960	13	120
I-III	0.82	0.66	29	20	9.5	0.053
I-IV	6.8	1.2	26	20	6.3	0.052
I-V	62	4.7	0.58	4.4	0.027	0.043

TABLE 4.6: CRITICAL-DOSE TDRFs AND DOMINANT ISOTOPES (ESECOM RESULTS)[a]

Case and mobility category	First wall		Rest of inner blanket		Manifold/reflector		Shield	
	Threshold release fraction	Dominant isotopes	Threshold release fraction	Dominant isotopes	Threshold release fraction	Dominant isotopes	Threshold release fraction	Dominant isotopes
Case 1: V-Li/TOK								
I	50	H3	2e4	H3	1e4	H3	3e5	H3
I-II	6	Ca45,Ca47	8	Ca45,Ca47	10	P32,Ca45	400	P32
I-III	5	Ca45,Na24	6	Ca45,Na24	0.03	Mn56,Mn54	0.6	Mn56
I-IV	4	Ca45,Na24	5	Ca45,Na24	0.03	Mn56,Mn54	0.6	Mn56
I-V	0.04	Sc48	0.04	Sc48	0.02	Mn56,Mn54	0.4	Mn56,Fe59
Case 2: RAF-He/TOK								
I	200	H3	2e4	H3	3e6	H3	3e4	H3
I-II	6	Re186,Re188	3	Re186,Re188	7	Re188,Re186	400	P32
I-III	0.04	Mn56,Mn54	0.03	Mn56,Mn54	0.9	Mn56,Mn54	0.7	Mn56,Mn54
I-IV	0.04	Mn56,Mn54	0.03	Mn56,Mn54	0.3	W187,Mn56	0.5	Mn56,Mn54
I-V	0.03	Mn56,Mn54	0.03	Mn56,Mn54	0.3	W187,Mn56	0.4	Mn56,Fe59
Case 3: RAF-PbLi/RFP								
I	500	H3	4e3	Ar41	NA	NA	5e6	H3
I-II	2	Re188,Re186	0.6	P32,Re188	NA	NA	400	P32
I-III	0.03	Cu64,Mn56	0.01	Po210,Mn56	NA	NA	0.7	Mn56
I-IV	0.03	Cu64,Mn56	0.01	Po210,Mn56	NA	NA	0.7	Mn56
I-V	0.03	Cu64,Mn56	0.01	Po210,Mn56	NA	NA	0.6	Mn56,Fe59
Case 4: V-Li/RFP								
I	50	H3	6e4	H3,N13	NA	NA	2e4	H3,N13
I-II	20	Ca45,Ca47	10	Ca45	NA	NA	7	P32
I-III	10	Ca45,Na24	7	Ca45,Na24	NA	NA	0.01	Mn56,Cu64
I-IV	8	Ca45,Na24	6	Ca45,Na24	NA	NA	0.01	Mn56,Cu64
I-V	0.1	Sc48	0.04	Sc48	NA	NA	0.01	Mn56,Cu64
Case 5: SiC-He/TOK								
I	200	H3	1e4	H3	1e8	C14	200	H3
I-II	90	Mg27,H3	40	P32,Mg27	9000	Mg27	30	Re188,Re186
I-III	40	Na24,Mg27	20	P32,Mn54	8000	Mg27	4	Na24,Re188
I-IV	40	Na24,Mg27	10	P32,Mn54	1000	Co60,Mg27	0.1	W187
I-V	20	Al29,Na24	9	Al29,P32	500	Si31,Co60	0.1	W187
Case 6: V-FLiBe/TOK								
I	2000	H3	1e5	H3	NA	NA	2e8	H3
I-II	40	Ca45,Ca47	40	Ca45,P32	NA	NA	3e5	P32,Ca45
I-III	30	Ca45,Na24	20	Ca45,Na24	NA	NA	500	Mn56,Mn54
I-IV	20	Ca45,Na24	8	Ca45,Na24	NA	NA	100	Co60,Mn56
I-V	0.2	Sc48	0.2	Sc48	NA	NA	100	Co60,Mn56
Case 8: DHe /TOK								
I	500	H3	1e6	H3	NA	NA	3e6	H3
I-II	100	Ca45,H3	1e3	Ca45	NA	NA	9e3	H3,P32
I-III	80	Ca45,Na24	800	Ca45,Na24	NA	NA	20	Mn54,Mn56
I-IV	60	Ca45,Na24	700	Ca45,Na24	NA	NA	20	Mn54,Mn56
I-V	0.6	Sc48	6	Sc48	NA	NA	20	Mn54,Mn56

[a]The figures shown are the fraction (or multiple) of the inventory in the stated component and mobility category that would produce a critical whole-body dose of 200 rem at 1 km from the release under pessimistic assumptions. NA means not applicable.

TABLE 4.7: CHRONIC-DOSE TDRFs AND DOMINANT ISOTOPES (ESECOM RESULTS)[a]

Case and mobility category	First wall		Rest of inner blanket		Manifold/reflector		Shield	
	Threshold release fraction	Dominant isotopes	Threshold release fraction	Dominant isotopes	Threshold release fraction	Dominant isotopes	Threshold release fraction	Dominant isotopes
Case 1: V-Li/TOK								
I	15	H3	300	H3	4e3	H3	3e4	H3
I-II	0.8	Ca45,Ca47	1	Ca45,Ca47	6	P32,	300	P32,Ca45
I-III	0.6	Ca45,Mn54	0.6	Ca45,Mn54	1e-4	Mn54	0.01	Mn54
I-IV	0.02	Cr51	0.03	Cr51	1e-4	Mn54	0.004	Co60,Mn54
I-V	0.002	Sc46,Sc48	0.002	Sc46,Sc48	1e-4	Mn54	0.003	Co60,Mn54
Case 2: RAF-He/TOK								
I	50	H3	5e3	H3	1e6	H3	4e4	C14
I-II	2	Re186, Re188	1	Re186, Re188	2	Ag110m, Re186	400	P32
I-III	1e-4	Mn54	1e-4	Mn54	0.007	Mn54	0.007	Mn54
I-IV	1e-4	Mn54	1e-4	Mn54	0.003	Co60,Mn54	0.005	Mn54,Co60
I-V	1e-4	Mn54	1e-4	Mn54	0.003	Co60,Mn54	0.004	Mn54,Co60
Case 3: RAF-PbLi/RFP								
I	200	H3	6e3	H3	NA	NA	1e6	H3
I-II	0.7	Re188, Re186	0.08	Ag108m, Ag110m	NA	NA	300	P32
I-III	9e-4	Mn54	2e-4	Mn54	NA	NA	0.02	Mn54
I-IV	1e-4	Co60,Mn54	1e-4	Mn54,Co60	NA	NA	0.02	Mn54
I-V	1e-4	Co60,Mn54	9e-5	Mn54,Bi207	NA	NA	9e-3	Mn54,Fe59
Case 4: V-Li/RFP								
I	20	H3	1e3	Ar52	NA	NA	1e3	Ar42
I-II	2	Ca45,Ca47	5	Ca45	NA	NA	0.2	Ag108m
I-III	2	Ca45,Mn54	3	Ca45,Mn54	NA	NA	1e-4	Mn54
I-IV	0.06	Cr51	0.1	Cr51	NA	NA	8e-5	Mn54,Co60
I-V	0.005	Sc46,Sc48	0.008	Sc46,Sc48	NA	NA	8e-5	Mn54,Cu60
Case 5: SiC-He/TOK								
I	50	H3	4e3	H3,Ar41	3e6	C14	80	H3
I-II	50	H3	30	P32,Ca47	4e4	P32	20	Re188,Re186
I-III	8	Mn54,Na24	0.1	Mn54,Na22	400	Mn54	1.5	Na24,Re188
I-IV	3	Co60,Mn54	0.06	Mn54,Co60	0.6	Co60	0.02	W187,W181
I-V	3	Co60,Mn54	0.06	Mn54,Co60	0.6	Co60	0.02	W187,W181
Case 6: V-FLiBe/TOK								
I	500	H3	6e3	H3,C14	NA	NA	6e7	C14,H3
I-II	5	Ca45,Ca47	5	Ca45,Ca47	NA	NA	8e3	P32
I-III	3	Ca45,Na24	0.4	Mn54	NA	NA	4	Mn54
I-IV	0.1	Cr51	0.07	Ca51,Co60	NA	NA	0.1	Co58,Mn54
I-V	0.01	Sc46,Sc48	0.009	Sc46,Sc48	NA	NA	0.1	Co48,Mn54
Case 8: DHe /TOK								
I	200	H3	3e4	H3,Ar42	NA	NA	3e3	H3,C14
I-II	15	Ca45	100	Ca45,Ca47	NA	NA	2e3	H3,P32
I-III	10	Ca45,Mn54	90	Ca45,Mn54	NA	NA	0.05	Mn54
I-IV	0.3	Cr51	4	Cr51,Ca45	NA	NA	0.05	Mn54
I-V	0.03	SC46,Sc48	0.2	Sc46,Sc48	NA	NA	0.05	Mn54

[a] The figures are the fraction (or multiple) of the inventory in the stated component and mobility category that would produce a chronic whole-body dose of 25 rem at 10 km from the release under pessimistic assumptions. NA means not applicable.

Table 4.8. DOSE-THRESHOLD RELEASE FRACTIONS BY COMPONENT AND MOBILITY CLASS

Case and Mobility Categories	Inventories (MCi)		Release Fraction that Would Produce:					
			200 rem Critical Dose from Plume at 1 km		25-rem 50-yr Chronic Dose (ground, resusp., ingestion)		25-rem 50-yr Chronic Dose (ground + resusp only; no ingestion)	
	First Wall	BOFC	First Wall	BOFC	First Wall	BOFC	First Wall	BOFC
CASE 1: V-Li/TOK								
I	5	0.068	345	1.8e+04	0.46	21.7	17.9	4.07e+03
I-II	10	6.0	7.1	9.1	0.0060	0.0058	1.18	1.25
I-III	10.5	576	3.0	0.0042	0.0060	0.0002	0.913	0.00044
I-IV	95	670	1.01	0.0041	0.0057	0.00018	0.463	0.00042
I-V	544	2490	0.0039	0.002	0.0018	0.00011	0.0034	0.00034
CASE 2: RAF-He/TOK								
I	1.7	0.051	1021	3700	1.36	27.2	53.2	3571
I-II	7.2	16	4.08	1.54	0.10	0.002	3.76	1.53
I-III	392	446	0.0047	0.0044	0.00023	0.00021	0.00046	0.00044
I-IV	460	620	0.0046	0.0039	0.00023	0.00019	0.00046	0.00041
I-V	1240	1260	0.0043	0.0036	0.00013	0.00013	0.00044	0.00040
CASE 3: RAF-PbLi/RFP								
I	0.51	0.40	3390	1053	4.55	39.1	179	1121
I-II	21.5	24.0	1.18	0.435	0.096	0.0043	1.22	0.119
I-III	1800	1290	0.008	0.0036	0.0014	9.3e-06	0.0030	0.00068
I-IV	1880	1480	0.0061	0.0031	0.00032	9.3e-06	0.00053	0.00042
I-V	2490	1860	0.0059	0.0027	0.00029	8.9e-06	0.00052	0.00029
CASE 4: V/Li/RFP								
I	5.0	0.02	339	1.8e+04	0.455	119	18.0	1.1e+04
I-II	6.5	3.7	18.2	11.1	0.0206	0.0147	3.47	0.689
I-III	6.6	941	8.00	0.0034	0.0206	0.00019	2.84	0.00040
I-IV	38	1050	0.3636	0.0032	0.0179	0.00017	0.179	0.00034
I-V	182	4540	0.01	0.0018	0.0056	0.00013	0.0096	0.00031
CASE 5: SiC-He/TOK								
I	1.8	2	1000	833	1.32	1.32	51.0	53.2
I-II	8.4	14	48.8	12.5	1.32	0.25	51.0	16.0
I-III	8.4	15	12.5	0.714	1.14	0.044	12.5	0.309
I-IV	8.4	230	12.5	0.0218	1.04	0.0094	7.58	0.025
I-V	797	1500	4.17	0.0215	1.0	0.0089	7.58	0.025
CASE 6: V-FLIBE/TOK								
I	0.18	0.002	8897	2.5e+05	13.16	78.12	510	1.67e+05
I-II	1.09	1.1	39.0	54.1	0.036	0.035	7.14	7.35
I-III	1.13	1.1	16.67	7.78	0.036	0.033	5.43	1.19
I-IV	59	164	3.85	2.30	0.033	0.028	2.06	0.25
I-V	114	223	0.022	0.023	0.011	0.0097	0.0192	0.0192
CASE 7: V-D^3 He/TOK								
I	0.5	0.036	3448	4.9e+04	4.55	64.1	178.6	2500
I-II	0.81	0.073	133	1429	0.10	0.86	22.1	192.3
I-III	0.82	0.70	54	2.25	0.10	0.093	17.2	0.23
I-IV	6.8	1.2	2.00	2.04	0.086	0.089	0.93	0.23
I-V	62	4.77	0.061	0.47	0.029	0.061	0.056	0.16

Table 4.9. DOMINANT ISOTOPES FOR CRITICAL AND CHRONIC DOSES

Case and Mobility Categories	Dominant Isotopes (≥ ~10% of the Dose)					
	Critical (2-day Whole Body Dose)		Chronic - 50 yrs: ground, resusp., *and* ingestion		Chronic - 50 yrs: ground and resusp.; *no* ingestion	
	First Wall	BOFC	First Wall	BOFC	First Wall	BOFC
CASE 1	Isotope (Ci; % of total dose)	Isotope (Ci; % of total dose)	Isotope (Ci; % of total dose)	Isotope (Ci; % of total dose)	Isotope (Ci; % of total dose)	Isotope (Ci; % of total dose)
I	H-3 (0.57; 98%)	N-13 (7.2e-03; 65%) H-3 (2.2e-03; 20%) Ar-41 (1.8e-03; 16%)	H-3 (54; 100%)	C-14 (0.94; 82%) H-3 (0.21; 18%)	H-3 (1.4; 100%)	H-3 (5.5e-03; 89%)
I-II	Ca-47 (23; 82%) Ca-45 (3.4; 12%)	Ca-47 (16; 73%) Ca-45 (3.3; 15%) P-32 (2.5; 11%)	Ca-45 (4.1e+03; 100%)	Ca-45 (4.0e+03; 93%)	Ca-45 (17; 81%) Ca-47 (2.7; 13%)	Ca-45 (17; 85%)
I-III	Na-24 (35; 53%) Ca-47 (23; 35%)	Mn-54 (4.0e+04; 83%) Mn-56 (8.3e+03; 17%)	Ca-45 (4.1e+03; 100%)	Mn-54 (1.2e+05; 92%)	Ca-45 (17; 63%) Na-24 (3.2; 12%) Mn-54 (3.0; 11%) Ca-47 (2.7; 10%)	Mn-54 (5.6e+04; 99%)
I-IV	V-48 (95; 50%) Na-24 (35; 19%) V-52 (24; 13%) Ca-47 (23; 12%)	Mn-54 (4.0e+04; 82%) Mn-56 (8.3e+03; 17%)	Ca-45 (4.1e+03; 93%)	Mn-54 (1.2e+05; 86%)	V-48 (18; 34%) Ca-45 (17; 32%) V-49 (5.4; 10%)	Mn-54 (5.6e+04; 93%)
I-V	Sc-48 (4.6e+04; 89%)	Sc-48 (4.1e+04; 41%) Mn-54 (4.0e+04; 40%)	Sc-48 (5.9e+03; 42%) Ca-45 (4.1e+03; 29%) Sc-46 (2.7e+03; 19%)	Mn-54 (1.2e+05; 55%) Fe-55 (6.0e+04; 27%)	Sc-48 (4.6e+03; 63%) Sc-46 (2.2e+03; 30%)	Mn-54 (5.6e+04; 80%)
CASE 2						
I	H-3 (0.2; 100%)	Ar-41 (0.05; 100%)	H-3 (18; 100%)	C-14 (0.91; 99%)	H-3 (0.47; 100%)	Ar-41 (6.5e-03; 93%
I-II	Re-186 (37; 76%) Re-188 (11; 22%)	Re-186 (63; 49%) Re-188 (63; 49%)	Re-186 (89; 39%) Ca-45 (82; 36%) P-32 (50; 22%)	P-32 (170; 39%) Re-186 (150; 34%) Ca-45 (77; 18%) Re-188 (40; 9%)	Re-186 (4.4; 76%) Re-188 (0.93; 14%)	Re-186 (7.5; 47%) Re-188 (5.3; 33%) Ag-110m (1.8; 11%)
I-III	Mn-54 (3.8e+04; 88%) Mn-56 (5300; 12%)	Mn-54 (4.0e+04; 87%) Mn-56 (6000; 13%)	Mn-54 (1.1e+05; 100%	Mn-54 (1.2e+05; 100%)	Mn-54 (5.4e+04; 99%)	Mn-54 (5.7e+04; 100%)
I-IV	Mn-54 (3.8e+04; 86%) Mn-56 (5300; 12%)	Mn-54 (4.0e+04; 78%) Mn-56 (6000; 12%)	Mn-54 (1.1e+05; 100%	Mn-54 (1.2e+05; 92%)	Mn-54 (5.4e+04; 98%)	Mn-54 (5.7e+04; 93%)
I-V	Mn-54 (3.8e+04; 81%) Mn-56 (5300; 11%)	Mn-54 (4.0e+04; 73%) Mn-56 (6000; 11%)	Mn-54 (1.1e+05; 55% Fe-55 (8.1e+04; 41%)	Mn-54 (1.2e+05; 60%) Fe-55 (6.5e+04; 33%)	Mn-54 (5.4e+04; 95%)	Mn-54 (5.7e+04; 91%)
CASE 3						
I	H-3 (0.59; 100%)	Ar-41 (0.18; 95%)	H-3 (5.5; 100%)	C-14 (0.62; 97%)	H-3 (0.14; 100%)	Ar-41 (0.022; 100%)
I-II	Re-188 (110; 65%) Re-186 (52; 31%)	Hg-203 (300; 65%) Re-188 (57; 12%) P-32 (44; 10%)	Re-186 (130; 52%) Re-188 (70; 27%) P-32 (23; 9%)	P-32 (5.1e+03; 88%)	Re-188 (9.3; 47%) Re-186 (6.2; 31%) Ag-110m (4.3; 22%)	Hg-203 (110; 52%) Ag-108m (47; 22%) Ag-110m (22; 11%) P-32 (22; 11%)
I-III	Cu-64 (1.8e+04; 72%) Mn-54 (4800; 19%)	Mn-54 (2.2e+04; 40%) Pb-203 (1.2e+04; 22%) Mn-56 (8800; 16%) Tl-202 (6900; 13%)	Mn-54 (1.4e+04; 78%) Cu-64 (2300; 13%)	Po-210 (2.6e+06; 96%)	Mn-54 (6.7e+03; 81%) Cu-64 (1.5e+03; 18%)	Mn-54 (3.0e+04; 81%) Po-210 (3.8e+03; 10%)

Case and Mobility Categories	Dominant Isotopes (≥ ~10% of the Dose)					
	Critical (2-day Whole Body Dose)		Chronic - 50 yrs: ground, resusp., *and* ingestion		Chronic - 50 yrs: ground and resusp.; *no* ingestion	
	First Wall	BOFC	First Wall	BOFC	First Wall	BOFC
CASE 3						
I-IV	Cu-64 (1.8e+04; 55%) Co-60 (7100; 22%) Mn-54 (4800; 15%)	Mn-54 (2.2e+04; 34%) Pb-203 (1.2e+04; 19%) Mn-56 (8800; 14%) Tl-202 (6900; 11%)	Co-60 (6.1e+04; 77%) Mn-54 (1.4e+04; 18%)	Po-210 (2.6e+06; 96%)	Co-60 (3.9e+04; 83%) Mn-54 (6.7e+03; 14%)	Mn-54 (3.0e+04; 51%) Co-60 (2.1e+04; 36%)
I-V	Cu-64 (1.8e+04; 53%) Co-60 (7100; 21%) Mn-54 (4800; 14%)	Mn-54 (2.2e+04; 30%) Pb-203 (1.2e+04; 16%) Mn-56 (8800; 12%) Tl-202 (6900; 9%)	Co-60 (6.1e+04; 76%) Mn-54 (1.4e+04; 16%)	Po-210 (2.6e+06; 93%)	Co-60 (3.9e+04; 81%) Mn-54 (6700; 14%)	Mn-54 (3.0e+04; 35%) Bi-207 (2.2e+04; 26%) Co-60 (2.1e+04; 25%)
CASE 4						
I	H-3 (0.58; 98%)	N-13 (9.1e-03; 83%)	H-3 (5.5e+01; 100%)	C-14 (0.12; 57%) 57%) H-3 (0.086; 41%)	H-3 (1.4; 100%)	H-3 (2.2e-03; 96%)
I-II	Ca-47 (8.9; 90%)	Ca-47 (6.1; 34%) P-32 (43; 24%) Re-188 (2.7; 15%)	Ca-45 (1100; 92%)	Ca-45 (1.2e+03; 71%) P-32 (500; 29%)	Ca-45 (4.8; 67%) H-3 (1.4; 19%) Ca-47 (1.0; 14%)	Ag-108m (27; 75%) Ca-45 (5.1; 14%)
I-III	Na-24 (13; 52%) Ca-47 (8.9; 36%)	Mn-54 (4.3e+04; 74%) Mn-56 (1.5e+04; 26%)	Ca-45 (1100; 92%)	Mn-54 (1.3ee+05; ~100%)	Ca-45 (4.8; 55%) H-3 (1.4; 16%) Na-24 (1.1; 13%) Ca-47 (1.0; 11%)	Mn-54 (6.1e+04; 98%)
I-IV	Cr-51 (520; 95%)	Mn-54 (4.3e+04; 69%) Mn-56 (1.5e+04; 24%)	Ca-45 (1100; 79%) Cr-51 (230; 16%)	Mn-54 (1.3e+05; 87%) Co-60 (1.5e+04; 10%)	Cr-51 (130; 93%)	Mn-54 (6.1e+04; 84%) Co-60 (9800; 13%)
I-V	Sc-48 (1.7e+04; 85%)	Mn-54 (4.3e+04; 39%) Cu-64 (2.1e+04; 19%) Sc-48 (1.7e+04; 15%) Mn-56 (1.5e+04; 14%) Fe-59 (1.1e+04; 10%)	Sc-48 (2100; 47%) Ca-45 (1100; 24%) Sc-46 (900; 20%)	Mn-54 (1.3e+05; 65% Fe-55 (3.2e+04; 16%)	Sc-48 (1700; 65%) Sc-46 (750; 29%)	Mn-54 (6.1e+04; 75%) Co-60 (9800; 12%)
CASE 5						
I	H-3 (0.2; 100%)	H-3 (0.19; 79%) Ar-41 (0.048; 20%)	H-3 (19; 100%)	H-3 (18; 95%)	H-3 (0.49; 100%)	H-3 (0.47; 100%)
I-II	Mg-27 (3.9; 95%)	Re-188 (6.4; 40%) Mg-27 (6.2; 39%) Re-186 (2.0; 13%)	H-3 (19; 100%)	P-32 (74; 74%) H-3 (18; 18%)	H-3 (0.49; 100%)	Re-188 (0.53; 34%) H-3 (0.47; 30%) P-32 (0.32; 21%) Re-186 (0.24; 15%)
I-III	Na-24 (12; 75%) Mg-27 (3.9; 24%)	Na-24 (220; 79%) Mn-54 (31; 12%)	H-3 (19; 86%)	Na-22 (350; 61%) Mn-54 (91; 16%) P-32 (74; 13%)	Na-24 (1.1; 55%) H-3 (0.49; 25%) Mn-54 (0.37; 19%)	Mn-54 (44; 54%) Na-24 (20; 25%) Na-22 (15; 19%)
I-IV	Na-24 (12; 75%) Mg-27 (3.9; 24%)	W-187 (8800; 96%)	H-3 (19; 79%)	W-187 (1200; 44%) W-185 (710; 26%) Na-22 (350; 13%)	Co-60 (1.2; 36%) Na-24 (1.1; 33%) H-3 (0.49; 15%) Mn-54 (0.37; 11%)	W-187 (830; 83%)
I-V	Al-29 (18; 38%) Al-28 (14; 29%) Na-24 (12; 25%)	W-187 (8800; 95%)	H-3 (19; 76%)	W-187 (1200; 43%) W-185 (710; 25%) Na-22 (350; 13%)	Co-60 (1.2; 36%) Na-24 (1.1; 33%) H-3 (0.49; 15%) Mn-54 (0.37; 11%)	W-187 (830; 83%)

Case and Mobility Categories	Dominant Isotopes (≥ ~10% of the Dose)					
	Critical (2-day Whole Body Dose)		Chronic - 50 yrs; ground, resusp., *and* ingestion		Chronic - 50 yrs; ground and resusp.; *no* ingestion	
	First Wall	BOFC	First Wall	BOFC	First Wall	BOFC
CASE 6						
I	H-3 (0.02; 87%)	N-13 (7.1e-04; 88%)	H-3 (1.9; 100%)	C-14 (0.32; 100%)	H-3 (4.9e-02; 100%)	C-14 (1.5e-04; 100%
I-II	Ca-47 (4.5; 88%) Ca-45 (0.58; 11%)	Ca-47 (3.0; 81%) Ca-45 (0.59; 16%)	Ca-45 (700; 100%)	Ca-45 (710; 99%)	Ca-45 (2.9; 83%) Ca-47 (0.52; 15%)	Ca-45 (3.0; 88%) Ca-47 (0.35; 10%)
I-III	Na-24 (5.9; 49%) Ca-47 (4.5; 38%)	Mn-54 (12; 46%) Na-24 (5.9; 23%) Ca-47 (3.0; 12%)	Ca-45 (700; 100%)	Ca-45 (710; 93%)	Ca-45 (2.9; 63%) Mn-54 (0.62; 13%) Na-24 (0.53; 12%) Ca-47 (0.52; 11%)	Mn-54 (17; 81%) Ca-45 (3.0; 14%)
I-IV	V-48 (33; 63%) V-52 (6.6; 13%) Na-24 (5.9; 11%)	Co-58 (24; 28%) V-52 (22; 25%) Co-60 (12; 14%) Mn-54 (12; 14%)	Ca-45 (700; 92%)	Ca-45 (710; 80%) Co-60 (100; 11%)	V-48 (6.2; 52%) Ca-45 (2.9; 24%) V-49 (1.3; 11%)	Co-60 (68; 68%) Mn-54 (17; 17%) Co-58 (12; 12%)
I-V	Sc-48 (8100; 88%)	Sc-48 (7700; 87%)	Sc-48 (1000; 42%) Ca-45 (700; 29%) Sc-46 (440; 18%)	Sc-48 (980; 38%) Ca-45 (710; 27%) Sc-46 (480; 18%)	Sc-48 (810; 62%) Sc-46 (370; 29%)	Sc-48 (770; 59%) Sc-46 (400; 31%)
CASE 7						
I	H-3 (0.058; 100%)	H-3 (4.1e-03; 100%)	H-3 (5.5; 100%)	H-3 (0.39; 100%)	H-3 (0.14; 100%)	H-3 (0.01; 100%)
I-II	Ca-47 (1.2; 80%) Ca-45 (0.2; 13%)	Ca-47 (0.11; 79%) Ca-45 (0.023; 16%)	Ca-45 (240; 96%)	Ca-45 (28; 97%)	Ca-45 (0.99; 88%) H-3 (0.14; 12%)	Ca-45 (0.12; 92%)
I-III	Na-24 (2.0; 54%) Ca-47 (1.2; 32%)	Mn-54 (81; 91%)	Ca-45 (240; 96%)	Mn-54 (240; 89%) Ca-45 (28; 10%)	Ca-45 (0.99; 62%) Na-24 (0.18; 11%)	Mn-54 (110; 100%)
I-IV	Cr-51 (97; 97%)	Mn-54 (81; 83%)	Ca-45 (240; 83%) Cr-51 (42; 15%)	Mn-54 (240; 86%) Ca-45 (28; 10%)	Cr-51 (25; 93%)	Mn-54 (110; 100%)
I-V	Sc-48 (2900; 88%)	Sc-48 (300; 70%) Mn-54 (81; 19%)	Sc-48 (360; 42%) Ca-45 (240; 28%) Sc-46 (150; 18%)	Mn-54 (240; 59%) Fe-55 (65; 16%) Sc-48 (38; 9%)	Sc-48 (290; 64%) Sc-46 (120; 27%)	Mn-54 (110; 69%) Sc-48 (30; 19%) Sc-46 (16; 10%)

obtained directly from Fetter's case files stored on the Cray. The tritium inventories were obtained directly from Table 6.2 in [8], because the ESECOM study accounted for tritium removal systems, which would decrease the amount of tritium found in the blanket. As with the ESECOM study, all of the tritium in the blanket was treated as if it were in the first wall. The only other tritium was located in the shield (and was assumed to remain in the shield). (See Table 6.2 in [8] for tritium inventories used.) Furthermore, some isotopes had large inventories but negligible contribution to the total dose (N–16 and V–52, for example). It was noticed that Fetter did not include the inventories from these isotopes in his data table (Table 4.5), since such an inclusion would be misleading. The same tactic was employed in the generation of Tables 4.8 and 4.9.

4.2.2 Differences Between FUSEDOSE and FUSCRAC3

Before any comparisons are made, it is *essential* that one be aware of the differences between the two computer codes (FUSEDOSE and FUSCRAC3); some of these differences are very significant and have large effects on the data:

1) Prompt or critical dose: (The word "prompt" is associated with FUSCRAC3, and the word "critical" is associated with FUSEDOSE; there are differences in the meanings as described below, but essentially they both refer to doses incurred during initial plume passage.)
   i) Inhalation exposure: As described in Section 2.1.1, the prompt dose due to inhalation during plume passage is calculated by FUSCRAC3 by integrating over an organ–dependent time period. For the whole body, this time period is two days. FUSEDOSE, on the other hand, considers the "critical" dose to be that dose due to inhalation during

plume passage delivered in the first seven days after the initial exposure, plus one–half the dose delivered in the next 23 days. The duration of plume passage used by FUSCRAC3 was three minutes, while that used by FUSEDOSE was 10 hours. However, the total amount of radioactivity released in both cases was the same. Thus, if an inhalation–dominated isotope has a biological half–life significantly greater than 10 hours (tritium, for example) the biological decay–pathway can be ignored, and the amount of the isotope inhaled can be assumed to be the same in both cases. Thus, the difference in the durations of plume passage should not cause significant differences in the prompt doses calculated by the two codes for inhalation–dominated isotopes. However, the vast difference in the definitions of critical time period (2 days vs. 7 days plus one–half the next 23 days) *should* result in significant differences. Thus, for inhalation–dominated isotopes such as H–3, P–32, Ca–45, and Fe–55, one would expect the "critical" dose calculated by FUSEDOSE to be higher than the "prompt" dose calculated by FUSCRAC3. This conclusion is indeed supported by the data in the table in Appendix D. The effect of this difference is particularly pronounced in the TDRFs for mobility category I, which is tritium dominated. The TDRFs calculated by FUSCRAC3 for this category exceed those calculated by FUSEDOSE by factors of 6 to 7 for each design.

ii) Groundshine exposure: As discussed in Section 2.4.3, the "prompt" groundshine exposure time is decided by the user. The conservative choice is seven days, and for reasons of consistency and conservatism,

seven days was indeed chosen. However, the FUSEDOSE "critical" groundshine dose was calculated based on an irradiation time corresponding to the duration of release, which was chosen to be 10 hours. This large difference in assumed exposure time leads one to conclude that for groundshine–dominated isotopes such as Na–24, Sc–48, Mn–54, Fe–59, Co–60, W–187, Tl–202, and Pb–203, FUSCRAC3's "prompt" dose should be significantly greater than the "critical" dose calculated by FUSEDOSE. This conclusion is also supported by the table in Appendix D. For every design, this effect was quite significant, causing FUSCRAC3's critical TDRFs for the summation over all mobility categories (I–V) to be anywhere from 5 to 10 times lower than those calculated by FUSEDOSE. The reason for this, as can be seen from Table 4.9, is that the overall largest contributors to the total critical dose for each design are groundshine–dominated isotopes (i.e., those noted above).

It was decided that such a large difference in groundshine exposure time warranted further investigation. For 10 groundshine–dominated isotopes, each of which was one of the overall largest contributors to the dose for one or more of the seven designs, FUSCRAC3 was run again using a 10–hour groundshine exposure time. It was found that for 10–hour groundshine exposure times, the total critical dose calculated by FUSCRAC3 for these isotopes was within a factor of two of the doses calculated by Fetter's FUSEDOSE. This extremely important effect is investigated in detail in Appendix E (please see). An important secondary effect which also contributes to this trend is

the difference in the way the codes calculate finite plume correction factors. FUSCRAC3 utilizes the same finite–plume correction factors that are found in the original WASH–1400 CRAC code. These factors were calculated for cloudshine only; nothing was done for groundshine (i.e., a semi–infinite plume is assumed for groundshine). Furthermore, the correction factors for cloudshine are calculated as a function of the plume dimensions only; the energy of the photon was assumed to be 0.7 MeV (typical value for fission isotopes). But a high energy photon (1–3 MeV) has a much longer mean free path in the plume than a low–energy photon (0–1 MeV). Hence, for a high–energy photon, the plume appears smaller than it does to a low–energy photon. Thus, calculations of the plume size based on a photon energy of 0.7 MeV lead to overly conservative estimates of the plume volume. The CRAC code does do a linear extrapolation for higher energy photons, but the actual dependence of the finite plume corrections upon photon energy is not linear. Furthermore, the CRAC model does not include the effect of the Pasquill stability class upon the plume size. For a class F stability, the plume size is significantly smaller than semi–infinite. For cloudshine, then, FUSCRAC3 integrates the concentration of radioactivity over a volume that is much larger than it should be. Furthermore, because FUSCRAC3 includes no corrections for groundshine, it integrates over a semi–infinite plume, which for high energy photons and class F stability is grossly over–conservative. Fetter, on the other hand, wrote a separate computer code which calculated finite plume correction factors for both cloudshine and

groundshine as a function of plume dimensions, stability class, and photon energy. As a result, the volume integrated over by FUSEDOSE is significantly smaller (but more realistic) than that integrated over by FUSCRAC3 for both cloudshine and groundshine. This difference contributes to the fact that the critical doses calculated by FUSCRAC3 are higher than those calculated by FUSEDOSE for groundshine–dominated isotopes.

iii) Cloudshine exposure: Both FUSCRAC3 and FUSEDOSE assume an irradiation time equal to the duration of release. But, for reasons explained in 4.1, the duration of release for FUSEDOSE calculations was 10 hours, while for FUSCRAC3, it was three minutes. This difference would lead to higher cloudshine doses calculated by FUSEDOSE. This effect is at least partially counteracted, however, by the difference in finite–plume correction factors described above which predicts FUSCRAC3's cloudshine doses to be larger than those of FUSEDOSE. In fact, there is some evidence that this finite–plume correction factor difference causes FUSCRAC3 to yield higher critical doses for cloudshine–dominated isotopes. A look at Al–28 and Al–29, for example, reveals a higher rem/Ci value calculated by FUSCRAC3 than that calculated by Fetter's FUSEDOSE (see Appendix D).

2) Chronic dose: FUSEDOSE does not account for ingestion, while FUSCRAC3 does include ingestion for 145 isotopes. Thus, one would expect a much larger chronic dose calculated by FUSCRAC3 than that calculated by FUSEDOSE for ingestion–dominated isotopes such as H–3, Ca–45, P–32, Fe–55, W–185, and Po–210. (This is confirmed by the data in the table in

Appendix D.) In fact, Table 4.9 indicates a dramatic difference in doses calculated by FUSCRAC3 when ingestion is included versus when it is not included. The differences for ingestion–dominated isotopes range from a factor of 40 for H–3 up to a factor of 700 for Po–210. It can be seen in Tables 4.8 and 4.9 that the FUSCRAC3 chronic doses (including ingestion) for mobility categories II through IV are higher (up to a factor of 5) than the chronic doses (no ingestion) calculated by FUSEDOSE. (The FUSCRAC3 TDRFs are therefore lower.) When group V is added in, the TDRFs calculated by the two codes are very similar due to the fact that, at the I–V level, much of the dose is a result of isotopes whose chronic dose commitment from groundshine is higher than that from ingestion (i.e., Co–60), and in those cases, the rem/Ci values calculated by the two codes are similar (i.e., within factors of 2 to 4; see below).

3) Dose conversion factors: The numbers calculated by FUSEDOSE do not reflect the most up–to–date dose conversion factors used by FUSCRAC3. Thus, factors of 2 to 4 between the chronic doses calculated by FUSEDOSE and those chronic doses excluding ingestion, calculated by FUSCRAC3 are explicable by the differences between the old and new dose conversion factors.

4) The Ar–42 discrepancy: An unusual situation was discovered for Ar–42: Fetter's chronic rem/Ci value is 4 orders of magnitude higher than that of FUSCRAC3's (see Appendix D). Ar–42 has an inhalation dose conversion factor equal to zero. Furthermore, because it is a noble gas, its deposition velocity is 0.0 and thus its groundshine dose is zero. It does have a non–zero cloudshine dose conversion factor, but the majority of its dose

comes from its daughter, K–42, which does deposit on the ground at a rate of 0.01 m/s. K–42 has a non–zero groundshine dose conversion factor and a cloudshine dose conversion factor, which is much larger than that of Ar–42. Both FUSEDOSE and FUSCRAC3 calculate in–cloud decay of parent to daughter, so the problem is not one of FUSCRAC3's neglecting the daughter dose. FUSCRAC3's K–42 rem/Ci chronic value is 1.52×10^{-6} and Fetter's is 1.47×10^{-6} (excellent agreement). FUSCRAC3's rem/Ci value for Ar–42 is roughly five times lower than that of K–42, whereas Fetter's rem/Ci value for Ar–42 is roughly 2,000 times higher than that of K–42. The discrepancy can be partially explained by the large difference in cloudshine exposure times. (FUSCRAC3's three–minute puff release results in an exposure time 200 times less than that of ESECOM's 10–hour release. The amount of time that Ar–42 is in the air is important, because the build–up of K–42 depends on the in–cloud decay of Ar–42. Now, Ar–42 has a half–life over 20,000 times greater than that of K–42. (Ar–42's is 33 years; K–42's is 12.4 hours.) Therefore,

$$\lambda(\text{K–42}) - \lambda(\text{Ar–42}) \simeq \lambda(\text{K–42}) \tag{4.2a}$$

Thus, Equation (2.4e) reduces to:

$$D_1 \lambda_{D_1} = P_o \lambda_p \left[e^{-\lambda_p t} - e^{-\lambda_{D_1} t} \right] \tag{4.2b}$$

$$= P_o \lambda_p \text{ [number less than 1]}$$

Since $\lambda_p = \lambda(\text{Ar–42}) = 2.4 \times 10^{-6}$ hr^{-1}, the activity of K–42 is apt to be small. Thus, while the difference in cloudshine exposure time may account for a small part of the discrepancy, it certainly does not

explain a difference of 4 orders of magnitude. It is possible that Fetter's number reflects an erroneous entry.

4.2.3 Implication of Results for ESECOM Cases

The best way to examine the results is by comparing the data in Tables 4.5, 4.6, and 4.7 (which were generated by FUSEDOSE) with the data in Tables 4.8 and 4.9 from FUSCRAC3. The numbers are different, but all of the differences can be understood through the detailed explanations found in Section 4.2.2. The important point to be made is that, although the numbers themselves are different, the general trends for the TDRFs within each design and between designs are the same for both sets of data.

For example, for critical doses, Case 5's first wall maintains TDRFs above unity for all five mobility classes, and Cases 6 and 7 (or 6 and 8 in the ESECOM study) maintain first wall TDRFs above unity for the first four mobility categories. Cases 6 and 7 also maintain critical–dose TDRFs above unity for the balance of the fusion core for the first four mobility categories. Fetter's chronic dose TDRFs tend to lie between the TDRFs calculated for the FUSCRAC3 chronic dose with ingestion and without ingestion. In general, for both FUSEDOSE and FUSCRAC3, the chronic dose TDRFs are significantly lower than the critical–dose TDRFs, suggesting that efforts will have to be made to lower the chronic dose.

The effect of the ingestion pathway on the chronic dose is a very prominent one. It is seen from Table 4.9 that the large inventory of Po–210 from the Li–Pb coolant breeder in Case 3 contributes an extremely large chronic dose (in excess of 10^6 rem) due to its high ingestion dose conversion factor. Fe–55, which is found in large amounts in Cases 1, 2, 3, 4, and 7, also contributes a significant

dose to the total chronic dose when ingestion is accounted for. And Ca–45 plays an important role in Cases 1, 4, 6, and 7 due to its large ingestion dose conversion factor. In Case 5, W–185 becomes a significant isotope when ingestion is included, as does Na–22.

Thus, it would seem wise to reconsider the choice of LiPb (source of Po–210) and also perhaps of Li_2O (source of Na–22) as coolant/breeder materials. Furthermore, it would also be wise to consider structural materials of lower iron content, lower tungsten content, and lower titanium content (the source of Ca–45) in order to reduce the effect of ingestion upon the chronic dose, thereby reducing the chronic dose itself.

5.0 CONCLUSIONS

The modifications made to FUSCRAC2 in creating FUSCRAC3 were described in detail in Chapter 2. The focus of these modifications centered upon the expansion of the code's capabilities to include 259 radionuclides, as well as the inclusion of the most up–to–date dose conversion factors and environmental transfer factors. Several validation procedures were implemented, including the application of both FUSCRAC2 and FUSCRAC3 to a specific example for the purpose of direct comparison.

Finally, the new code was used to generate a comprehensive data base which includes rem/Ci data for all 259 isotopes based on pessimistic release characteristics. FUSCRAC3 was also applied to the ESECOM study for the purpose of qualitative comparison with the existing ESECOM accident analysis. It was determined that the general trends exhibited in the original study remained unchanged when FUSCRAC3 was applied. Furthermore, it was discovered that the inclusion of the ingestion pathway in the calculation of the chronic doses significantly increases the dose for certain isotopes, particularly H–3, Na–22, P–32, Ca–45, Fe–55, W–185, Re–186, and Po–210. Due to its large inventory in the majority of cases (all except 5 and 6), the most important of the above isotopes was Fe–55. However, when the ingestion pathway was excluded, Fe–55 did not even remain in the top 10% in terms of its contribution to the total chronic dose for any of the fusion designs. Hence, the use of low–iron–content materials appears to be particularly important. In addition, the extraordinarily high chronic dose from Po–210 due to ingestion strongly suggests the need to steer away from Li–Pb coolant/breeder designs.

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Appendix A

BRIEF DESCRIPTION OF FETTER'S DOSE CONVERSION FACTOR FILES

File Name	Title/Description	Organs Involved
edrcf.1**	External Dose–rate Conversion Factors for Exposure to a Contaminated Cloud (rem/sec)(Ci/m^3)	Skin, thymus, lower large intestine*, small intestine*, stomach*, upper large intestine*, kidneys, liver, lungs*, muscle, ovaries*
edrcf.2**	External Dose–rate Conversion Factors for Exposure to a Contaminated Cloud (rem/sec)(Ci/m^3)	pancreas, red marrow*, skeleton*, spleen, testes*, thyroid*, bladder, uterus, yellow marrow, total body*, EDE+
edrcf.3**	External Dose–rate Conversion Factors Exposure to a Contaminated Plane (rem/sec)(Ci/m^2)	skin, thymus, lower large intestine*, small intestine*, stomach*, upper large intestine*, kidneys, liver, lungs*, muscle, ovaries*
edrcf.4**	External Dose–rate Conversion Factors for Exposure to a Contaminated Plane (rem/sec)(Ci/m^2)	pancreas, red marrow*, skeleton*, spleen, testes*, thyroid*, bladder, uterus, yellow marrow, total body*, EDE+
idcf.1nb**	Internal Dose Conversion Factors: Rem/Ci Inhaled Time periods: 2 days, 7 days, 30 days 1 year, 10 years, 20 years, 30 years, 40 years, 50 years	adrenals, brain, lower large intestine*, small intestine*, stomach*, upper large intestine*, kidneys, liver, lungs*, ovaries*, muscle

idcf.2nb**	Internal Dose Conversion Factors: Rem/Ci Inhaled Time periods: 2 days, 7 days, 30 days, 1 year, 10 years, 20 years, 30 years, 40 years, 50 years	pancreas,marrow*, skeleton*, spleen, testes*, thyroid*, bladder, others, whole body*,total body, EDE+
idcf.3nb++	Internal Dose Conversion Factors: Rem/Ci Ingested Time periods: 2 days, 7 days, 30 days, 1 year, 10 years, 20 years, 30 years, 40 years, 50 years	adrenals, brain, lower large intestine*, small intestine*, stomach*, upper large intestine*, kidneys, liver, lungs*, muscle, ovaries*
idcf.4nb++	Internal Dose Conversion Factors: Rem/Ci Ingested Time periods: 7 days, 30 days, 1 year, 10 years, 20 years, 30 years, 40 years, 50 years	pancreas, marrow*, skeleton*, spleen, testes*, thyroid*, bladder, others, whole body*, total body, EDE+

* indicates organ used by FUSCRAC3

** indicates file used in creating fusdos3

++ indicates file used in updating fus.i

+ EDE ≡ Effective Dose Equivalent: weighted average of the dose to certain organs; because FUSCRAC3 uses whole body DCF's, this number is not needed, since the whole body dose is the dose to the entire body computed as if all transformations were uniformly distributed throughout the body

Appendix B

COMPUTER CODES

B.1 Definitions of important variables found in the computer codes:

Step 1

idcf.1nb, idcf.2nb:	Fetter's inhalation dose conversion factor data files (see Appendix A)
fusdos3:	This refers to the old fusdos file before ti was updated; it is used to obtain the isotope array.
first:	This is the data file which STEP1 creates.
dcflli:	Dose conversion factor for the lower large intestine
dcffsi:	Dose conversion factor for the small intestine
dcfst:	Dose conversion factor for the stomach
dcfuli:	Dose conversion factor for the upper large intestine
dcflun:	Dose conversion factor for the lung
dcfov:	Dose conversion factor for the ovaries
dcfmar:	Dose conversion factor for the marrow
dcfskl:	Dose conversion factor for the skeleton
dcftst:	Dose conversion factor for the testes
dcfthy:	Dose conversion factor for the thyroid
dcfwb:	Dose conversion factor for the whole body

Step 2

second:	this is the data file which STEP2 creates
temp (i, j, k):	the array containing data for all 9 time period found in Fetter's files (organ i, time period j, isotope k)
inc (i, j, k):	the final dose conversion factors containing data for the 7 time periods of interest to FUSCRAC3 (organ i, time period j, isotope k)

Step 3

dcftb:	dose conversion factor for the total body
edrcf.1 & edrcf.2:	external dose rate conversion factor (cloudshine) files from Fetter (see Appendix A)
third:	this is the data file that STEP3 creates

Step4gd

edrcf.3b & edrcf.4b:	external dose rate conversion factors (groundshine) from Fetter (see Appendix A)
fourth:	the data file created by Step4gd
iso(i):	isotope name
lam(i):	decay constant of isotope i
hf(i):	half–life of isotope (i)
nbr(i):	number of branches associated with isotope (i)
b1brp(i):	branch1 branching percent for isotope(1)
b1nd(i):	branch1 number of radioactive daughters
b1d1(i):	branch1 radioactive daughter1 for isotope(i)
b1d1hf(i):	branch1 radioactive daughter1 half–life for isotope(i)
b1d2(i):	branch1 radioactive daughter2 (granddaughter) for isotope(i)
b1d2hf(i):	branch1 radioactive daughter2 half–life for isotope(i)
b2brp(i):	branch2 branching percent for isotope(i)
b2nd(i):	branch2 number of radioactive daughters
b2d1(i):	branch2 radioactive daughter1 for isotope(i)
b2d1hf(i):	branch2 radioactive daughter1 half–life for isotope(i)
b2d2(i):	branch2 radioactive daughter2 (granddaughter) for isotope(i)
b2d2hf(i):	branch2 radioactive daughter2 half–life for isotope(i)
lt1(i):	dimensionless number = lambda * time, for time = 8 hrs for isotope(i)
lt2(i):	dimensionless number = lambda * time, for time = 7 days for isotope(i)
ep1(i):	$\exp(-\lambda t)$ of isotope i for time = 8 hrs
ep2(i):	$\exp(-\lambda t)$ of isotope i for time = 7 days
spl8(i):	$[1 - \exp(-\lambda t)]$ for the parent isotope(i) for time = 8 hrs; the expression contains numerical methods corrections
spl7(i):	$[1 - \exp(-\lambda t)]$ for the parent isotope(i) for time = 7 days; the expression contains numerical methods corrections
b1lam1(i):	decay constant ($\ln 2 / t_{\frac{1}{2}}$) for branch1 daughter1 for isotope(i)
b1lam2(i):	decay constant for branch1 daughter2 for isotope(i)
b2lam1(i):	decay constant for branch2 daughter1 for daughter1 for isotope(i)
b2lam2(i):	decay constant for branch2 daughter2 for isotope(i)
b1l1t1(i):	dimensionless number = lambda * time, for time = 8 hrs, for branch1 daughter1 for isotope(i)
b1l1t2(i):	dimensionless number = lambda * time, for time = 7 days, for branch1 daughter1 for isotope(i)

b1l2t1(i): dimensionless number = lambda * time, for time = 8 hours, for branch1 daughter2 for isotope(i)

b1l2t2(i): dimensionless number = lambda * time, for time = 7 days, for branch1 daughter2 for isotope(i)

b2l1t1(i): dimensionless number = lambda * time, for time = 8 hours, for branch2 daughter1 for isotope(i)

b2l1t2(i): dimensionless number = lambda * time, for time = 7 days, for branch2 daughter1 for isotope(i)

b2l2t1(i): dimensionless number = lambda * time, for time = 8 hours, for branch2 daughter2 for isotope(i)

b1b2l2t2(i): dimensionless number = lambda * time, for time = 7 days, for branch2 daughter2 for isotope(i)

b1e11(i): $\exp(-\lambda t_1)$, where t_1 = 8 hours, for branch1, daughter1, for isotope(i)

b1e12(i): $\exp(-\lambda t_2)$, where t_2 = 7 days, for branch1, daughter2, for isotope(i)

b1e21(i): $\exp(-\lambda t_1)$, branch1, daughter2, isotope(i)

b1e22(i): $\exp(-\lambda t_2)$, branch1, daughter2, isotope(i)

b2e11(i): $\exp(-\lambda t_1)$, branch2, daughter1, isotope(i)

b2e12(i): $\exp(-\lambda t_2)$, branch2, daughter1, isotope(i)

b2e21(i): $\exp(-\lambda t_1)$, branch2, daughter2, isotope(i)

b2e22(i): $\exp(-\lambda t_2)$, branch2, daughter2, isotope(i)

gp(i,j): dose conversion factor for organ j and isotope i

s18(i): $[1-\exp(-\lambda t_1)]$, t_1 = 8 hrs, for daugher1; this calculation is called twice; once for branch1 and once for branch2

s17(i): $[1-\exp(-\lambda t_2)]$, t_2 = 7 days, for daughter1, called for both branches

s28(i): $[1-\exp(-\lambda t_1)]$; daughter2; called for both branches

s27(i): $[1-\exp(-\lambda t_2)]$; daughter2; called for both branches

count: keeps track of which branch is being calculated

sd38h: 8 hr integrated dose from granddaughter; called for both branches

sd37d: 7 day integrated dose from granddaughter; called for both branches

sd28h: 8 hr integrated dose from daughter; called for both branches

sd27h: 7 day integrated dose from daughter; called for both branches

sd18h: 8 hr integrated dose from parent isotope (i); called for branches

sd17d: 7 day integrated dose from parent isotope (i); called for both branches

brld8h: total branch1 8 hr dose

brld7d: total branch1 7 day dose

br2d8h: total branch2 8 hr dose

br2d7d: total branch2 7 day dose

d(i,1,j): total 8 hr integrated groundshine dose conversion factor for organ(j) and isotope(i)

d(i,2,j): total 7 day integrated groundshine dose conversion factor for organ (j) and isotope (i)

d(i,3,j): dose rate conversion factor ((rem/yr)/Ci/m^2)) for organ(j) and isotope(i)

Step 5

fdtr1:	STEP5 created this file, which, after validation, became fusdos3
in1(i,j,k):	inhalation dose conversion factors for isotope(k), organ(i), and seven cumulative time periods (0–t_{acute}, 0–1 year, 0–10 years, 0–20 years, 0–30 years, 0–40 years, 0–50 years)
incon(i,j,k):	inhalation dose conversion factors for isotope(k), organ(i), and seven differential time periods (0–t_{acute}, 0–1 year, 1–10 years, 10–20 years, 20–30 years, 30–40 years, 40–50 years)
second2:	a file containing inhalation dose conversion factors; similar to second, except it contains the corrected time periods (i.e., 1–10, 10–20, 20–30, 30–40, and 40–50 years)
grcon(i,j,k):	groundshine dose conversion factor for isotope(k), organ(i), and time(j), where j=1 is the 8 hr integrated dose, j=2 is the 7 day integrated dose, and j=3 is the dose rate
clcon(i,k):	cloudshine dose rate conversion factor for isotope(k) and organ(i)

Note: The organs are listed in fusdos3 in the following order: lung, marrow, skeleton, stomach, small intestine, upper large intestine, lower large intestine, testes, thyroid, ovaries, whole body. References to organ(j) refer to the j^{th} organ in this list.

Step 6

ingest:	this is the ingestion dose conversion factor data file which STEP6 creates
idcf.3nb & idcf.4nb:	Fetter's ingestion dose conversion factor data files (see Appendix A)
ing1(i,j,k):	ingestion dose conversion factor for organ(k), isotope(i), and time(j), where j refers to one of 9 time periods from Fetter's files
ing(i,j,k):	ingestion dose conversion factor for organ(k), isotope(i), and time(j), where j refers to one of the 6 time periods required for FUSCRAC3 (0–50 yrs, 0–10, 10–20, 20–30, 30–40, and 40–50)

Setup

fusisub:	data file created by SETUP, which after validation, replaced the existing chronic section of the input file
cfmod:	direct environmental transfer factor file [6]
cf2mod:	indirect environmental transfer factor file [6]
orgnam:	organ name of the j^{th} organ
beef(i):	direct environmental transfer factor for beef for isotope(i) in Rood's file
milk(i):	direct environmental transfer factor for milk for isotope(i) in Rood's file

crop(i):	direct environmental transfer factor for crops for isotope(i) in Rood's file
beefi(i):	indirect environmental transfer factor for beef for isotope(i) in Rood's file
milki(i):	indirect environmental transfer factor for milk for isotope(i) in Rood's file
cropi(i):	indirect environmental transfer factor for crops for isotope(i) in Rood's file
cr(i):	direct environmental transfer factor for crops for isotope(i) in FUSCRAC3
m(i):	direct environmental transfer factor for milk for isotope(i) in FUSCRAC3
b(i):	direct environmental transfer factor for beef for isotope(i) in FUSCRAC3
cri(i):	indirect environmental transfer factor for crops for isotope(i) in FUSCRAC3
bfmki(i):	indirect environmental transfer factor for beef plus milk in isotope(i) in FUSCRAC3
temp(i,j,k):	ingestion dose conversion factor for all 259 isotopes from Fetter's files
ing(l,j,k):	ingestion dose conversion factor for those 144 isotopes handled by Rood

B.2: COMPUTER CODES

```
c step1 computer code; cray fortran
c
c
c declaration of variables
c
      real dcflli(259,9),dcfsi(259,9),dcfst(259,9),dcfuli(259,9),
     1dcflun(259,9),dcfov(259,9),dcfmar(259,9),dcfskl(259,9),
     2dcftst(259,9),dcfthy(259,9),dcfwb(259,9)
      character*8 iso(259)
      character*10 time(9)
c
      call dropfile(0)
      open(unit=2,file='idcf.1nb',status='old')
      open(unit=3,file='idcf.2nb',status='old')
      open(unit=4,file='fusdos3',status='old')
      open(unit=5,file='first',status='unknown')
c
c
c assigning isotope names to iso array
      read (4,150) (iso(i),i=1,259)
150   format(10a8)
c
c  reading dose conversion factors
c
      do 10 i=1,259
      do 20 j=1,9
      read (2,100) dcflli(i,j),dcfsi(i,j),dcfst(i,j),dcfuli(i,j),
     1dcflun(i,j),dcfov(i,j)
      read (3,110) dcfmar(i,j),dcfskl(i,j),dcftst(i,j),dcfthy(i,j),
     1dcfwb(i,j)
100   format(40x,1pe10.2,1pe10.2,1pe10.2,1pe10.2,20x,1pe10.2,10x,
     11pe10.2)
110   format(30x,1pe10.2,1pe10.2,10x,1pe10.2,1pe10.2,20x,1pe10.2)
20    continue
10    continue
c read time periods
c234567
      rewind 2
      read(2,55) (time(j),j=1,9)
55    format(10x,a10)
c
c
      write(5,300)
300   format('  NUCLIDE ','  TIME     ','    LUNG  ','  MARROW  ',
     1' SKELETON ','  GI:ST   ','   GI:SI  ','  GI:ULI  ','  GI:LLI  ',
     2'   TESTES ','  THYROID ','  OVARIES ','  WH BODY ')
c
      do 50 i=1,259
      do 60 j=1,9
      if(j.eq.1) write(5,400) iso(i),time(j),dcflun(i,j),dcfmar(i,j),
     1dcfskl(i,j),dcfst(i,j),dcfsi(i,j),dcfuli(i,j),dcflli(i,j),
     2dcftst(i,j),dcfthy(i,j),dcfov(i,j),dcfwb(i,j)
c
      if(j.ne.1) write(5,500) time(j),dcflun(i,j),dcfmar(i,j),
     1dcfskl(i,j),dcfst(i,j),dcfsi(i,j),dcfuli(i,j),dcflli(i,j),
     2dcftst(i,j),dcfthy(i,j),dcfov(i,j),dcfwb(i,j)
c
c
400   format(a8,2x,a10,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,
     11pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2)
500   format(10x,a10,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,
     11pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2)
60    continue
50    continue
      stop
      end
```

```
c step2 computer code; cray fortran
c
c   THIS CODE TAKES CARE OF THE FACT THAT DIFFERENT ORGANS HAVE
c   DIFFERENT VALUES FOR THE FIRST TIME PERIOD (SEE CRAC MANUAL)
c
c   declaration of variables
c
      real temp(11,9,259),inc(11,7,259)
      integer ntime(11)
      character*8 iso(259)
      character*10 heading(13)
c
      call dropfile(0)
      open(unit=2,file='first',status='old')
      open(unit=3,file='fusdos3',status='old')
      open(unit=4,file='second',status='unknown')
c
c   initializing ntime array to zero
c
      do 15 n= 1,11
      ntime(n) = 0
15    continue
c
c assigning isotope names to iso array
      read (3,150) (iso(i),i=1,259)
150   format(10a8)
c   reading in information from first
c
      read(2,155) (heading(c),c=1,13)
155   format(13a10)
      do 50 k=1,259
      do 40 j=1,9
      read (2,160) (temp(i,j,k), i=1,11)
160   format(20x,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,
     11pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2)
40    continue
50    continue
c
c
      do 70 k=1,259
      do 80 j= 1,9
      do 90 i= 1,11
      if (j.eq.1) go to 101
      if (j.eq.2) go to 102
      if (j.eq.3) go to 103
      if (j.eq.4) go to 104
      if (j.ge.5) go to 105
90    continue
80    continue
      do 12 m=1,11
      ntime(m)=0
12    continue
70    continue
      go to 21
```

```
c
c go to subsection
c
101    if (i.le.7) go to 110
       ntime(i) = ntime(i) + 1
       inc(i,ntime(i),k) = temp(i,j,k)
110    go to 90
102    if (i.eq.1) go to 130
       if (i.ge.8) go to 130
       ntime(i) = ntime(i) + 1
       inc(i,ntime(i),k) = temp(i,j,k)
130    go to 90
c    skip 30 day time period
103    go to 90
c
104    if (i.eq.1) go to 170
       ntime(i) = ntime(i) + 1
       inc(i,ntime(i),k) = temp(i,j,k)
       go to 90
170    ntime(i) = ntime(i) + 1
       inc(i,ntime(i),k) = temp(i,j,k)
       ntime(i) = ntime(i) + 1
       inc(i,ntime(i),k) = temp(i,j,k)
       go to 90
105    ntime(i) = ntime(i) + 1
       inc(i,ntime(i),k) = temp(i,j,k)
       go to 90
c
c
c writing to file called second
c
21     write(4,300)
300    format(' NUCLIDE  ','TIME INDEX','   LUNG   ','  MARROW  ',
      1' SKELETON ','  GI:ST   ','   GI:SI  ','  GI:ULI  ','  GI:LLI  ',
      2'  TESTES  ','  THYROID ',' OVARIES  ','  WH BODY ')
       do 25 k = 1,259
       do 35 j = 1,7
       if (j.eq.1) write(4,500) iso(k),j,(inc(i,j,k), i=1,11)
       if (j.ne.1) write(4,600) j,(inc(i,j,k), i=1,11)
500    format(a8,2x,5x,I1,4x,1pe10.2,1pe10.2,1pe10.2,1pe10.2,
     11pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2)
600    format(10x,5x,I1,4x,1pe10.2,1pe10.2,1pe10.2,1pe10.2,
     11pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2)
35     continue
25     continue
       stop
       end
```

```
c step3 computer code; cray fortran
c
c THIS PROGRAM TAKES CARE OF EXTERNAL RADIATION FROM CLOUDSHINE
c
c declaration of variables
      real dcflli(259),dcfsi(259),dcfst(259),dcfuli(259),dcflun(259),
     1dcfov(259),acfmar(259),dcfskl(259),dcftst(259),dcfthy(259),
     2dcftb(259)
      character*8 iso(259)
c
      call dropfile(0)
      open(unit=2,file='edrcf.1',status='old')
      open(unit=3,file='edrcf.2',status='old')
      open(unit=4,file='fusdos3',status='old')
      open(unit=5,file='third',status='unknown')
c
c  assigning isotope names to iso array
      read(4,150) (iso(i), i=1,259)
150   format(10a8)
c
c  read dose conversion factors
      do 10 i=1,259
      read(2,100) dcflli(i),dcfsi(i),dcfst(i),dcfuli(i),dcflun(i),
     1dcfov(i)
      read(3,110) dcfmar(i),dcfskl(i),dcftst(i),dcfthy(i),dcftb(i)
100   format(37x,1pe10.2,1pe10.2,1pe10.2,1pe10.2,20x,1pe10.2,
     110x,1pe10.2)
110   format(27x,1pe10.2,1pe10.2,10x,1pe10.2,1pe10.2,30x,1pe10.2)
10    continue
c
c     write to third
c
      write(5,300)
300   format(' NUCLIDE  ','   LUNG   ',' MARROW  ',' SKELETON ',
     1'  GI:ST   ','  GI:SI   ','  GI:ULI  ','  GI:LLI  ','  TESTES  ',
     2'  THYROID ',' OVARIES  ',' TOT BODY ')
      do 50 i=1,259
      write(5,400) iso(i),dcflun(i),dcfmar(i),dcfskl(i),dcfst(i),
     1dcfsi(i),dcfuli(i),dcflli(i),dcftst(i),dcfthy(i),dcfov(i),
     2dcftb(i)
400   format(a8,2x,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,
     11pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2)
50    continue
      stop
      end
```

——hflife2 data file; p.1 ———

NUCLIDE	HFLF (s)	nbr	brperc	nd	daught1	d1hflife	daught2	d2hflife
h-3	3.89e+08	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
be-7	4.61e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
be-10	5.05e+13	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
c-14	1.81e+11	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
n-13	5.98e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
n-16	7.13e+00	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
f-18	6.59e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
na-22	8.21e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
na-24	5.41e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
mg-27	5.68e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
mg-28	7.56e+04	1	1.0000	1	al-28	1.34e+02	xxxxxxxx	0.00e+00
al-26	2.27e+13	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
al-28	1.34e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
al-29	3.96e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
si-31	9.43e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
si-32	2.05e+10	1	1.0000	1	p-32	1.23e+06	xxxxxxxx	0.00e+00
p-32	1.23e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
p-33	2.19e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
s-35	7.55e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
s-37	3.00e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
cl-36	9.46e+12	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
cl-40	8.10e+01	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ar-39	8.48e+09	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ar-41	6.59e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ar-42	1.04e+09	1	1.0000	1	k-42	4.45e+04	xxxxxxxx	0.00e+00
k-40	4.04e+16	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
k-42	4.45e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
k-43	8.03e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ca-41	3.15e+12	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ca-45	1.43e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ca-47	3.92e+05	1	1.0000	1	sc-47	2.95e+05	xxxxxxxx	0.00e+00
sc-44	1.41e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sc-44m	2.11e+05	2	0.0139	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
			0.9861	1	sc-44	1.41e+04	xxxxxxxx	0.00e+00
sc-46	7.24e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sc-47	2.95e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sc-48	1.57e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sc-49	3.42e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sc-50	1.03e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ti-44	1.48e+09	1	1.0000	1	sc-44	1.41e+04	xxxxxxxx	0.00e+00
ti-45	1.11e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ti-51	3.48e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
v-48	1.38e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
v-49	2.85e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
v-52	2.26e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
v-53	9.60e+01	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
cr-49	2.51e+03	1	1.0000	1	v-49	2.85e+07	xxxxxxxx	0.00e+00
cr-51	2.39e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
cr-55	2.13e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
mn-52	4.83e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
mn-52m	1.27e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
mn-53	1.17e+14	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
mn-54	2.70e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
mn-56	9.28e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
mn-57	9.60e+01	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
fe-53	5.11e+02	1	1.0000	1	mn-53	1.17e+14	xxxxxxxx	0.00e+00
fe-55	8.51e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
fe-59	3.85e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
fe-60	9.46e+12	1	1.0000	2	co-60m	6.30e+02	co-60	1.66e+08
co-57	2.34e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
co-58	6.12e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
co-58m	3.31e+04	1	1.0000	1	co-58	6.12e+06	xxxxxxxx	0.00e+00
co-60	1.66e+08	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
co-60m	6.30e+02	1	1.0000	1	co-60	1.66e+08	xxxxxxxx	0.00e+00
co-61	5.94e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
co-62m	8.34e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ni-57	1.30e+05	1	1.0000	1	co-57	2.34e+07	xxxxxxxx	0.00e+00
ni-59	2.37e+12	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ni-63	3.15e+09	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ni-65	9.07e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00

—— hflife2 data file; p.2 ——

cu-62	5.84e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
cu-64	4.57e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
cu-66	3.06e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
zn-63	2.29e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
zn-65	2.11e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
zn-69	3.36e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
zn-69m	5.04e+04	1	1.0000	1	zn-69	3.36e+03	xxxxxxxx	0.00e+00
as-74	1.54e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
as-76	9.47e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
se-75	1.02e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
se-79	2.05e+12	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
kr-81	6.62e+12	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
kr-85	3.37e+08	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
kr-87	4.56e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
kr-88	1.02e+04	1	1.0000	1	rb-88	1.07e+03	xxxxxxxx	0.00e+00
rb-86	1.62e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
rb-86m	6.12e+01	1	1.0000	1	rb-86	1.62e+06	xxxxxxxx	0.00e+00
rb-87	1.51e+18	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
rb-88	1.07e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sr-89	4.36e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sr-90	9.08e+08	1	1.0000	1	y-90	2.31e+05	xxxxxxxx	0.00e+00
sr-91	3.42e+04	2	0.5700	2	y-91m	2.98e+03	y-91	5.05e+06
			0.4300	1	y-91	5.05e+06	xxxxxxxx	0.00e+00
y-88	9.21e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
y-90	2.31e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
y-90m	1.15e+04	1	1.0000	1	y-90	2.31e+05	xxxxxxxx	0.00e+00
y-91	5.05e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
y-91m	2.98e+03	1	1.0000	1	y-91	5.05e+06	xxxxxxxx	0.00e+00
y-92	1.27e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
y-93	3.67e+04	1	1.0000	2	zr-93	4.73e+13	nb-93m	4.29e+08
y-94	1.12e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
zr-89	2.82e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
zr-93	4.73e+13	1	1.0000	1	nb-93m	4.29e+08	xxxxxxxx	0.00e+00
zr-95	5.53e+06	1	1.0000	1	nb-95	3.02e+06	xxxxxxxx	0.00e+00
zr-97	6.08e+04	1	1.0000	1	nb-97	4.32e+03	xxxxxxxx	0.00e+00
nb-90	5.26e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
nb-91	8.66e+14	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
nb-91m	5.36e+06	1	1.0000	1	nb-91	8.66e+14	xxxxxxxx	0.00e+00
nb-92	1.01e+15	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
nb-92m	8.77e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
nb-93m	4.29e+08	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
nb-94	6.31e+11	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
nb-94m	3.76e+02	1	1.0000	1	nb-94	6.31e+11	xxxxxxxx	0.00e+00
nb-95	3.02e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
nb-95m	3.13e+05	1	1.0000	1	nb-95	3.02e+06	xxxxxxxx	0.00e+00
nb-96	8.42e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
nb-97	4.32e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
nb-97m	6.00e+01	1	1.0000	1	nb-97	4.32e+03	xxxxxxxx	0.00e+00
nb-98m	3.06e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
mo-91	9.29e+02	1	1.0000	1	nb-91	8.66e+14	xxxxxxxx	0.00e+00
mo-93	9.46e+10	1	1.0000	1	nb-93m	4.29e+08	xxxxxxxx	0.00e+00
mo-93m	2.48e+04	1	1.0000	2	mo-93	9.46e+10	nb-93m	4.29e+08
mo-99	2.38e+05	2	0.8700	2	tc-99m	2.17e+04	tc-99	6.75e+12
			0.1300	1	tc-99	6.75e+12	xxxxxxxx	0.00e+00
mo-101	8.76e+02	1	1.0000	1	tc-101	8.58e+02	xxxxxxxx	0.00e+00
tc-97	8.20e+13	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
tc-98	1.32e+14	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
tc-99	6.75e+12	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
tc-99m	2.17e+04	1	1.0000	1	tc-99	6.75e+12	xxxxxxxx	0.00e+00
tc-101	8.58e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ru-103	3.40e+06	1	1.0000	1	rh-103m	3.37e+03	xxxxxxxx	0.00e+00
ru-105	1.60e+04	1	1.0000	1	rh-105	1.27e+05	xxxxxxxx	0.00e+00
ru-106	3.17e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
rh-101	1.04e+08	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
rh-101m	3.75e+05	2	0.0800	1	rh-101	1.04e+08	xxxxxxxx	0.00e+00
			0.9200	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
rh-103m	3.37e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
rh-105	1.27e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
pd-107	2.05e+14	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
pd-109	4.83e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
pd-111	1.32e+03	1	1.0000	1	ag-111	6.44e+05	xxxxxxxx	0.00e+00

—— hflife2 data file; p.3 ——

pd-111m	1.98e+04	1	1.0000	2	pd-111	1.32e+03	ag-111	6.44e+05
ag-108	1.44e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ag-108m	4.01e+09	2	0.0870	1	ag-108	1.44e+02	xxxxxxxx	0.00e+00
			0.9130	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ag-110	2.44e+01	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ag-110m	2.18e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ag-111	6.44e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
cd-109	3.91e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
cd-113m	4.42e+08	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
cd-115	1.92e+05	1	1.0000	2	in-115m	1.62e+04	in-115	1.61e+22
in-114	7.19e+01	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
in-114m	4.28e+06	1	1.0000	1	in-114	7.19e+01	xxxxxxxx	0.00e+00
in-115	1.61e+22	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
in-115m	1.62e+04	1	1.0000	1	in-115	1.61e+22	xxxxxxxx	0.00e+00
in-116	1.41e+01	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
in-116m	3.25e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sn-113	9.94e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sn-113m	1.26e+03	1	1.0000	1	sn-113	9.94e+06	xxxxxxxx	0.00e+00
sn-121	9.76e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sn-121m	1.73e+09	2	0.2240	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
			0.7760	1	sn-121	9.76e+04	xxxxxxxx	0.00e+00
sn-123	1.11e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sn-126	3.15e+12	2	0.8600	1	sb-126m	1.14e+03	xxxxxxxx	0.00e+00
			0.1400	2	sb-126m	1.14e+03	sb-126	1.07e+06
sb-122	2.32e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sb-124	5.20e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sb-125	8.51e+07	2	0.2300	1	te-125m	5.01e+06	xxxxxxxx	0.00e+00
			0.7700	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sb-126	1.07e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sb-126m	1.14e+03	2	0.8600	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
			0.1400	1	sb-126	1.07e+06	xxxxxxxx	0.00e+00
sb-129	1.58e+04	1	1.0000	2	te-129	4.14e+03	i-129	5.05e+14
te-125m	5.01e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
te-129	4.14e+03	1	1.0000	1	i-129	5.05e+14	xxxxxxxx	0.00e+00
te-129m	2.89e+06	2	0.6340	2	te-129	4.14e+03	i-129	5.05e+14
			0.3660	1	i-129	5.05e+14	xxxxxxxx	0.00e+00
te-131	1.50e+03	1	1.0000	1	i-131	6.95e+05	xxxxxxxx	0.00e+00
te-131m	1.08e+05	2	0.2200	2	te-131	1.50e+03	i-131	6.95e+05
			0.7800	1	i-131	6.95e+05	xxxxxxxx	0.00e+00
te-132	2.81e+05	1	1.0000	1	i-132	8.21e+03	xxxxxxxx	0.00e+00
i-129	5.05e+14	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
i-131	6.95e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
i-132	8.21e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
i-133	7.52e+04	1	1.0000	1	xe-133	4.54e+05	xxxxxxxx	0.00e+00
i-134	3.16e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
i-135	2.38e+04	1	1.0000	2	xe-135	3.28e+04	cs-135	9.46e+13
xe-133	4.54e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
xe-135	3.28e+04	1	1.0000	1	cs-135	9.46e+13	xxxxxxxx	0.00e+00
cs-134	6.50e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
cs-135	9.46e+13	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
cs-136	1.13e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
cs-137	9.51e+08	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ba-133	3.37e+08	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ba-140	1.11e+06	1	1.0000	1	la-140	1.45e+05	xxxxxxxx	0.00e+00
la-137	1.89e+12	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
la-138	3.47e+18	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
la-140	1.45e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ce-144	2.45e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
pm-145	5.58e+08	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
pm-146	1.73e+08	2	0.6610	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
			0.3390	1	sm-146	3.25e+15	xxxxxxxx	0.00e+00
sm-146	3.25e+15	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sm-147	3.34e+18	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
sm-151	2.84e+09	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
eu-150	1.14e+09	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
eu-152	4.10e+08	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
eu-154	2.68e+08	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
gd-148	3.09e+09	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
gd-150	5.68e+13	1	1.0000	1	sm-146	3.25e+15	xxxxxxxx	0.00e+00
tb-157	4.73e+09	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
tb-158	4.73e+09	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00

—— hflife2 data file; p.4 ——

dy-154	4.68e+04	1	1.0000	2	gd-150	5.68e+13	sm-146	3.25e+15
ho-166	9.65e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
lu-176	1.14e+18	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
lu-177	5.80e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
lu-177m	1.39e+07	2	0.7800	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
			0.2200	1	lu-177	5.80e+05	xxxxxxxx	0.00e+00
lu-178	1.70e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
lu-178m	1.38e+03	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
hf-175	6.05e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
hf-178m	9.78e+08	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
hf-181	3.66e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
hf-182	2.84e+14	1	1.0000	1	ta-182	9.94e+06	xxxxxxxx	0.00e+00
hf-183	3.84e+03	1	1.0000	1	ta-183	4.41e+05	xxxxxxxx	0.00e+00
ta-179	5.36e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ta-180m	2.92e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ta-182	9.94e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ta-182m	9.50e+02	1	1.0000	1	ta-182	9.94e+06	xxxxxxxx	0.00e+00
ta-183	4.41e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ta-184	3.13e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ta-185	2.94e+03	1	1.0000	1	w-185	6.49e+06	xxxxxxxx	0.00e+00
ta-186	6.30e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
w-179	2.28e+03	1	1.0000	1	ta-179	5.36e+07	xxxxxxxx	0.00e+00
w-179m	3.84e+02	2	0.9969	2	w-179	2.28e+03	ta-179	5.36e+07
			0.0031	1	ta-179	5.36e+07	xxxxxxxx	0.00e+00
w-181	1.05e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
w-185	6.49e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
w-187	8.60e+04	1	1.0000	1	re-187	1.26e+18	xxxxxxxx	0.00e+00
w-188	6.00e+06	1	1.0000	1	re-188	6.08e+04	xxxxxxxx	0.00e+00
re-186	3.27e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
re-186m	6.31e+12	1	1.0000	1	re-186	3.27e+05	xxxxxxxx	0.00e+00
re-187	1.26e+18	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
re-188	6.08e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
re-188m	1.12e+03	1	1.0000	1	re-188	6.08e+04	xxxxxxxx	0.00e+00
re-189	8.75e+04	2	0.8950	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
			0.1050	1	os-189m	2.05e+04	xxxxxxxx	0.00e+00
os-189m	2.05e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
os-194	1.89e+08	1	1.0000	1	ir-194	6.91e+04	xxxxxxxx	0.00e+00
ir-192	6.41e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
ir-192m	7.60e+09	1	1.0000	1	ir-192	6.41e+06	xxxxxxxx	0.00e+00
ir-194	6.91e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
pt-190	1.89e+19	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
pt-193	1.58e+09	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
pt-193m	3.72e+05	1	1.0000	1	pt-193	1.58e+09	xxxxxxxx	0.00e+00
au-194	1.42e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
au-198	2.33e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
hg-194	1.64e+10	1	1.0000	1	au-194	1.42e+05	xxxxxxxx	0.00e+00
hg-203	4.04e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
hg-205	3.12e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
tl-202	1.05e+06	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
tl-204	1.19e+08	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
tl-206	2.52e+02	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
pb-202	9.46e+12	1	1.0000	1	tl-202	1.05e+06	xxxxxxxx	0.00e+00
pb-203	1.87e+05	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
pb-205	4.42e+14	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
pb-209	1.17e+04	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
pb-210	7.03e+08	1	1.0000	2	bi-210	4.33e+05	po-210	1.20e+07
bi-207	1.20e+09	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
bi-208	1.16e+13	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00
bi-210	4.33e+05	1	1.0000	1	po-210	1.20e+07	xxxxxxxx	0.00e+00
bi-210m	9.46e+13	1	1.0000	1	tl-206	2.52e+02	xxxxxxxx	0.00e+00
po-209	3.22e+09	1	1.0000	1	pb-205	4.42e+14	xxxxxxxx	0.00e+00
po-210	1.20e+07	1	1.0000	0	xxxxxxxx	0.00e+00	xxxxxxxx	0.00e+00

```
c     step4gd computer code; cray fortran
c
c     declaration of variables
      real hf(259), b1brp(259), b1d1hf(259),b1d2hf(259),b2brp(259),
     1b2d1hf(259),b2d2hf(259),dcflli(259),dcfsi(259),dcfst(259),
     2dcfuli(259),dcfskl(259),dcflun(259),dcfov(259),dcfmar(259),
     3dcftst(259),dcfthy(259),dcftb(259),lam(259),lt1(259),lt2(259),
     4b2lam2(259),b2lam1(259),b2l2t1(259),sp8tp(259),sp8bt(259),
     4sp18(259),sp7tp(259),sp7bt(259),sp17(259),s18tp(259),
     4s18bt(259),s18(259),s17tp(259),s17bt(259),s17(259),s28tp(259),
     4s28bt(259),s28(259),s27tp(259),s27bt(259),s27(259),
     5b2l2t2(259),b2l1t1(259),b2l1t2(259),b1lam2(259),b1lam1(259),
     6b1l2t1(259),b1l2t2(259),b1l1t1(259),b1l1t2(259),b2e21(259),
     7b2e22(259),b2e11(259),b2e12(259),b1e21(259),b1e22(259),
     8b1e12(259),b1e11(259),gp(259,11),b2gd2(259,11),b1gd2(259,11),
     9sd38h,sd37d,b2gd1(259,11),b1gd1(259,11),sd28h,sd27d,sd18h,
     1sd17d,br2d8h(259),br2d7d(259),br1d8h(259),br1d7d(259),
     1d(259,3,11),cmf,smf,lam2,lam1,gf,gff,ep1(259),ep2(259),
     2sd3fa,sd3fb,sd3fc,sd2fa,sd2fb,s1f
      integer count,b1nd(259),b2nd(259),nbr(259)
      character*8 iso(259),b1d1(259),b1d2(259),b2d1(259),b2d2(259)
c
c
      call dropfile(0)
      open(unit=2,file='edrcf.3b',status='old')
      open(unit=3,file='edrcf.4b',status='old')
      open(unit=4,file='hflife2',status='old')
      open(unit=5,file='fourth',status='unknown')
c
c
c     initialize variables
      sd38h = 0.0
      sd37d = 0.0
      sd28h = 0.0
      sd27d = 0.0
      sd18h = 0.0
      sd17d = 0.0
      do 7 i=1,259
      b1brp(i) = 0.0
      b2brp(i) = 0.0
      br1d8h(i) = 0.0
      br1d7d(i) = 0.0
      br2d8h(i) = 0.0
      br2d7d(i) = 0.0
      b1lam1(i) = 0.0
      b1lam2(i) = 0.0
      b2lam1(i) = 0.0
      b2lam2(i) = 0.0
      b2e11(i) = 0.0
      b2e12(i) = 0.0
      b2e21(i) = 0.0
      b2e22(i) = 0.0
      b1e11(i) = 0.0
      b1e12(i) = 0.0
      b1e21(i) = 0.0
      b1e22(i) = 0.0
      sp8tp(i) = 0.0
      sp8bt(i) = 0.0
      sp18(i) = 0.0
      sp7tp(i) = 0.0
      sp7bt(i) = 0.0
      sp17(i) = 0.0
      s18tp(i) = 0.0
      s18bt(i) = 0.0
      s18(i) = 0.0
      s17tp(i) = 0.0
      s17bt(i) = 0.0
      s17(i) = 0.0
```

```
      s28tp(i) = 0.0
      s28bt(i) = 0.0
      s28(i) = 0.0
      s27tp(i) = 0.0
      s27bt(i) = 0.0
      s27(i) = 0.0
7     continue
c
c     read hflife2 info
c
c     skip top line
      read(4,105)
105   format(74x)
c
      do 10 i=1,259
      read(4,115) iso(i),hf(i),nbr(i),b1brp(i),b1nd(i),b1d1(i),
     1b1d1hf(i),b1d2(i),b1d2hf(i)
115   format(a8,e10.2,2x,I1,3x,F6.4,3x,I1,1x,a8,e10.2,1x,
     1a8,e10.2)
      if(nbr(i).ne.2) go to 10
      read(4,125) b2brp(i),b2nd(i),b2d1(i),b2d1hf(i),b2d2(i),b2d2hf(i)
125   format(24x,F6.4,3x,I1,1x,a8,e10.2,1x,a8,e10.2)
10    continue
c
c
c     read ground dose conversion factors
      do 30 i=1,259
      read(2,100) dcflli(i),dcfsi(i),dcfst(i),dcfuli(i),dcflun(i),
     1dcfov(i)
      read(3,110) dcfmar(i),dcfski(i),dcftst(i),dcfthy(i),dcftb(i)
100   format(36x,e10.2,e10.2,e10.2,e10.2,20x,e10.2,10x,
     1e10.2)
110   format(26x,e10.2,e10.2,10x,e10.2,e10.2,30x,e10.2)
30    continue
c
c     this section determines all of the lambdas of the parents,
c     and their corresponding daughters and granddaughters.
c     it also determines the dimensionless constants (lambda*time)
c     to be used in the exponential expressions.
c     the maximum number that the computer can handle in an exp is
c     5500.0.  the code sets 1/exp(lt) = 0.0 if lt > 5500.0.
c
      do 15 i=1,259
      lam(i) = log(2.0) / hf(i)
      lt1(i) = lam(i) * 28800.0
      lt2(i) = lam(i) * 604800.0
      if(lt1(i).gt.5500.0) ep1(i) = 0.0
      if(lt2(i).gt.5500.0) ep2(i) = 0.0
      if(lt1(i).le.5500.0) ep1(i) = 1 / exp(lt1(i))
      if(lt2(i).le.5500.0) ep2(i) = 1 / exp(lt2(i))
      sp8tp(i) = 1.0 - (ep1(i) * ep1(i) * ep1(i) * ep1(i))
      sp8bt(i) = (ep1(i) * ep1(i) * ep1(i)) + (ep1(i) * ep1(i)) +
     1ep1(i) + 1.0
      sp18(i) = sp8tp(i) / sp8bt(i)
      sp7tp(i) = 1.0 - (ep2(i) * ep2(i) * ep2(i) * ep2(i))
      sp7bt(i) = (ep2(i) * ep2(i) * ep2(i)) + (ep2(i) * ep2(i)) +
     1ep2(i) + 1.0
      sp17(i) = sp7tp(i) / sp7bt(i)
      if(nbr(i).eq.2) go to 50
      if(nbr(i).eq.1) go to 70
15    continue
      go to 31
```

```
50    if(b2nd(i).eq.0) go to 70
      if(b2nd(i).eq.1) go to 55
      b2lam2(i) = log(2.0) / b2d2hf(i)
      b2l2t1(i) = b2lam2(i) * 28800.0
      b2l2t2(i) = b2lam2(i) * 604800.0
      if(b2l2t1(i).gt.5500.0) b2e21(i) = 0.0
      if(b2l2t2(i).gt.5500.0) b2e22(i) = 0.0
      if(b2l2t1(i).le.5500.0) b2e21(i) = 1/ exp(b2l2t1(i))
      if(b2l2t2(i).le.5500.0) b2e22(i) = 1/ exp(b2l2t2(i))
55    b2lam1(i) = log(2.0) / b2d1hf(i)
      b2l1t1(i) = b2lam1(i) * 28800.0
      b2l1t2(i) = b2lam1(i) * 604800.0
      if(b2l1t1(i).gt.5500.0) b2e11(i) = 0.0
      if(b2l1t2(i).gt.5500.0) b2e12(i) = 0.0
      if(b2l1t1(i).le.5500.0) b2e11(i) = 1 / exp(b2l1t1(i))
      if(b2l1t2(i).le.5500.0) b2e12(i) = 1 / exp(b2l1t2(i))
70    if(b1nd(i).eq.0) go to 15
      if(b1nd(i).eq.1) go to 75
      b1lam2(i) = log(2.0) / b1d2hf(i)
      b1l2t1(i) = b1lam2(i) * 28800.0
      b1l2t2(i) = b1lam2(i) * 604800.0
      if(b1l2t1(i).gt.5500.0) b1e21(i) = 0.0
      if(b1l2t2(i).gt.5500.0) b1e22(i) = 0.0
      if(b1l2t1(i).le.5500.0) b1e21(i) = 1 / exp(b1l2t1(i))
      if(b1l2t2(i).le.5500.0) b1e22(i) = 1 / exp(b1l2t2(i))
75    b1lam1(i) = log(2.0) / b1d1hf(i)
      b1l1t1(i) = b1lam1(i) * 28800.0
      b1l1t2(i) = b1lam1(i) * 604800.0
      if(b1l1t1(i).gt.5500.0) b1e11(i) = 0.0
      if(b1l1t2(i).gt.5500.0) b1e12(i) = 0.0
      if(b1l1t1(i).le.5500.0) b1e11(i) = 1 / exp(b1l1t1(i))
      if(b1l1t2(i).le.5500.0) b1e12(i) = 1 / exp(b1l1t2(i))
      go to 15
c
c
c
31    do 35 i=1,259
      gp(i,1) = dcflun(i)
      gp(i,2) = dcfmar(i)
      gp(i,3) = dcfskl(i)
      gp(i,4) = dcfst(i)
      gp(i,5) = dcfsi(i)
      gp(i,6) = dcfuli(i)
      gp(i,7) = dcflli(i)
      gp(i,8) = dcftst(i)
      gp(i,9) = dcfthy(i)
      gp(i,10) = dcfov(i)
      gp(i,11) = dcftb(i)
35    continue
c
c     BIG LOOP!!   7 day and 8 hr integrated dose calculations
c     daughter and granddaughter contributions are included
c     some isotopes have more than one pathway or "branch"
c     that too is accounted for
c
c
      do 1000 i=1,259
      do 1005 j= 1,11
      if(nbr(i).eq.2) go to 2000
      if(nbr(i).eq.1) go to 3000
1005  continue
1000  continue
      go to 6000
c     isotopes with two branches
2000  count = 1
      if(b2nd(i).eq.0) go to 2500
      if(b2nd(i).eq.1) go to 2010
      do 37 l=1,259
      if(b2d2(i).eq.iso(l)) go to 2008
37    continue
      print*,'SOMETHING IS WRONG'
      stop
```

```
2008  b2gd2(i,j) = gp(l,j)
      lam2 = b2lam2(i)
      lam1 = b2lam1(i)
c
      s18tp(i) = 1.0 - (b2e11(i) * b2e11(i) * b2e11(i) * b2e11(i))
      s18bt(i) = (b2e11(i) * b2e11(i) * b2e11(i)) +
     1(b2e11(i) * b2e11(i)) + b2e11(i) + 1.0
      s18(i) = s18tp(i) / s18bt(i)
      s17tp(i) = 1.0 - (b2e12(i) * b2e12(i) * b2e12(i) * b2e12(i))
      s17bt(i) = (b2e12(i) * b2e12(i) * b2e12(i)) +
     1(b2e12(i) * b2e12(i)) + b2e12(i) + 1.0
      s17(i) = s17tp(i) / s17bt(i)
      s28tp(i) = 1.0 - (b2e21(i) * b2e21(i) * b2e21(i) * b2e21(i))
      s28bt(i) = (b2e21(i) * b2e21(i) * b2e21(i)) +
     1(b2e21(i) * b2e21(i)) + b2e21(i) + 1.0
      s28(i) = s28tp(i) / s28bt(i)
      s27tp(i) = 1.0 - (b2e22(i) * b2e22(i) * b2e22(i) * b2e22(i))
      s27bt(i) = (b2e22(i) * b2e22(i) * b2e22(i)) +
     1(b2e22(i) * b2e22(i)) + b2e22(i) + 1.0
      s27(i) = s27tp(i) / s27bt(i)
      gf = b2gd2(i,j)
      go to 2300
2010  do 47 l=1,259
      if(b2d1(i).eq.iso(l)) go to 2012
47    continue
      print*,'SOMETHING IS WRONG'
      stop
2012  b2gd1(i,j) = gp(l,j)
      lam1 = b2lam1(i)
      s18tp(i) = 1.0 - (b2e11(i) * b2e11(i) * b2e11(i) * b2e11(i))
      s18bt(i) = (b2e11(i) * b2e11(i) * b2e11(i)) +
     1(b2e11(i) * b2e11(i)) + b2e11(i) + 1.0
      s18(i) = s18tp(i) / s18bt(i)
      s17tp(i) = 1.0 - (b2e12(i) * b2e12(i) * b2e12(i) * b2e12(i))
      s17bt(i) = (b2e12(i) * b2e12(i) * b2e12(i)) +
     1(b2e12(i) * b2e12(i)) + b2e12(i) + 1.0
      s17(i) = s17tp(i) / s17bt(i)
      gff = b2gd1(i,j)
      go to 2450
2001  br2d8h(i) = sd38h + sd28h + sd18h
      br2d7d(i) = sd37d + sd27d + sd17d
      sd38h = 0.0
      sd28h = 0.0
      sd18h = 0.0
      sd37d = 0.0
      sd27d = 0.0
      sd17d = 0.0
3000  count = 0
      if(b1nd(i).eq.0) go to 2500
      if(b1nd(i).eq.1) go to 3010
      do 56 l=1,259
      if(b1d2(i).eq.iso(l)) go to 3020
56    continue
      print*,'SOMETHING IS WRONG'
      stop
3020  b1gd2(i,j) = gp(l,j)
      lam2 = b1lam2(i)
      lam1 = b1lam1(i)
      s18tp(i) = 1.0 - (b1e11(i) * b1e11(i) * b1e11(i) * b1e11(i))
      s18bt(i) = (b1e11(i) * b1e11(i) * b1e11(i)) +
     1(b1e11(i) * b1e11(i)) + b1e11(i) + 1.0
      s18(i) = s18tp(i) / s18bt(i)
      s17tp(i) = 1.0 - (b1e12(i) * b1e12(i) * b1e12(i) * b1e12(i))
      s17bt(i) = (b1e12(i) * b1e12(i) * b1e12(i)) +
     1(b1e12(i) * b1e12(i)) + b1e12(i) + 1.0
      s17(i) = s17tp(i) / s17bt(i)
      s28tp(i) = 1.0 - (b1e21(i) * b1e21(i) * b1e21(i) * b1e21(i))
      s28bt(i) = (b1e21(i) * b1e21(i) * b1e21(i)) +
     1(b1e21(i) * b1e21(i)) + b1e21(i) + 1.0
      s28(i) = s28tp(i) / s28bt(i)
```

```
      s27tp(i) = 1.0 - (b1e22(i) * b1e22(i) * b1e22(i) * b1e22(i))
      s27bt(i) = (b1e22(i) * b1e22(i) * b1e22(i)) +
     1(b1e22(i) * b1e22(i)) + b1e22(i) + 1.0
      s27(i) = s27tp(i) / s27bt(i)
      gf = b1gd2(i,j)
      go to 2300
3010  do 67 l=1,259
      if(b1d1(i).eq.iso(l)) go to 3015
67    continue
      print*,'SOMETHING IS WRONG'
      stop
3015  b1gd1(i,j) = gp(l,j)
      lam1 = b1lam1(i)
      s18tp(i) = 1.0 - (b1e11(i) * b1e11(i) * b1e11(i) * b1e11(i))
      s18bt(i) = (b1e11(i) * b1e11(i) * b1e11(i)) +
     1(b1e11(i) * b1e11(i)) + b1e11(i) + 1.0
      s18(i) = s18tp(i) / s18bt(i)
      s17tp(i) = 1.0 - (b1e12(i) * b1e12(i) * b1e12(i) * b1e12(i))
      s17bt(i) = (b1e12(i) * b1e12(i) * b1e12(i)) +
     1(b1e12(i) * b1e12(i)) + b1e12(i) + 1.0
      s17(i) = s17tp(i) / s17bt(i)
      gff = b1gd1(i,j)
      go to 2450
3001  br1d8h(i) = sd38h + sd28h + sd18h
      br1d7d(i) = sd37d + sd27d + sd17d
      sd38h = 0.0
      sd28h = 0.0
      sd18h = 0.0
      sd37d = 0.0
      sd27d = 0.0
      sd17d = 0.0
      d(i,1,j) = b1brp(i) * br1d8h(i) + b2brp(i) * br2d8h(i)
      d(i,2,j) = b1brp(i) * br1d7d(i) + b2brp(i) * br2d7d(i)
      go to 1005
c
c
c
c
c
c     subdose3 - dose from granddaughter
c     8 hr and 7 day
2300  sd3fa = (lam2 * lam1) / (lam(i) * (lam1 - lam(i)) *
     1(lam2 - lam(i)))
      sd3fb = lam2 / ((lam2 - lam1) * (lam1 - lam(i)))
      sd3fc = lam1 / ((lam2 - lam1) * (lam2 - lam(i)))
      sd38h = ((sd3fa * sp18(i)) - (sd3fb * s18(i)) +
     1(sd3fc * s28(i))) * gf
      sd37d = ((sd3fa * sp17(i)) - (sd3fb * s17(i)) +
     1(sd3fc * s27(i))) * gf
      sd3fa = 0.0
      sd3fb = 0.0
      sd3fc = 0.0
      if(count.eq.1) go to 2010
      go to 3010
c     subdose2 - dose from daughter
2450  sd2fa = lam1 / lam(i)
      sd2fb = 1 / (lam1 - lam(i))
      sd28h = ((sd2fa * sd2fb * sp18(i)) - (sd2fb * s18(i))) * gff
      sd27d = ((sd2fa * sd2fb * sp17(i)) - (sd2fb * s17(i))) * gff
      sd2fa = 0.0
      sd2fb = 0.0
c     subdose1 - dose from itself
2500  s1f = 1 / lam(i)
      sd18h = gp(i,j) * s1f * sp18(i)
      sd17d = gp(i,j) * s1f * sp17(i)
      if(count.eq.1) go to 2001
      go to 3001
```

```
c
c
c
c     converting from (rem/s)/(ci/m2) to (rem/yr)/(ci/m2)
6000  smf = 3.1536e+07
      do 90 i=1,259
      do 95 j=1,11
      d(i,3,j) = gp(i,j) * smf
95    continue
90    continue
c
c
c
c     writing to fourth
      write(5,350)
350   format(' NUCLIDE  ','TIME INDEX','   LUNG   ','  MARROW  ',
     1' SKELETON ','   GI:ST  ','   GI:SI  ','  GI:ULI  ','  GI:LLI  ',
     2'  TESTES  ','  THYROID ','  OVARIES ',' TOT BODY ')
      do 145 i=1,259
      do 155 j=1,3
      if(j.eq.1) write(5,406) iso(i),j,(d(i,j,k), k=1,11)
      if(j.ne.1) write(5,408) j,(d(i,j,k), k=1,11)
406   format(a8,2x,5x,I1,4x,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,
     11pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2)
408   format(10x,5x,I1,4x,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,
     11pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2)
155   continue
145   continue
      stop
      end
```

```
c  step5 computer program; cray fortran
c
c      this program writes all of the information to fusdos from all
c      of the other sub-files, namely, second, third, and fourth.
c      The name of the file for now will be fdtr1, standing for fusdos-
c      trial 1.
c
c      note:  something will have to be done about the e notation.  The
c      old fusdos has e10.4 format.  However, fetter's files had e10.2.
c      Thus for now, fdtr1 will have e10.2 format.  We can change the way
c      fusdos is read in fuscr3 at format statement 201, which now reads
c      (7e10.4/4e10.4).  We can change this to (11e10.2).
c
c      regarding the above comment; FUSCRAC3 was changed so that it read
c      in 11e10.2 format.
c
c
       real in1(11,7,259),incon(11,7,259),grcon(11,3,259),clcon(11,259)
       integer isonum,time
       character*8 iso(259), orgnam(11)
c
c
       call dropfile(0)
       open(unit=2,file='second',status='old')
       open(unit=3,file='third',status='old')
       open(unit=4,file='fourth',status='old')
       open(unit=5,file='fusdos3',status='old')
       open(unit=6,file='fdtr1',status='unknown')
       open(unit=7,file='second2',status='unknown')
c
c      read in isotope names
       read(5,180) (iso(i),i=1,259)
180    format(10a8)
c      read inhalation dose conversion factors
c      skip top line
       read(2,90)
90     format(130x)
c
c234567
       do 10 k=1,259
       do 11 j=1,7
       read(2,100)(in1(i,j,k), i=1,11)
c      NOTE:  THESE 7 TIME PERIODS ARE 0-ACUTE TIME PERIOD, 0-1, 0-10
c      0-20,0-30,0-40, AND 0-50
100    format(20x,11e10.2)
11     continue
10     continue
c
c      read ground dose conversion factors
c
c      skip top line
       read(4,90)
c
c
       do 20 k=1,259
       do 21 j=1,3
       read(4,110)(grcon(i,j,k), i=1,11)
110    format (20x,11e10.2)
21     continue
20     continue
c
c      read cloud dose conversion factors
c
c      skip top line
       read(3,90)
c
       do 30 k=1,259
       read(3,120)(clcon(i,k), i=1,11)
120    format(10x,11e10.2)
30     continue
```

```
c     assigning orgnames to orgnam array
      orgnam(1) = 'lung      '
      orgnam(2) = 't marrow'
      orgnam(3) = 'skeleton'
      orgnam(4) = 'st wall '
      orgnam(5) = 'si+cont '
      orgnam(6) = 'uli wall'
      orgnam(7) = 'lli wall'
      orgnam(8) = 'testes  '
      orgnam(9) = 'thyroid '
      orgnam(10) = 'ovaries '
      orgnam(11) = 'w body  '
c
c
c      NOTE:  FOR INHALATION:
c      THE TIME PERIODS 3 THROUGH 7 MUST BE CHANGED TO 1-10,10-20,20-30,
c      30-40, AND 40-50.  TIME PERIODS 1 AND 2 REMAIN THE SAME.
c
      do 220 k=1,259
      do 230 i=1,11
      incon(i,1,k) = in1(i,1,k)
      incon(i,2,k) = in1(i,2,k)
      do 240 j=3,7
      m = j - 1
      incon(i,j,k) = in1(i,j,k) - in1(i,m,k)
240   continue
      m = 0
230   continue
220   continue
c
c
c     writing to fdtr1
      write(6,140) (iso(i), i=1,259)
140   format(10a8)
      do 85 i=1,11
      write(6,150) orgnam(i)
150   format(a8)
      write(6,160)((incon(i,time,isonum), time=1,7),
     1(grcon(i,time,isonum), time=1,3), clcon(i,isonum), isonum=1,259)
160   format(1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,
     11pe10.2,1pe10.2,1pe10.2,1pe10.2)
85    continue
c
c     i will write to a file called second2 for the purpose of observing
c     more closely  the inhalation dose conversion factors, particularly
c     because of the correction due to the time periods.
c
c
      do 300 k=1,259
      do 310 i=1,11
      do 320 j=1,7
      inc(i,j,k) = incon(i,j,k)
320   continue
310   continue
300   continue
      write(7,303)
303   format(' NUCLIDE  ','TIME INDEX','   LUNG   ',' MARROW  ',
     1' SKELETON ',' GI:ST   ',' GI:SI  ',' GI:ULI  ',' GI:LLI  ',
     2'  TESTES  ',' THYROID ',' OVARIES  ',' WH BODY ')
      do 25 k = 1,259
      do 35 j = 1,7
      if (j.eq.1) write(7,500) iso(k),j,(inc(i,j,k), i=1,11)
      if (j.ne.1) write(7,600) j,(inc(i,j,k), i=1,11)
500   format(a8,2x,5x,I1,4x,1pe10.2,1pe10.2,1pe10.2,1pe10.2,
     11pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2)
600   format(10x,5x,I1,4x,1pe10.2,1pe10.2,1pe10.2,1pe10.2,
     11pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2)
35    continue
25    continue
      stop
      end
```

```
c   step6 computer code; cray fortran
c
c    this code reads in the necessary ingestion dose conversion factors
c    from Fetter's files.  The times of interest are: 0-50,0-10,10-20,
c    20-30,30-40, and 40-50.
c
c
c234567
c     declare variables
      real ing1(259,9,11),ing(259,6,11),dcflli(259,9),dcfsi(259,9),
     1dcfst(259,9),dcfuli(259,9),dcflun(259,9),dcfov(259,9),
     1dcfmar(259,9),dcfskl(259,9),dcftst(259,9),dcfthy(259,9),
     1dcfwb(259,9)
      character*8 iso(259)
c
      call dropfile(0)
      open(unit=2,file='idcf.3nb',status='old')
      open(unit=3,file='idcf.4nb',status='old')
      open(unit=4,file='ingest',status='unknown')
      open(unit=5,file='fusdos3',status='old')
c
c     read in isotope names
      read(5,180) (iso(i), i=1,259)
180   format(10a8)
c234567
c     skip top lines in both files
      read(2,90)
      read(3,90)
90    format(130x)
c
      do 10 i=1,259
      do 15 j=1,9
      read(2,100) dcflli(i,j),dcfsi(i,j),dcfst(i,j),dcfuli(i,j),
     1dcflun(i,j),dcfov(i,j)
      read(3,110) dcfmar(i,j),dcfskl(i,j),dcftst(i,j),dcfthy(i,j),
     1dcfwb(i,j)
100   format (40x,4e10.2,20x,e10.2,10x,e10.2)
110   format (30x,2e10.2,10x,2e10.2,20x,e10.2)
15    continue
10    continue
c
c
      do 25 i=1,259
      do 30 j=1,9
      ing1(i,j,1) = dcflun(i,j)
      ing1(i,j,2) = dcfmar(i,j)
      ing1(i,j,3) = dcfskl(i,j)
      ing1(i,j,4) = dcfst(i,j)
      ing1(i,j,5) = dcfsi(i,j)
      ing1(i,j,6) = dcfuli(i,j)
      ing1(i,j,7) = dcflli(i,j)
      ing1(i,j,8) = dcftst(i,j)
      ing1(i,j,9) = dcfthy(i,j)
      ing1(i,j,10) = dcfov(i,j)
      ing1(i,j,11) = dcfwb(i,j)
30    continue
25    continue
      do 50 i=1,259
      do 60 k=1,11
      ing(i,1,k) = ing1(i,9,k)
      ing(i,2,k) = ing1(i,5,k)
      do 65 l=3,6
      j = l + 3
      m = l + 2
      ing(i,l,k) = ing1(i,j,k) - ing1(i,m,k)
65    continue
      j = 0
      m = 0
      l = 0
60    continue
50    continue
```

```
c
c     writing to ingest
c
      write(4,147)
147   format(' NUCLIDE  ','TIME INDEX','   LUNG    ',' T MARROW ',
     1' SKELETON ','  ST WALL ','  SI+CONT ',' ULI WALL ',' LLI WALL ',
     2'  TESTES  ',' THYROID  ',' OVARIES  ','  W BODY  ')
      do 105 i=1,259
      do 115 j=1,6
      if(j.eq.1) write(4,150) iso(i),j,(ing(i,j,k), k=1,11)
      if(j.ne.1) write(4,160) j,(ing(i,j,k), k=1,11)
150   format(a8,2x,5x,I1,4x,1pe10.2,1pe10.2,1pe10.2,1pe10.2,
     11pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2)
160   format(10x,5x,I1,4x,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,
     11pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2,1pe10.2)
115   continue
105   continue
      stop
      end
```

Appendix C

CREATION OF THE OUTPUT FILE FUSFET.O

Definitions of important variables:

k:	spatial interval; k=2 corresponds to 1 km; k=10 corresponds to 10 km	
labd:	label variable	
1sec:	sector number; sector of interest = #1	
wb:	whole body	
ires:	result number:	6 corresponds to total latent effects from initial plus chronic exposure 7 corresponds to the total whole body man rem 19 corresponds to the total effects to the whole body, where the whole body is treated as a single organ

Note: The single quotes that appear in the format statements were needed so that when the output files were downloaded from the Cray to an IBM PC, the single quotes were easily changed to double quotes uniformly by the KEDIT processor. The files were then transferred to Lotus and treated as numerical files.

```
 line no.          coding
  in the
tedi editor

    731     c
  * 732        call open(47,'fusfet.o',2,len)
  * 733        call skipeof(47,1)
  * 734        backspace(47)
    735     c


   1091        write (not,60) id,icd
  * 1092        write (47,61) id,icd
   1093     60 format (1h0,10x,18a4,7x,a1,//)
  * 1094     61 format ("'",12a4,"'",7x,a1)
   1095     c


   4934        if(nph .lt. 3) go to 715
   4935        if(nlc.eq.1 .or. nlc.eq.2) go to 715
   4936        write(not,635)
   4937    635 format(///,20x,"latent effects from chronic exposure",/)
  * 4938        if((k.ne.2).and.(k.ne.8)) go to 8906
  * 4939        write(47,8635)
  * 4940   8635 format(///,20x,"'latent effects from chronic exposure'",/)
   4941     c check for interdiction
  * 4942   8906 if(timek .le. 10950.) go to 715


   5778     c
   5779     c print heading for health effects if nph>0
   5780        if(nph.ge.1) write(not,2001) k
   5781        if(nph.ge.1) write(not,2003) il
  * 5782        if(k.eq.2) write(47,8001) k
  * 5783        if(k.eq.2) write(47,8003) il
   5784     c


   5882     c erlinj is the total probability of occurence of an injury
   5883        if(fatfac(iearly) .lt. 1.0) erlinj(il) = erlinj(il) +
   5884       1 pb(iearly,il) * (1. - erlinj(il))
   5885        if(nph.ge.1) write (not,2000) erlorg(iearly),pb(iearly,il),
   5886       1 totdos(iearly,il),cloud(iorg),ground(iorg),breath(iorg),
   5887       2 fatal(il),erlinj(il)
  * 5888          if(k.eq.2) write(47,8000) erlorg(iearly),pb(iearly,il),
  * 5889       1 totdos(iearly,il),cloud(iorg),ground(iorg),breath(iorg),
  * 5890       2 fatal(il),erlinj(il)


   5912     c
   5913     c print heading for detailed output
   5914        if(nph.ge.2) write(not,2002)
  * 5915        if(k.eq.2) write(47,8002)
  * 5916        if(k.eq.8) write(47,8002)
   5917     c


  * 4454        real labd(4)
  * 4455        real wb
  * 4456        data wb /6hw body/


  * 4471        data labd /8h'inh ds ,8h'ing ds ,8h'grd ds',7h'cases'/
```

```
 line no.          coding
  in the
tedi editor

   5040       if(nph .le. 2) go to 1710
   5041       write(not,1800) laorg(lorg),laeff(lorg),k,lsec
 * 5042       if((k.ne.2).and.(k.ne.8)) go to 8901
 * 5043       if(lsec.ne.1) go to 8901
 * 5044       if((laorg(lorg).ne.wb).or.(laeff(lorg).ne.wb)) go to 8901
 * 5045       write(47,8808) laorg(lorg), laeff(lorg),k,lsec
 * 5046 8901  if(lsec .eq. 1) write(not,1801)
   5047      1       alabel(1),ibl,(temc1(itime,lorg),itime=1,10),
   5048      2       alabel(2),ihm,(temc2m(itime,lorg),itime=1,10),
   5049      3       alabel(2),ihc,(temc2c(itime,lorg),itime=1,10),
   5050      4       alabel(3),(temc3(itime,lorg),itime=1,10)
 * 5051        if((k.ne.2).and.(k.ne.8)) go to 8931
 * 5052        if(lsec.ne.1) go to 8931
 * 5053        if((laorg(lorg).ne.wb).or.(laeff(lorg).ne.wb)) go to 8931
 * 5054        write(47,8801)
 * 5055      1       labd(1),ibl,(temc1(itime,lorg),itime=1,10),
 * 5056      2       labd(2),ihm,(temc2m(itime,lorg),itime=1,10),
 * 5057      3       labd(2),ihc,(temc2c(itime,lorg),itime=1,10),
 * 5058      4       labd(3),(temc3(itime,lorg),itime=1,10)
 * 5059 8931  write(not,1802) alabel(4), (totchr(lorg,itime),itime=1,10)
 * 5060       if((k.ne.2).and.(k.ne.8)) go to 1710
 * 5061       if(lsec.ne.1) go to 1710
 * 5062       if((laorg(lorg).ne.wb).or.(laeff(lorg).ne.wb)) go to 1710
 * 5063       write(47,8802) labd(4),(totchr(lorg,itime),itime=1,10)
   5064 1800  format(10h organ is ,a8,13h   effect is ,a8,11h   interval,i3,
   5065      1      13h  and sector ,i3)
 * 5066 8808  format(10h'organ is ,a8,13h' 'effect is ,a8,11h' 'interval,i3,
 * 5067      1 1h',13h' and sector ,i3,1h')
   5068 1801  format(3(1x,a8,1x,a1,1p10e11.3/),1x,a8,2x,1p10e11.3)
   5069 1802  format(1x,a5,5x,1p10e11.3/)
 * 5070 8801  format(3(1x,a8,1x,a1,"'",1p10e11.3/),1x,a8,2x,1p10e11.3)
 * 5071 8802  format(1x,a7,3x,1p10e11.3/)
   5072    c
 * 5073 1710  continue


 * 5737       real labd(3)
 * 5738       real wb
 * 5739       data wb /6hw body/


 * 5745       data labd /"'cl,grd'","'inh ds'","'case/p'"/


   6083    c print results for this organ if requested
   6084       if(nph.lt.2) go to 720
   6085       write(not,2005) laorg(ila),laeff(ila),cloud(iorg),ground(iorg)
   6086       write(not,2010) alabel(2), (airin(i), i=1,intime)
   6087       write(not,2010) alabel(3),
   6088      1 (totlat(ila,itime),itime=1,intime),totorg(ila)
 * 6089       if((k.ne.2).and.(k.ne.8)) go to 720
 * 6090       if((laorg(ila).ne.wb).or.(laeff(ila).ne.wb)) go to 720
 * 6091       write(47,8005) laorg(ila),laeff(ila),cloud(iorg),ground(iorg)
 * 6092       write(47,8010) labd(2), (airin(i), i=1,intime)
 * 6093       write(47,8010) labd(3),
 * 6094      1 (totlat(ila,itime),itime=1,intime),totorg(ila)
 * 6095   720 continue
```

```
 line no.          coding
  in the
tedi editor

  6097   c
  6098 2000 format(" ",a8,3x,1p7e11.3)
* 6099 8000 format(" ","'",a8,"'",3x,1p7e11.3)
  6100 2001 format("1",20x,"* * * * * health effects detailed output - ",
  6101     1 "spatial interval number =",i3," * * * * *",//)
* 6102 8001 format("1",20x,"' * * * * health effects detailed output - ",
* 6103     1 "spatial interval number =",i3," * * * * '",//)
  6104 2003 format(20x,"acute effects from early exposure, evacuation
  6105     1 scheme",i3,//,1x,"organ        prob      total ds   cloud ds
  6106     2     ground ds     inhal ds   cum",
  6107     4 "fatal  cum injur",/)
* 6108 8003 format(20x,"'acute effects from early exposure'",
* 6109     1 i3,//,1x,"'organ'     'prob'    'total ds' 'cloud ds'
* 6110     2 'ground ds' 'inhal ds' 'cum",
* 6111     4 "fatal' 'cum injur'",/)
  6112 2002 format(///,20x,"latent effects from early exposure",/)
* 6113 8002 format(///,20x,"'latent effects from early exposure'",/)
  6114 2005 format(" ","organ is ",a8,"   effect is ",a8,"  cloud ds =",
  6115     1 1pe10.3,"   ground ds =",1pe10.3)
* 6116 8005 format(" ","'organ is ",a8,"'","'effect is ",a8,"'",
* 6117     1 "'cloud ds ='",1pe10.3,"'ground ds ='",1pe10.3)
  6118 2006 format("1",20x,"isotope percentage contribution to dose",//,
  6119     1 1x,"isotope  ",8(7x,a8))
  6120 2007 format(15x,8(a1,"dose",4x,"0",5x),/)
  6121 2008 format(1x,a8,2x,8(f10.2,1x,f4.1))
  6122 2009 format(1x,"total   ",2x,8(f10.2,5x))
  6123 2010 format(" ",a8,11(1pe11.3))
* 6124 8010 format(" ",a8,11(1pe11.3))


  7941       write(not,960)
* 7942       write(47,9601)
  7943       if(nl .eq. np2p1) write(net,960)
  7944       ip2=0
  7945 7500 continue
  7946       ires=i
  7947       if(nevac .eq. 1) ires=i - neres
  7948       ip1 = ip1 + 1
  7949       ip2 = ip2 + 1
  7950       write(not,980) ires,(resnam(l,ii),l=1,2),(resu(iii,in),in=1,5),
  7951     1 itrial,itime,ibin
* 7952       if((ires.ne.6).and.(ires.ne.7).and.(ires.ne.19)) go to 7777
* 7953       write(47,9801) ires,(resnam(l,ii),l=1,2),(resu(iii,in),in=1,5),
* 7954     1 itrial,itime,ibin
* 7955 7777 if(nl.eq.np2p1) write(net,980) ires,(resnam(l,ii),l=1,2),
  7956     1 (resu(iii,in),in=1,5),itrial,itime,ibin
  7957 7000 continue


  8056  960 format(/,
  8057     1 5x,"** description **  *** mean ***  * variance *  * p(not 0)
  8058     2 "," *  *** peak ***  ** p(peak) *  ******** trial ********")
* 8059 9601 format(/,5x,
* 8060     1  " ' ''**description**' '** mean **' '*variance*' '*p(not 0)'
* 8061    - 2  ","'*  *** peak ***''** p(peak) *''******** trial ********'")
  8062  980 format(1x,i3,1x,2a8,3x,1pe10.2,4(4x,1pe10.2),5x,i8,i8,i3)
* 8063 9801 format(1x,i3,1x,"'",2a8,"'",3x,1pe10.2,
  8064     1  4(4x,1pe10.2),5x,i8,i8,i3)
```

THE FOLLOWING IS A SAMPLE OUTPUT FILE CREATED BY THE ADDITIONS NOTED ABOVE, COMBINED WITH THE DATA FROM FETTER'S ESECOM FILES, AND MANIPULATED USING IBM LOTUS.

ISOTOPE = PO-210 AMOUNT RELEASED = 1 Ci 2,3,5,6,8

execute FUSCRAC3

**** 1 km info: ****

acute effects from early exposure

organ	prob	total ds	cloud ds	ground ds	inhal ds	cumfatal	cum injur
t marrow	0.000E+00	3.463E-04	1.522E-11	4.507E-09	3.463E-04	0.000E+00	0.000E+00
lli wall	0.000E+00	5.564E-04	8.799E-12	2.589E-09	5.564E-04	0.000E+00	0.000E+00
lung	0.000E+00	4.307E-01	1.234E-11	3.675E-09	4.307E-01	0.000E+00	0.000E+00
w body	0.000E+00	8.052E-04	1.315E-11	3.883E-09	8.052E-04	0.000E+00	0.000E+00

latent effects from early exposure

organ is w bodyeffect is w bodcloud ds = 1.315E-11 ground ds = 3.883E-09

inh ds	1.231E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
case/p	1.943E-06	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

latent effects from chronic exposure

organ is w bodyeffect is w bodinterval 2 and sector 1

inh ds	1.352E-03	1.216E-02	2.162E-13	0.000E+00	0.000E+00	0.000E+00	2.922E-22	2.922E-22
ing ds m	1.678E+00	1.510E+01	3.079E-25	3.079E-25	3.079E-25	3.079E-25	7.684E-26	7.684E-26
ing ds c	7.969E-02	7.172E-01	1.462E-26	1.462E-26	1.462E-26	1.462E-26	3.624E-27	3.624E-27
grd ds	3.618E-08	1.617E-09	1.617E-09	1.617E-09	0.000E+00	0.000E+00	0.000E+00	4.136E-24
cases	1.990E-03	1.791E-02	8.595E-14	8.594E-14	3.652E-28	3.652E-28	1.782E-26	1.807E-26

**** 10 km info: ****

latent effects from early exposure

organ is w bodyeffect is w bodcloud ds = 1.105E-12 ground ds = 2.697E-10

inh ds	8.544E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
case/p	1.349E-07	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

tot lat erl: 8.544E-04

latent effects from chronic exposure

organ is w bodyeffect is w bodinterval 8 and sector 1

inh ds	9.386E-05	8.447E-06	1.501E-14	0.000E+00	0.000E+00	0.000E+00	2.029E-23	2.029E-23
ing ds m	1.165E-01	1.049E+00	2.138E-26	2.138E-26	2.138E-26	2.138E-26	5.334E-27	5.334E-27
ing ds c	5.534E-03	4.980E-02	1.015E-27	1.015E-27	1.015E-27	1.015E-27	2.517E-28	2.517E-28
grd ds	2.513E-09	9.838E-11	9.838E-11	9.838E-11	0.000E+00	0.000E+00	0.000E+00	2.872E-25
cases	4.059E-04	3.653E-03	1.753E-14	1.753E-14	7.448E-29	7.448E-29	3.634E-27	3.685E-27
tot ing:	1.220E-01	1.099E+00	2.240E-26	2.240E-26	2.240E-26	2.240E-26	5.588E-27	5.588E-27
inh + grd:	9.386E-05	8.447E-06	9.840E-11	9.838E-11	0.000E+00	0.000E+00	2.029E-23	2.058E-23
tot chron:	1.221E-01	1.100E+00	9.840E-11	9.838E-11	2.240E-26	2.240E-26	2.030E-23	2.058E-23

inh+grd;50yrs: 9.386E-04

inh+grd;50yrs +
tot lat erl: 1.793E-03

chron 50 yrs: 1.222E+00

chron 50 yrs +
tot lat erl: 1.223E+00

	description**	mean **	*variance*	*p(not 0)	* *** peak *****	p(peak) *	********	trial *******
6.000E+00	tot lat/total	1.440E+00	0.000E+00	1.000E+00	1.440E+00	1.000E+00	1.010E+06	4.001E+05
7.000E+00	tot wbody manre	3.630E+04	0.000E+00	1.000E+00	3.630E+04	1.000E+00	1.010E+06	4.001E+05
1.900E+01	total w body	5.740E+00	0.000E+00	1.000E+00	5.740E+00	1.000E+00	1.010E+06	4.001E+05

FETTER'S NUMBERS

Nuclide	Activity Released (Ci)	Critical Dose (1 km) (rem)	Chronic Dose (10 km) (rem)	Critical Dose (1 km) (rem/Ci)	Chronic Dose (10 km) (rem/Ci)
Po-210	1.060E+02	5.110E-01	2.740E-01	4.821E-03	2.585E-03

Appendix D

REM/CI DATA FOR ALL 259 ISOTOPES

The following is a presentation of the rem/Ci data generated from pessimistic release assumptions as specified in Section 4.1, and as listed at the beginning of the following table. Because of the enormous quantity of data, it was decided tht the following was the optimal presentation of the data, allowing for the complete, uncut information while maintaining readability.

The column labels require further explanation, which is given below:

PROMPT DOSE AT 1 KM:	The dose delivered to a particular organ at 1 km from the release, from cloudshine during plume passage, 7 days of groundshine, and the dose commitment over an organ–dependent critical acute time period from inhalation during plume passage
WB:	Whole body, t_{acute} = 2 days
BM:	Bone marrow, t_{acute} = 7 days
LLI:	Lower large intestine, t_{acute} = 7 days
Lung:	Lung, t_{acute} = 1 year
FETTER WB:	Fetter's critical whole body dose at 1 km, where the critical dose is that dose delivered from cloudshine and groundshine during a 10–hour plume passage, plus the dose due to inhalation during a 10–hour plume passage delivered over the first 7 days after initial exposure plus one–half the dose delivered over the next 23 days
WB EARLY DOSE:	The whole body early dose, where early dose is the dose from initial exposure; i.e., cloudshine during plume passage, 7 days of groundshine, plus the 50–year dose commitment from radioactivity inhaled during plume passage; differs from prompt because the inhalation commitment is over a longer time period
WB CHRONIC DOSE AT 1 KM AND AT 10 KM	The whole body dose at 1 km/10 km from the release due to both initial exposure and chronic (50 year) exposure:

Inh+grd:	Chronic exposure considers the 50–year groundshine exposure plus the 50–year dose commitment from inhaled resuspended radioactivity. Ingestion is not included. (This corresponds to Fetter's definition of whole body chronic dose.)
Ing:	Chronic exposure considers the ingestion pathway only.
Total:	Chronic exposure considers all three pathways: resuspension, groundshine, and ingestion.
Fetter WB at 10 km:	Fetter's whole body chronic dose at 10 km, which includes the dose due to initial plume exposure plus groundshine and resuspension over a 50–year chronic exposure period. (See the above definition of "WB CHRONIC DOSE AT 10 KM: Inh+grd".) Note that Fetter's chronic dose does not account for ingestion.
CANCERS: Sum Organs	Total number of cancers in a 50–mile radius from initial and chronic exposure, where the body is treated as a sum of individual organs and calculations are based on organ–specific dose factors and dose responses.
CANCERS: WB	Total number of cancers in a 50–mile radius from initial and chronic exposure, where the body is treated as a single organ and the whole body dose conversion factors and dose response are used.
WB: Man–rems	Total whole body man–rem due to both initial exposure plus an 80–year chronic exposure to the whole body — this is a population dose.

THE FOLLOWING IS A TABLE OF THE DOSE INFORMATION FOR A RELEASE OUTLINED BELOW:

STABILITY = CLASS F
WINDSPEED = 1 m/s
INVERSION LAYER = 250m
GROUND LEVEL RELEASE
PUFF RELEASE: DURATION = 0.05 HRS
POPULATION DENSITY = 50 PEOPLE/km2

DEPOSITION VELOCITIES:
H-3: 0.001 m/s
NOBLE GASES: 0.0 m/s
ALL OTHERS: 0.01 m/s

PLUME DIMENSIONS:
SIGMA-Y = 100m
SIGMA-Z = 50m

GROUNDSHINE SHIELDING:
PROMPT DOSE = 0.7
CHRONIC DOSE = 0.33

REM/Ci VALUES:

ISOTOPE	PROMPT DOSE AT 1 KM WB	BM	Lung	LLI	Fetter WB	WB EARLY DOSE 1 km	10 km	WB CHRONIC DOSE AT 1 KM (chronic plus early) Inh+ord	Ingestion	Total	WB CHRONIC DOSE AT 10 KM (chronic plus early) Inh+ord	Ingestion	Total	Fetter WB at 10 km	CANCERS Sum organs	CANCERS WB	WB Non-preg
H-3	1.169E-07	4.261E-07	9.345E-07	1.454E-07	7.919E-07	9.010E-07	2.087E-07	1.239E-06	4.641E-05	4.765E-05	2.869E-07	1.075E-05	1.104E-05	2.815E-07	1.370E-05	2.780E-05	1.760E-01
BE-7	2.423E-05	3.001E-05	3.538E-05	1.945E-05	--------	2.542E-05	1.765E-06	1.400E-04	0.000E+00	1.400E-04	9.769E-06	0.000E+00	9.769E-06	--------	1.150E-06	2.010E-06	1.270E-02
BE-10	1.531E-06	1.822E-07	4.184E-03	1.363E-04	7.544E-06	3.566E-04	2.477E-05	1.829E-03	1.189E-02	1.372E-02	1.271E-04	8.260E-04	9.531E-04	1.219E-04	2.670E-02	2.920E-03	1.850E+01
C-14	3.211E-08	4.962E-08	4.644E-07	1.615E-08	1.033E-07	2.173E-07	1.509E-08	2.149E-06	4.719E-03	4.721E-03	1.493E-07	3.279E-04	3.281E-04	4.066E-07	2.240E-04	4.550E-04	2.880E+00
N-13	7.496E-07	9.036E-07	1.106E-06	5.401E-07	2.300E-07	7.496E-07	1.748E-12	8.581E-07	0.000E+00	8.581E-07	1.970E-12	0.000E+00	1.970E-12	7.274E-13	1.010E-09	1.620E-09	1.020E-05
N-16	8.278E-19	7.346E-19	7.623E-19	7.210E-19	0.000E+00	8.278E-19	6.960E-20	8.290E-19	0.000E+00	8.290E-19	6.948E-20	0.000E+00	6.948E-20	0.000E+00	0.000E+00	0.000E+00	9.899E-17
F-18	8.947E-06	1.092E-05	1.184E-05	6.496E-06	--------	8.946E-06	2.495E-07	1.238E-05	4.268E-07	1.280E-05	3.421E-07	1.151E-08	3.536E-07	--------	8.190E-08	1.370E-07	8.670E-04
NA-22	1.046E-03	1.208E-03	1.060E-03	8.029E-04	8.963E-05	1.100E-03	7.642E-05	4.723E-02	1.036E+00	1.083E+00	3.282E-03	7.194E-02	7.523E-02	1.400E-02	9.930E-02	1.420E-01	9.010E+02
NA-24	2.243E-04	2.257E-04	2.490E-04	1.902E-04	4.854E-05	2.249E-04	1.401E-05	3.246E-04	1.702E-04	4.948E-04	2.018E-05	1.054E-05	3.072E-05	1.701E-05	2.730E-05	3.870E-05	2.450E-01
MG-27	5.940E-07	6.695E-07	1.107E-06	3.832E-07	1.612E-07	5.940E-07	7.992E-13	6.722E-07	1.575E-09	6.738E-07	8.909E-13	1.846E-15	8.928E-13	3.008E-13	7.990E-10	1.250E-09	7.890E-06
MG-28	2.618E-04	2.807E-04	5.079E-04	3.073E-04	5.182E-05	2.635E-04	1.693E-05	3.170E-04	2.043E-04	5.213E-04	2.035E-05	1.307E-05	3.342E-05	2.345E-05	8.620E-05	2.720E-05	1.720E-01
AL-26	1.279E-03	1.413E-03	4.529E-03	1.385E-03	1.054E-04	1.534E-03	1.667E-04	4.928E-01	1.065E-02	5.035E-01	3.425E-02	7.403E-04	3.499E-02	1.515E-01	1.730E-02	2.390E-02	1.510E+02
AL-28	1.846E-08	1.887E-08	2.254E-08	1.588E-08	1.338E-09	1.865E-08	2.563E-20	1.929E-08	0.000E+00	1.929E-08	2.637E-20	0.000E+00	2.637E-20	0.000E+00	2.838E-12	5.120E-12	3.240E-08
AL-29	5.062E-07	5.275E-07	7.881E-07	3.906E-07	9.346E-08	5.062E-07	5.841E-15	5.531E-07	0.000E+00	5.531E-07	6.304E-15	0.000E+00	6.304E-15	1.385E-15	4.230E-10	6.990E-10	4.438E-06
SI-31	3.609E-07	2.390E-08	1.912E-05	7.073E-07	2.078E-07	3.609E-07	1.296E-08	3.652E-07	7.989E-07	1.164E-06	1.309E-08	2.862E-08	4.171E-08	8.826E-09	9.570E-08	3.660E-08	2.320E-04
SI-32	8.440E-07	7.775E-07	3.208E-03	8.613E-05	1.542E-05	9.857E-05	6.859E-06	5.005E-04	4.944E-06	5.055E-04	3.479E-05	3.427E-06	3.822E-05	3.380E-05	5.870E-05	1.320E-05	8.390E-02
P-32	5.215E-06	5.179E-05	6.915E-05	2.964E-05	3.142E-05	3.205E-05	2.216E-06	3.754E-05	8.749E-03	8.784E-03	2.595E-06	6.048E-04	6.074E-04	5.047E-06	3.250E-03	1.660E-03	1.050E+01
P-33	5.888E-07	2.065E-06	8.621E-06	3.735E-06	4.611E-06	5.958E-06	4.127E-07	7.488E-06	2.400E-03	2.408E-03	5.187E-07	1.663E-04	1.669E-04	9.081E-07	4.810E-04	4.440E-04	2.810E+00
S-35	1.934E-07	2.663E-07	6.627E-06	2.241E-06	--------	1.969E-06	1.367E-07	3.481E-06	2.488E-03	2.491E-03	2.416E-07	1.727E-04	1.729E-04	--------	4.120E-04	4.090E-04	2.590E+00
S-37	5.988E-07	5.728E-07	6.636E-07	5.112E-07	--------	5.988E-07	6.520E-17	6.354E-07	0.000E+00	6.354E-07	4.754E-17	0.000E+00	4.754E-17	--------	3.120E-10	5.940E-10	3.760E-06
CL-36	2.051E-06	6.421E-06	3.920E-05	4.941E-06	1.547E-05	1.523E-05	1.058E-06	1.187E-04	0.000E+00	1.187E-04	8.244E-06	0.000E+00	8.244E-06	2.023E-05	2.160E-05	2.850E-05	1.810E-01
CL-40	1.301E-09	1.283E-09	1.357E-09	1.100E-09	--------	1.301E-09	5.265E-20	1.327E-09	0.000E+00	1.327E-09	5.353E-20	0.000E+00	5.353E-20	--------	6.800E-14	1.310E-13	8.280E-10
AR-39	2.042E-10	3.439E-10	1.661E-10	9.968E-11	1.369E-09	2.042E-10	6.441E-11	2.042E-10	0.000E+00	2.042E-10	6.441E-11	0.000E+00	6.441E-11	1.371E-10	2.490E-11	4.060E-11	2.570E-07
AR-41	2.258E-06	2.401E-06	2.143E-06	1.753E-06	4.666E-07	2.258E-06	2.764E-07	2.258E-06	0.000E+00	2.258E-06	2.764E-07	0.000E+00	2.764E-07	3.707E-08	3.020E-08	5.880E-08	3.720E-04
AR-42	2.849E-07	2.720E-07	1.309E-06	2.642E-07	2.741E-06	2.915E-07	1.900E-07	3.922E-07	9.023E-07	1.295E-06	2.553E-07	5.850E-07	8.403E-07	3.807E-03	3.860E-07	5.390E-07	3.540E-03
K-40	7.517E-05	8.965E-05	2.215E-04	7.261E-05	5.702E-05	1.725E-04	1.199E-05	2.794E-02	0.000E+00	2.794E-02	1.941E-03	0.000E+00	1.941E-03	8.493E-03	4.380E-01	7.400E-01	4.680E+03
K-42	1.826E-05	1.730E-05	8.336E-05	1.682E-05	9.513E-06	1.856E-05	1.127E-06	2.497E-05	5.747E-05	8.244E-05	1.514E-06	3.471E-06	4.985E-06	1.464E-06	4.200E-06	6.130E-06	3.880E-02
K-43	9.584E-05	1.184E-04	1.115E-04	6.797E-05	1.862E-05	9.657E-05	6.220E-06	1.397E-04	7.943E-05	2.192E-04	9.002E-06	5.107E-06	1.411E-05	8.768E-06	7.340E-06	1.090E-05	6.880E-02
CA-41	2.660E-08	4.951E-08	1.469E-05	9.528E-07	1.562E-07	1.319E-05	9.163E-07	6.910E-05	0.000E+00	6.910E-05	4.801E-06	0.000E+00	4.801E-06	5.382E-06	6.630E-06	4.180E-06	2.740E-02
CA-45	6.593E-07	1.319E-06	3.621E-04	3.578E-05	4.795E-06	2.154E-05	1.496E-06	4.837E-05	1.145E-02	1.150E-02	3.359E-06	7.953E-04	7.987E-04	5.049E-06	2.290E-03	1.410E-03	8.920E+00
CA-47	3.273E-04	3.754E-04	5.912E-04	3.825E-04	3.324E-05	3.365E-04	2.308E-05	5.511E-04	9.603E-04	1.519E-03	3.779E-05	6.632E-05	1.041E-04	6.122E-05	6.510E-04	1.600E-04	1.010E+00
SC-44	3.674E-05	4.167E-05	6.739E-05	2.950E-05	1.836E-05	3.675E-05	1.670E-06	5.191E-05	3.851E-06	5.576E-05	2.346E-06	1.717E-07	2.518E-06	1.469E-06	7.140E-07	7.550E-07	4.780E-03
SC-44m	4.977E-04	5.871E-04	7.006E-04	6.230E-04	--------	5.021E-04	3.479E-05	5.379E-04	2.809E-04	8.188E-04	3.758E-05	1.904E-05	5.662E-05	--------	1.160E-04	2.290E-05	1.450E-01
SC-46	8.893E-04	1.001E-03	2.312E-03	7.476E-04	5.888E-05	9.712E-04	6.747E-05	7.158E-03	1.493E-03	8.651E-03	4.970E-04	1.036E-04	6.006E-04	1.863E-03	5.890E-04	2.290E-04	1.450E+00
SC-47	3.421E-05	5.291E-05	1.127E-04	9.618E-05	4.966E-06	3.516E-05	2.394E-06	5.542E-05	6.827E-05	1.237E-04	3.771E-06	4.644E-06	8.415E-06	5.655E-06	3.950E-05	4.520E-06	2.860E-02
SC-48	5.322E-04	5.888E-04	6.125E-04	4.948E-04	5.806E-05	5.347E-04	3.578E-05	7.966E-04	2.115E-04	1.008E-03	5.326E-05	1.412E-05	6.738E-05	6.406E-05	5.810E-05	2.240E-05	1.420E-01
SC-49	1.609E-07	4.711E-09	1.020E-05	3.328E-08	6.535E-08	1.609E-07	1.808E-09	1.624E-07	1.315E-07	2.939E-07	1.825E-09	1.476E-09	3.300E-09	8.713E-10	1.420E-08	5.250E-09	3.320E-05
SC-50	6.573E-09	7.037E-09	7.245E-09	5.140E-09	3.977E-10	6.573E-09	4.332E-20	6.768E-09	0.000E+00	6.768E-09	4.439E-20	0.000E+00	4.439E-20	0.000E+00	5.640E-13	1.040E-12	6.610E-09
TI-44	1.062E-03	1.289E-03	4.946E-03	1.153E-03	--------	2.064E-03	1.440E-04	2.809E-02	1.942E-07	2.809E-02	1.953E-03	1.092E-07	1.953E-03	--------	4.040E-04	5.610E-04	3.560E+00
TI-45	1.281E-05	1.527E-05	2.744E-05	9.946E-06	--------	1.281E-05	5.171E-07	1.799E-05	1.265E-06	1.925E-05	7.217E-07	5.000E-08	7.717E-07	--------	2.260E-07	2.450E-07	1.550E-03
TI-51	1.049E-07	1.337E-07	2.856E-07	6.539E-08	2.291E-08	1.049E-07	1.401E-16	1.151E-07	0.000E+00	1.151E-07	1.518E-16	0.000E+00	1.518E-16	4.000E-17	1.050E-10	1.270E-10	8.030E-07
V-48	1.155E-03	1.300E-03	1.459E-03	9.910E-04	7.342E-05	1.178E-03	8.153E-05	3.162E-03	1.254E-03	4.416E-03	2.188E-04	8.671E-05	3.055E-04	5.871E-04	3.350E-04	1.260E-04	7.950E-01
V-49	3.024E-08	1.146E-08	2.039E-05	2.004E-06	1.600E-07	7.699E-07	5.343E-08	2.234E-06	8.393E-05	8.616E-05	1.552E-07	5.829E-06	5.984E-06	2.045E-07	3.230E-05	5.050E-06	3.200E-02
V-52	1.334E-07	1.370E-07	1.786E-07	1.103E-07	1.540E-08	1.334E-07	2.193E-20	1.412E-07	0.000E+00	1.412E-07	2.301E-20	0.000E+00	2.301E-20	0.000E+00	5.280E-11	9.200E-11	5.820E-07
V-53	1.268E-09	1.409E-09	1.557E-09	8.295E-10	7.772E-11	1.268E-09	1.358E-20	1.304E-09	0.000E+00	1.304E-09	1.390E-20	0.000E+00	1.390E-20	0.000E+00	9.770E-14	1.750E-13	1.110E-09

ISOTOPE	PROMPT DOSE AT 1 KM WB	BM	Lung	LLI	Fetter WB	WB EARLY DOSE 1 km	10 km	WB CHRONIC DOSE AT 1 KM Inh+ord	Ingestion	Total	WB CHRONIC DOSE AT 10 KM Inh+ord	Ingestion	Total	Fetter WB at 10 km	CANCERS Sum organs	CANCERS WB	WB Non-reas
CR-49	3.656E-06	4.559E-06	8.677E-06	2.509E-06	2.206E-06	3.656E-06	2.272E-08	4.760E-06	7.597E-08	4.836E-06	2.914E-08	9.126E-10	3.006E-08	1.985E-08	2.320E-08	3.000E-08	1.900E-04
CR-51	1.632E-05	2.195E-05	3.254E-05	1.364E-05	1.125E-06	1.697E-05	1.176E-06	6.123E-05	4.128E-05	1.025E-04	4.244E-06	2.846E-06	7.105E-06	1.320E-05	9.890E-06	3.970E-06	2.510E-02
CR-55	6.272E-10	4.405E-11	4.068E-08	3.714E-11	2.565E-10	6.271E-10	1.063E-22	6.295E-10	0.000E+00	6.295E-10	1.067E-22	0.000E+00	1.067E-22	0.000E+00	4.220E-12	3.740E-13	2.370E-09
MN-52	1.068E-03	1.191E-03	1.154E-03	8.902E-04	7.637E-05	1.080E-03	7.415E-05	1.924E-03	7.918E-04	2.716E-03	1.320E-04	5.430E-05	1.863E-04	2.395E-04	1.200E-04	7.120E-05	4.510E-01
MN-52m	4.406E-06	4.825E-06	8.243E-06	3.420E-06	1.881E-06	4.406E-06	2.501E-09	5.349E-06	3.047E-08	5.380E-06	2.983E-09	1.557E-11	2.999E-09	1.554E-09	1.290E-08	2.010E-08	1.270E-04
MN-53	4.371E-08	1.009E-07	2.839E-05	2.110E-06	2.470E-07	6.875E-07	4.776E-08	5.201E-06	2.583E-03	2.588E-03	3.614E-07	1.795E-04	1.798E-04	7.902E-07	1.020E-03	1.550E-04	9.790E-01
MN-54	3.871E-04	4.470E-04	5.846E-04	2.838E-04	2.667E-05	4.161E-04	2.892E-05	7.837E-03	8.603E-03	1.644E-02	5.443E-04	5.976E-04	1.142E-03	2.252E-03	6.980E-04	5.870E-04	3.720E+00
MN-56	1.849E-05	1.950E-05	4.602E-05	1.446E-05	1.022E-05	1.849E-05	6.733E-07	2.559E-05	1.781E-06	2.737E-05	9.244E-07	6.381E-08	9.874E-07	6.043E-07	2.900E-07	3.340E-07	2.120E-03
MN-57	7.685E-11	9.220E-11	3.995E-10	4.780E-11	5.260E-12	7.684E-11	8.137E-22	7.931E-11	0.000E+00	7.931E-11	8.357E-22	0.000E+00	8.357E-22	0.000E+00	1.320E-14	1.060E-14	6.720E-11
FE-53	6.939E-07	8.353E-07	1.401E-06	4.924E-07	1.948E-07	6.939E-07	2.738E-13	7.836E-07	8.398E-15	7.836E-07	3.046E-13	7.857E-16	3.054E-13	1.031E-13	8.900E-10	1.270E-09	8.050E-06
FE-55	5.647E-08	2.740E-08	3.059E-05	2.163E-06	3.098E-07	6.290E-06	4.349E-07	2.537E-05	1.670E-03	1.696E-03	1.762E-06	1.161E-04	1.178E-04	2.221E-06	1.460E-04	2.600E-04	1.640E+00
FE-59	5.140E-04	5.631E-04	9.475E-04	4.661E-04	4.153E-05	5.579E-04	3.873E-05	2.650E-03	4.298E-03	6.956E-03	1.845E-04	2.981E-04	4.826E-04	6.364E-04	7.888E-04	5.020E-04	3.180E+00
FE-60	4.495E-06	5.104E-06	6.609E-04	5.811E-05	6.172E-06	1.795E-03	1.247E-04	9.072E-03	2.594E-10	9.072E-03	4.302E-04	2.701E-11	6.302E-04	9.802E-04	1.210E-03	1.830E-03	1.160E+01
CO-57	6.863E-05	1.160E-04	4.604E-04	5.278E-05	5.125E-06	8.696E-05	6.043E-06	1.299E-03	5.843E-04	1.885E-03	9.021E-05	3.517E-05	1.254E-04	3.629E-04	1.490E-04	6.510E-05	4.120E-01
CO-58	4.455E-04	5.234E-04	9.413E-04	3.577E-04	2.914E-05	4.784E-04	3.320E-05	3.165E-03	1.058E-03	4.223E-03	2.196E-04	7.345E-05	2.931E-04	8.123E-04	2.600E-04	1.340E-04	8.500E-01
CO-58m	2.281E-06	2.600E-06	7.547E-06	2.686E-06	1.502E-07	2.461E-06	1.725E-07	2.764E-06	6.503E-07	3.414E-06	3.634E-07	1.057E-07	4.691E-07	4.488E-08	3.250E-07	1.430E-07	9.070E-04
CO-60	1.136E-03	1.721E-03	5.128E-03	1.883E-03	7.320E-05	1.841E-03	1.280E-04	9.121E-02	4.935E-02	1.406E-01	6.337E-03	3.429E-03	9.766E-03	2.683E-02	6.170E-03	5.050E-03	3.200E+01
CO-60m	8.645E-09	9.109E-09	7.712E-08	6.229E-09	1.382E-09	1.132E-08	4.859E-10	2.383E-07	1.251E-07	3.634E-07	2.406E-08	1.302E-08	3.709E-08	3.422E-10	2.040E-08	1.700E-08	1.070E-04
CO-61	6.568E-07	8.085E-07	8.177E-06	3.732E-07	5.672E-07	6.568E-07	1.007E-09	7.130E-07	1.916E-07	9.050E-07	1.092E-09	2.059E-10	1.298E-09	2.025E-08	1.180E-08	7.960E-09	5.040E-05
CO-62m	3.014E-06	3.187E-06	4.718E-06	2.237E-06	9.632E-07	3.014E-06	1.339E-10	3.499E-06	9.268E-09	3.508E-06	1.529E-10	3.625E-13	1.532E-10	6.158E-11	5.450E-09	9.160E-09	5.800E-05
NI-57	2.640E-04	2.862E-04	3.035E-04	2.570E-04	3.127E-05	2.651E-04	1.760E-05	3.900E-04	1.114E-04	5.014E-04	2.589E-05	7.383E-06	3.328E-05	2.902E-05	4.530E-05	1.670E-05	1.060E-01
NI-59	2.579E-07	2.067E-07	3.539E-05	2.512E-06	2.610E-07	3.957E-06	2.749E-07	1.015E-04	5.817E-03	5.919E-03	7.058E-06	4.041E-04	4.112E-04	2.695E-05	3.810E-04	4.100E-04	2.590E+00
NI-63	1.179E-07	2.475E-08	9.406E-05	9.582E-06	6.442E-07	9.581E-06	6.657E-07	4.816E-05	1.287E-02	1.292E-02	3.345E-06	8.943E-04	8.976E-04	3.358E-06	1.160E-03	9.030E-04	5.720E+00
NI-65	6.323E-06	6.356E-06	2.577E-05	5.411E-06	3.536E-06	6.323E-06	2.272E-07	8.686E-06	1.048E-06	9.734E-06	3.098E-07	3.661E-08	3.464E-07	2.044E-07	1.660E-07	1.440E-07	9.110E-04
CU-62	7.162E-07	8.548E-07	1.837E-06	5.008E-07	2.241E-07	7.162E-07	1.305E-12	9.175E-07	3.020E-09	8.205E-07	1.467E-12	4.821E-15	1.472E-12	5.498E-13	1.190E-09	1.580E-09	1.000E-05
CU-64	1.192E-05	1.405E-05	2.897E-05	1.398E-05	3.426E-06	1.195E-05	7.284E-07	1.715E-05	8.000E-06	2.523E-05	1.044E-06	4.898E-07	1.534E-06	8.459E-07	2.980E-06	1.180E-06	7.450E-03
CU-66	2.118E-08	2.107E-08	1.772E-07	1.241E-08	4.138E-09	2.110E-08	2.347E-18	2.262E-08	1.771E-10	2.280E-08	2.494E-18	1.706E-20	2.511E-18	6.038E-19	3.640E-11	2.770E-11	1.750E-07
ZN-62	3.592E-06	4.203E-06	1.074E-05	2.499E-06	--------	3.593E-06	1.757E-08	4.622E-06	9.225E-08	4.714E-06	2.226E-08	4.203E-10	2.268E-08	--------	2.180E-08	2.920E-08	1.850E-04
ZN-65	2.520E-04	2.809E-04	7.535E-04	1.897E-04	2.280E-05	3.551E-04	2.468E-05	4.535E-03	1.241E-01	1.286E-01	3.151E-04	8.620E-03	8.935E-03	1.240E-03	1.440E-02	2.180E-02	1.380E+02
ZN-69	5.979E-08	3.033E-10	3.898E-06	8.440E-09	---------	5.979E-08	6.491E-10	5.982E-08	5.798E-08	1.178E-07	6.494E-10	6.295E-10	1.279E-09	--------	5.670E-09	3.540E-09	2.240E-05
ZN-69m	2.739E-05	3.381E-05	7.274E-05	3.578E-05	--------	2.751E-05	1.699E-06	3.946E-05	3.259E-05	7.204E-05	2.433E-06	2.003E-06	4.436E-06	--------	2.120E-05	6.470E-06	4.180E-02
AS-74	3.280E-04	3.974E-04	7.387E-04	3.171E-04	--------	3.406E-04	2.358E-05	9.543E-04	0.000E+00	9.543E-04	6.605E-05	0.000E+00	6.605E-05	--------	8.880E-06	1.360E-05	8.630E-02
AS-76	4.875E-05	5.318E-05	2.533E-04	1.211E-04	1.352E-05	4.982E-05	3.250E-06	7.062E-05	0.000E+00	7.062E-05	4.603E-06	0.000E+00	4.603E-06	5.021E-06	1.220E-06	9.810E-07	6.210E-03
SE-75	2.101E-04	3.100E-04	3.653E-04	1.313E-04	--------	2.471E-04	1.716E-05	2.186E-03	2.247E-02	2.465E-02	1.518E-04	1.568E-03	1.712E-03	--------	3.340E-03	5.378E-03	3.400E+01
SE-79	4.260E-07	7.689E-07	3.015E-04	6.515E-06	--------	2.725E-05	1.893E-06	1.392E-04	0.000E+00	1.392E-04	9.670E-06	0.000E+00	9.670E-06	--------	2.660E-05	1.210E-05	7.650E-02
KR-81	1.926E-08	2.645E-08	1.725E-08	1.168E-08	--------	1.926E-08	6.078E-09	1.926E-08	0.000E+00	1.926E-08	6.078E-09	0.000E+00	6.078E-09	--------	2.160E-09	3.830E-09	2.430E-05
KR-85	4.116E-09	5.016E-09	3.841E-09	3.005E-09	--------	4.116E-09	1.298E-09	4.116E-09	0.000E+00	4.116E-09	1.298E-09	0.000E+00	1.298E-09	--------	4.460E-10	8.190E-10	5.190E-06
KR-87	1.400E-06	1.500E-06	1.318E-06	1.100E-06	--------	1.400E-06	1.125E-07	1.400E-06	0.000E+00	1.400E-06	1.125E-07	0.000E+00	1.125E-07	--------	1.310E-08	2.540E-08	1.610E-04
KR-88	4.331E-06	4.364E-06	7.300E-06	3.503E-06	--------	4.331E-06	6.742E-07	4.470E-06	2.057E-08	4.499E-06	6.866E-07	1.750E-09	6.884E-07	--------	9.330E-08	1.610E-07	1.020E-03
RB-86	4.281E-05	6.534E-05	1.433E-04	3.794E-05	--------	9.148E-05	6.333E-06	1.748E-04	2.148E-02	2.165E-02	1.210E-05	1.486E-03	1.498E-03	--------	2.910E-03	4.250E-03	2.690E+01
RB-86m	1.631E-09	2.487E-09	5.437E-09	1.444E-09	--------	3.474E-09	2.398E-10	6.631E-09	8.132E-07	8.199E-07	4.582E-10	5.628E-08	5.674E-08	--------	1.100E-07	1.610E-07	1.020E-03
RB-87	6.447E-07	3.093E-06	2.409E-05	1.524E-06	--------	2.041E-05	1.418E-06	1.072E-04	0.000E+00	1.072E-04	7.446E-06	0.000E+00	7.446E-06	--------	3.900E+00	5.520E+00	3.500E+04
RB-88	1.005E-06	9.520E-07	4.574E-06	7.480E-07	--------	1.005E-06	2.309E-10	1.173E-06	2.347E-08	1.197E-06	2.655E-10	4.826E-12	2.703E-10	--------	3.870E-09	4.370E-09	2.770E-05
SR-89	4.023E-06	1.220E-05	7.186E-05	9.144E-05	2.268E-05	3.864E-05	2.688E-06	5.752E-05	4.892E-03	4.950E-03	3.990E-06	3.395E-04	3.435E-04	7.377E-06	1.090E-03	3.480E-04	2.200E+00
SR-90	3.296E-06	3.644E-05	8.672E-05	8.291E-05	3.734E-05	2.183E-03	1.516E-04	1.075E-02	1.282E+01	1.283E+01	7.466E-04	8.906E-01	8.913E-01	8.347E-04	1.900E+00	7.280E-01	4.610E+03
SR-91	4.052E-05	4.663E-05	6.503E-05	4.268E-05	1.313E-05	4.080E-05	2.509E-06	5.277E-05	1.741E-05	7.018E-05	3.240E-06	1.089E-06	4.329E-06	2.575E-06	4.780E-06	1.770E-06	1.120E-02
Y-88	1.138E-03	1.200E-03	2.178E-03	9.870E-04	--------	1.247E-03	8.662E-05	1.008E-02	1.536E-03	1.241E-02	7.553E-04	1.067E-04	8.619E-04	--------	3.570E-04	2.550E-04	1.610E+00
Y-90	5.857E-06	1.069E-06	3.659E-04	3.524E-04	1.045E-05	8.976E-06	6.070E-07	9.484E-06	2.348E-04	2.443E-04	6.813E-07	1.601E-05	1.665E-05	1.177E-06	1.490E-04	1.270E-05	8.030E-02
Y-90m	9.965E-06	1.277E-05	2.921E-05	2.504E-05	--------	1.013E-05	4.298E-07	1.416E-05	1.817E-06	1.597E-05	5.932E-07	4.117E-07	1.005E-06	--------	2.400E-06	3.600E-07	2.280E-03
Y-91	5.903E-06	2.287E-06	3.218E-03	3.958E-04	2.003E-05	5.263E-05	3.651E-06	8.859E-05	1.019E-03	1.107E-03	6.146E-06	7.070E-05	7.685E-05	1.212E-05	8.360E-04	6.340E-05	4.020E-01
Y-91m	2.175E-06	2.607E-06	4.485E-06	1.778E-06	1.358E-06	2.202E-06	2.195E-08	2.905E-06	1.506E-07	3.056E-06	2.927E-08	3.792E-08	6.719E-08	2.216E-08	2.900E-07	4.030E-08	2.550E-04
Y-92	4.896E-06	4.169E-06	7.136E-05	8.125E-06	3.251E-06	4.896E-06	2.115E-07	6.638E-06	3.816E-06	1.025E-05	2.770E-07	1.623E-07	4.393E-07	2.112E-07	5.970E-07	2.340E-07	1.500E-03
Y-93	6.272E-06	4.181E-06	1.318E-04	5.927E-05	4.204E-06	6.333E-06	3.729E-07	7.940E-06	2.222E-05	3.016E-05	4.671E-07	1.303E-06	1.770E-06	6.668E-07	7.590E-06	1.200E-06	7.570E-03
Y-94	1.216E-06	1.277E-06	6.378E-06	7.805E-07	5.309E-07	1.216E-06	3.634E-10	1.446E-06	2.379E-08	1.470E-06	4.254E-10	6.400E-12	4.318E-10	2.204E-10	5.450E-09	5.310E-09	3.360E-05
ZR-89	2.810E-04	3.263E-04	3.273E-04	2.453E-04	2.435E-05	2.838E-04	1.931E-05	4.506E-04	1.524E-04	6.030E-04	3.064E-05	1.036E-05	4.100E-05	4.496E-05	4.180E-05	1.500E-05	9.520E-02
ZR-93	1.418E-07	1.694E-07	1.046E-04	1.116E-05	8.021E-07	1.283E-04	8.913E-06	6.492E-04	0.000E+00	6.492E-04	4.510E-05	0.000E+00	4.510E-05	4.866E-05	3.470E-03	2.850E-04	1.820E+00
ZR-95	3.622E-04	4.277E-04	9.521E-04	3.376E-04	2.908E-05	4.052E-04	2.820E-05	2.792E-03	8.218E-04	3.114E-03	1.593E-04	5.720E-05	2.165E-04	5.761E-04	5.250E-04	1.190E-04	7.550E-01
ZR-97	1.116E-04	1.290E-04	2.834E-04	1.942E-04	2.574E-05	1.122E-04	7.254E-06	1.402E-04	7.104E-05	2.113E-04	9.074E-06	4.464E-06	1.354E-05	9.446E-06	2.660E-05	5.500E-06	3.530E-02
NB-90	2.333E-04	2.521E-04	2.991E-04	2.334E-04	5.166E-05	2.336E-04	1.451E-05	3.381E-04	5.995E-05	3.980E-04	2.095E-05	3.700E-06	2.465E-05	1.740E-05	1.700E-05	8.810E-06	5.500E-02
NB-91	3.695E-06	3.058E-06	2.437E-04	7.205E-06	7.588E-07	2.587E-05	1.797E-06	1.510E-03	0.000E+00	1.510E-03	1.049E-04	0.000E+00	1.049E-04	4.309E-04	2.360E-02	2.560E-03	1.620E+01

ISOTOPE	PROMPT DOSE AT 1 KM WB	BM	Lung	LLI	Fetter WB	WB EARLY DOSE 1 km	10 km	WB CHRONIC DOSE AT 1 KM Inhaled	Ingestion	Total	WB CHRONIC DOSE AT 10 KM Inhaled	Ingestion	Total	Fetter WB at 10 km	CANCERS Sum organs	CANCERS WB	WB Non-trans
NB-91m	2.176E-05	2.232E-05	5.915E-04	7.862E-05	4.741E-06	3.129E-05	2.172E-06	1.499E-04	8.013E-04	9.513E-04	1.040E-05	5.561E-05	6.601E-05	3.586E-05	1.720E-03	1.820E-04	1.150E+00
NB-92	7.064E-04	8.285E-04	2.417E-03	5.377E-04	4.512E-05	1.457E-03	1.012E-04	2.763E-01	0.000E+00	2.763E-01	1.920E-02	0.000E+00	1.920E-02	8.435E-02	2.330E-01	1.110E-01	7.040E+02
NB-92m	3.479E-04	3.973E-04	3.893E-04	2.602E-04	2.246E-05	3.525E-04	2.434E-05	7.708E-04	4.100E-04	1.181E-03	5.319E-05	2.829E-05	8.149E-05	1.216E-04	6.960E-05	9.410E-01	
NB-93m	7.162E 07	4.156E-07	6.163E-04	2.013E-05	1.198E-06	3.337E-05	2.310E-06	2.338E-04	0.000E+00	2.338E-04	1.624E-05	0.000E+00	1.624E-05	3.453E-05	2.700E-05	3.480E-06	2.230E-02
NB-94	7.400E-04	8.617E-04	5.315E-03	6.490E-04	5.214E-05	1.720E-03	1.195E-04	2.894E-01	0.000E+00	2.894E-01	2.010E-02	0.000E+00	2.010E-02	8.799E-02	7.330E-03	1.290E-02	8.100E+01
NB-94m	2.088E-09	1.939E-09	1.559E-08	9.467E-10	--------	2.088E-09	7.122E-14	2.552E-09	0.000E+00	2.552E-09	1.190E-11	0.000E+00	1.190E-11	--------	8.370E-12	1.050E-11	6.620E-08
NB-95	3.384E-04	3.945E-04	5.914E-04	2.821E-04	2.240E-05	3.527E-04	2.447E-05	1.471E-03	1.160E-03	2.631E-03	1.020E-04	8.044E-05	1.824E-04	3.379E-04	9.030E-04	2.570E-04	1.630E+00
NB-95m	3.815E-05	4.869E-05	1.505E-04	1.030E-04	4.922E-06	6.063E-05	2.810E-06	5.420E-05	9.054E-05	1.447E-04	3.901E-06	6.603E-06	1.050E-05	4.225E-06	1.040E-04	1.110E-05	7.010E-02
NB-96	2.334E-04	2.685E-04	2.883E-04	2.239E-04	3.920E-05	2.341E-04	1.515E-05	3.408E-04	8.180E-05	4.227E-04	2.204E-05	5.270E-06	2.732E-05	2.176E-05	2.790E-05	1.110E-05	7.040E-02
NB-97	3.796E-08	4.361E-06	1.157E-05	2.592E-06	2.377E-06	3.796E-06	6.524E-08	5.098E-06	1.891E-07	5.287E-06	8.659E-08	3.100E-09	8.969E-08	6.173E-08	3.610E-08	4.610E-08	2.920E-04
NB-97m	5.344E-08	6.140E-08	1.629E-07	3.649E-08	3.344E-08	5.344E-08	9.182E-10	7.178E-08	2.661E-09	7.444E-08	1.219E-09	4.364E-11	1.262E-09	8.681E-10	5.080E-10	6.490E-10	4.110E-06
NB-98m	1.057E-05	1.177E-05	1.995E-05	7.300E-06	--------	1.057E-05	1.018E-07	1.387E-05	2.092E-07	1.407E-05	1.316E-07	1.890E-09	1.335E-07	--------	6.170E-08	9.680E-08	6.130E-04
NO-91	1.306E-06	1.531E-06	4.521E-06	9.140E-07	5.425E-07	1.306E-06	1.267E-10	1.549E-06	0.000E+00	1.549E-06	1.478E-10	0.000E+00	1.478E-10	7.034E-11	3.950E-09	4.360E-09	2.760E-05
NO-93	3.521E-06	2.740E-06	3.521E-04	8.973E-06	1.027E-06	4.544E-05	3.157E-06	1.522E-03	8.804E-03	1.033E-02	1.057E-04	6.117E-04	7.174E-04	4.217E-04	2.370E-03	6.850E-04	4.340E+00
NO-93m	6.690E-05	7.346E-05	7.938E-05	5.691E-05	2.455E-05	6.691E-05	3.657E-06	9.610E-05	8.668E-06	1.048E-04	5.234E-06	6.483E-07	5.703E-06	3.407E-06	1.940E-06	1.870E-06	1.180E-02
NO-99	6.843E-05	9.365E-05	2.246E-04	1.920E-04	9.201E-06	7.030E-05	4.829E-06	9.112E-05	1.746E-04	2.657E-04	6.267E-06	1.183E-05	1.809E-05	8.513E-06	1.790E-04	2.080E-05	1.320E-01
NO-101	2.455E-06	2.793E-06	4.771E-06	1.752E-06	9.637E-07	2.454E-06	3.909E-10	2.849E-06	1.166E-08	2.861E-06	4.559E-10	2.346E-12	4.582E-10	1.829E-10	6.240E-09	9.180E-09	5.760E-05
TC 97	3.355E-06	2.917E-06	6.469E-05	1.671E-06	--------	4.732E-06	3.287E-07	1.263E-03	0.000E+00	1.263E-03	8.778E-05	0.000E+00	8.778E-05	--------	1.050E-04	7.860E-05	4.980E-01
TC-98	6.699E-04	7.917E-04	1.672E-03	4.858E-04	4.730E-05	7.210E-04	5.013E-05	2.573E-01	0.000E+00	2.573E-01	1.788E-02	0.000E+00	1.788E-02	7.944E-02	1.090E-02	1.790E-02	8.160E+01
TC-99	6.386E-07	6.222E-07	4.571E-04	1.020E-05	3.601E-06	8.036E-06	5.582E-07	4.488E-05	7.207E-02	7.211E-02	3.119E-06	5.007E-03	5.010E-03	4.271E-06	2.460E-02	1.620E-02	1.030E+02
TC-99m	3.865E-06	6.263E-06	4.826E-06	2.144E-06	1.765E-06	3.865E-06	2.037E-07	5.551E-06	6.043E-07	6.155E-06	2.915E-07	3.149E-08	3.229E-07	1.899E-07	1.160E-07	1.410E-07	8.930E-04
TC-101	4.485E-07	5.842E-07	1.303E-06	2.781E-07	1.671E-07	4.485E-07	8.725E-11	5.391E-07	3.570E-09	5.427E-07	5.576E-11	3.354E-13	5.609E-11	1.234E-11	1.300E-09	1.620E-09	1.030E-05
RU-103	2.254E-04	2.746E-04	7.198E-04	2.484E-04	--------	2.486E-04	1.669E-05	1.066E-03	1.771E-03	2.837E-03	7.393E-05	1.220E-04	1.960E-04	--------	1.860E-03	4.310E-04	2.730E+00
RU-105	1.657E-05	1.968E-05	4.357E-05	1.910E-05	--------	1.661E-05	8.209E-07	2.285E-05	3.017E-06	2.587E-05	1.139E-06	2.240E-07	1.363E-06	--------	1.470E-06	4.950E-07	3.130E-03
RU-106	1.094E-04	1.203E-04	2.198E-02	9.847E-04	--------	6.427E-04	4.464E-05	3.867E-03	0.000E+00	3.867E-03	2.686E-04	0.000E+00	2.686E-04	--------	2.880E-04	5.630E-05	3.570E-01
RH-101	1.660E-04	2.524E-04	1.047E-03	1.214E-04	--------	2.626E-04	1.825E-05	9.337E-03	0.000E+00	9.337E-03	6.485E-04	0.000E+00	6.485E-04	--------	9.930E-05	1.340E-04	8.460E-01
RH-101m	9.795E-05	1.315E-04	1.094E-04	7.898E-05	--------	9.880E-05	6.759E-06	1.658E-04	8.066E-05	2.459E-04	1.138E-05	5.470E-06	1.685E-05	--------	4.060E-05	1.260E-05	7.990E-02
RH-103m	1.155E-08	4.766E-09	4.666E-07	1.794E-09	--------	1.155E-08	1.266E-10	1.342E-08	0.000E+00	1.342E-08	1.471E-10	0.000E+00	1.471E-10	--------	5.990E-10	9.320E-11	5.900E-07
RH-105	1.308E-05	1.677E-05	5.163E-05	4.546E-05	--------	1.334E-05	8.845E-07	1.926E-05	3.010E-05	4.936E-05	1.276E-06	1.991E-06	3.267E-06	--------	3.210E-05	3.860E-06	2.450E-02
PD-107	6.726E-08	5.492E-10	1.934E-04	6.241E-06	--------	1.336E-05	9.282E-07	6.766E-05	0.000E+00	6.766E-05	4.700E-06	0.000E+00	4.700E-06	--------	4.320E-03	3.560E-04	2.250E+00
PD-109	1.862E-06	8.483E-07	5.970E-05	3.429E-05	1.590E-06	1.931E-06	1.180E-07	2.209E-06	1.652E-05	1.873E-05	1.350E-07	1.000E-06	1.143E-06	1.443E-07	1.300E-05	1.730E-06	1.090E-02
PD-111	1.468E-07	1.206E-07	3.857E-06	4.455E-07	--------	1.553E-07	2.615E-09	1.857E-07	7.191E-07	9.048E-07	4.212E-09	1.200E-07	1.250E-07	--------	3.010E-06	3.110E-07	1.970E-03
PD-111m	4.630E-06	4.604E-06	7.815E-05	2.037E-05	--------	4.760E-06	2.502E-07	5.561E-06	0.000E+00	5.561E-06	2.920E-07	0.000E+00	2.920E-07	--------	2.380E-07	7.030E-08	4.450E-04
AG-108	3.007E-10	3.035E-10	3.636E-09	1.768E-10	2.714E-11	3.007E-10	2.763E-22	3.124E-10	0.000E+00	3.124E-10	2.856E-22	0.000E+00	2.856E-22	0.000E+00	2.240E-13	9.570E-14	6.060E-10
AG-108m	7.277E-04	8.821E-04	3.855E-03	6.064E-04	5.165E-05	1.520E-03	1.062E-04	2.503E-01	0.000E+00	2.503E-01	1.739E-02	0.000E+00	1.739E-02	7.685E-02	4.160E-03	7.410E-03	4.700E+01
AG-110	2.225E-20	2.527E-20	8.136E-20	1.482E-20	0.000E+00	2.226E-20	3.920E-22	2.240E-20	7.769E-19	7.993E-19	3.950E-22	1.144E-20	1.184E-20	0.000E+00	2.360E-16	5.970E-18	3.780E-10
AG-110m	1.213E-03	1.381E-03	4.222E-03	1.012E-03	8.222E-05	1.469E-03	1.021E-04	2.163E-02	0.000E+00	2.163E-02	1.502E-03	0.000E+00	1.502E-03	6.057E-03	1.080E-04	3.090E-04	1.960E+00
AG-111	1.362E-05	1.486E-05	3.255E-04	1.944E-04	8.065E-06	1.791E-05	1.233E-06	2.916E-05	8.577E-04	8.868E-04	2.007E-06	5.901E-05	6.102E-05	3.903E-06	1.990E-03	2.050E-04	1.300E+00
CD-109	1.022E-05	1.303E-05	1.128E-03	4.507E-05	--------	5.489E-05	3.810E-06	3.994E-04	3.979E-03	4.378E-03	2.774E-05	2.764E-04	3.041E-04	--------	1.950E-04	2.300E-04	1.450E+00
CD-113m	1.438E-06	2.437E-07	3.710E-03	1.178E-04	--------	5.598E-04	3.888E-05	2.690E-03	0.000E+00	2.690E-03	1.869E-04	0.000E+00	1.869E-04	--------	1.670E-04	3.888E-05	2.610E-01
CD-115	7.754E-05	9.550E-05	2.453E-04	2.284E-04	1.116E-05	7.942E-05	5.427E-06	1.004E-04	1.358E-04	2.363E-04	6.873E-06	9.155E-06	1.603E-05	9.163E-06	6.790E-05	8.780E-06	5.510E-02
IN-114	2.471E-13	9.872E-17	1.712E-11	1.335E-18	5.008E-14	2.471E-13	2.470E-23	2.471E-13	0.000E+00	2.471E-13	2.470E-23	0.000E+00	2.470E-23	0.000E+00	2.450E-16	2.030E-17	1.290E-13
IN-114m	5.117E-05	1.027E-04	2.490E-03	5.308E-04	3.991E-05	1.286E-04	8.925E-06	3.649E-04	2.792E-03	3.157E-03	2.532E-05	1.937E-04	2.190E-04	7.550E-05	1.510E-03	1.090E-04	1.190E+00
IN-115	1.248E-06	8.017E-06	9.230E-04	9.669E-05	--------	2.426E-03	1.685E-04	1.227E-02	0.000E+00	1.227E-02	8.525E-04	0.000E+00	8.525E-04	--------	4.340E+06	1.490E+06	9.420E+09
IN-115m	3.667E-06	4.730E-06	1.348E-05	3.348E-05	1.935E-06	3.667E-06	1.760E-07	5.157E-06	9.849E-07	6.142E-06	2.464E-07	4.661E-08	2.931E-07	1.579E-07	1.840E-07	1.040E-07	6.610E-04
IN-116	2.767E-21	2.807E-21	1.106E-20	2.050E-21	0.000E+00	2.767E-21	2.307E-22	2.779E-21	0.000E+00	2.779E-21	2.314E-22	0.000E+00	2.314E-22	0.000E+00	0.000E+00	0.000E+00	0.000E+00
IN-116m	1.036E-05	1.112E-05	1.026E-05	7.761E-06	5.820E-06	1.036E-05	1.125E-07	1.360E-05	1.535E-07	1.376E-05	1.456E-07	1.563E-09	1.471E-07	9.660E-08	5.520E-08	9.620E-08	6.090E-04
SN-113	1.155E-04	1.557E-04	6.122E-04	1.487E-04	1.155E-05	1.320E-04	9.169E-06	1.168E-03	1.580E-03	2.747E-03	8.108E-05	1.097E-04	1.908E-04	3.122E-04	1.580E-03	2.570E-04	1.630E+00
SN-113m	4.804E-08	6.222E-08	3.093E-07	2.291E-08	3.092E-08	5.017E-08	1.181E-09	1.169E-07	8.479E-08	2.017E-07	1.020E-08	1.387E-08	2.415E-08	5.328E-10	1.500E-07	2.480E-08	1.570E-04
SN-121	4.876E-07	3.020E-07	2.348E-05	1.859E-05	6.944E-07	5.914E-07	3.854E-08	6.009E-07	1.077E-05	1.137E-05	3.916E-08	7.021E-07	7.413E-07	5.382E-08	8.030E-06	8.060E-07	5.100E-03
SN-121m	3.123E-06	5.103E-06	6.614E-04	5.832E-05	4.667E-06	3.160E-05	2.198E-06	9.044E-04	7.676E-08	9.044E-04	6.284E-05	5.167E-08	6.289E-05	2.484E-04	2.610E-05	1.940E-05	1.230E-01
SN-123	6.704E-06	5.447E-06	2.025E-03	2.983E-04	1.912E-05	5.244E-05	3.641E-06	1.331E-04	3.328E-06	1.364E-04	9.240E-06	2.311E-07	9.471E-06	2.041E-05	1.060E-05	2.190E-06	1.390E-02
SN-126	8.273E-04	1.022E-03	5.629E-03	1.055E-03	--------	1.158E-03	8.078E-05	1.524E-02	1.160E-08	1.524E-02	1.059E-03	--------	1.165E-09	1.059E-03	--------	1.150E-03	8.010E-04	5.070E+00
SB-122	1.048E-04	1.236E-04	3.116E-04	2.615E-04	1.544E-05	1.073E-04	7.268E-06	1.635E-04	1.922E-04	3.557E-04	1.107E-05	1.300E-05	2.407E-05	1.515E-05	1.270E-04	1.520E-05	9.600E-02
SB-124	7.769E-04	8.575E-04	2.100E-03	8.766E-04	5.848E-05	8.104E-04	5.684E-05	4.886E-03	1.704E-03	6.591E-03	3.391E-04	1.103E-04	4.573E-04	1.227E-03	9.090E-04	1.960E-04	1.240E+00
SB-125	2.160E-04	2.702E-04	8.609E-04	2.164E-04	1.697E-05	2.348E-04	1.646E-05	1.006E-02	6.458E-04	1.070E-02	6.988E-04	4.484E-05	7.436E-04	2.970E-03	4.440E-04	1.990E-04	1.260E+00
SB-126	1.106E-03	1.317E-03	1.582E-03	1.015E-03	--------	1.126E-03	7.784E-05	2.668E-03	1.253E-03	3.921E-03	1.843E-04	8.654E-05	2.708E-04	--------	4.940E-04	1.250E-04	7.940E-01
SB-126m	3.105E-06	3.688E-06	5.121E-06	2.756E-06	--------	3.116E-06	8.360E-08	4.390E-06	6.215E-07	5.012E-06	1.970E-07	9.202E-08	2.890E-07	--------	4.120E-07	1.170E-07	7.430E-04
SB-129	2.159E-05	2.391E-05	6.826E-05	2.054E-05	--------	2.159E-05	1.047E-06	2.991E-05	0.000E+00	2.991E-05	1.441E-06	0.000E+00	1.441E-06	--------	3.040E-07	3.500E-07	2.210E-03
TE-125m	1.864E-05	2.998E-05	3.441E-04	5.496E-05	6.319E-06	2.808E-05	1.949E-06	1.241E-04	0.000E+00	1.241E-04	8.612E-06	0.000E+00	8.612E-06	2.902E-05	3.120E-06	1.790E-06	1.140E-02

ISOTOPE	PROMPT DOSE AT 1 KM WB	BM	Lung	LLI	Fetter WB	WB EARLY DOSE 1 km	10 km	WB CHRONIC DOSE AT 1 KM Inh+ord	Ingestion	Total	WB CHRONIC DOSE AT 10 KM Inh+ord	Ingestion	Total	Fetter WB at 10 km	CANCERS Sum organs	CANCERS WB	WB Non-rems
TE-129	4.487E-07	4.040E-07	8.160E-06	2.416E-07	--------	4.487E-07	7.138E-09	5.622E-07	0.000E+00	5.622E-07	8.804E-09	0.000E+00	8.804E-09	--------	1.200E-08	4.300E-09	2.730E-05
TE-129m	3.843E-05	5.440E-05	1.380E-03	3.001E-04	--------	6.900E-05	4.815E-06	1.352E-04	0.000E+00	1.352E-04	9.480E-06	0.000E+00	9.480E-06	--------	7.110E-06	2.010E-06	1.270E-02
TE-131	1.158E-06	1.461E-06	4.292E-06	8.289E-07	--------	1.167E-06	2.376E-08	1.484E-06	0.000E+00	1.484E-06	4.615E-08	0.000E+00	4.615E-08	--------	9.510E-09	1.280E-08	8.090E-05
TE-131m	1.876E-04	2.235E-04	2.880E-04	1.991E-04	--------	1.893E-04	1.262E-05	2.632E-04	0.000E+00	2.632E-04	1.757E-05	0.000E+00	1.757E-05	--------	2.400E-06	3.680E-06	2.330E-02
TE-132	5.790E-04	6.978E-04	8.163E-04	5.984E-04	--------	5.861E-04	4.063E-05	6.276E-04	0.000E+00	6.276E-04	4.375E-05	0.000E+00	4.375E-05	--------	5.990E-06	9.010E-06	5.700E-02
I-129	1.292E-05	2.146E-05	1.331E-05	2.521E-06	--------	2.049E-05	1.980E-06	4.980E-03	0.000E+00	4.980E-03	3.460E-04	0.000E+00	3.460E-04	--------	2.820E-04	1.660E-03	1.050E+01
I-131	1.480E-04	1.927E-04	1.567E-04	1.001E-04	--------	1.523E-04	1.049E-05	3.023E-04	0.000E+00	3.023E-04	2.082E-05	0.000E+00	2.082E-05	--------	2.420E-06	4.306E-06	2.720E-02
I-132	2.116E-05	2.417E-05	2.790E-05	1.473E-05	--------	2.116E-05	7.080E-07	2.946E-05	0.000E+00	2.946E-05	9.780E-07	0.000E+00	9.780E-07	--------	1.670E-07	2.900E-07	1.840E-03
I-133	5.332E-05	6.238E-05	7.601E-05	3.952E-05	--------	5.372E-05	3.447E-06	7.767E-05	0.000E+00	7.767E-05	4.979E-06	0.000E+00	4.979E-06	--------	6.340E-07	1.060E-06	6.700E-03
I-134	9.307E-06	1.045E-05	1.301E-05	6.317E-06	--------	9.307E-06	9.571E-08	1.224E-05	0.000E+00	1.224E-05	1.241E-07	0.000E+00	1.241E-07	--------	4.700E-08	8.110E-08	5.130E-04
I-135	4.323E-05	4.589E-05	6.062E-05	3.353E-05	--------	4.325E-05	2.345E-06	6.177E-05	0.000E+00	6.177E-05	3.334E-06	0.000E+00	3.334E-06	--------	4.400E-07	7.640E-07	4.830E-03
XE-133	5.467E-08	9.982E-08	4.155E-08	2.311E-08	--------	5.467E-08	4.536E-09	5.467E-08	0.000E+00	5.467E-08	4.536E-09	0.000E+00	4.536E-09	--------	6.430E-10	1.020E-09	6.460E-06
XE-135	3.898E-07	5.476E-07	3.527E-07	2.344E-07	--------	3.898E-07	2.711E-08	3.898E-07	0.000E+00	3.898E-07	2.711E-08	0.000E+00	2.711E-08	--------	3.660E-09	6.390E-09	4.050E-05
CS-134	7.219E-04	8.575E-04	1.027E-03	5.145E-04	--------	1.055E-03	7.333E-05	2.838E-02	0.000E+00	2.838E-02	1.972E-03	0.000E+00	1.972E-03	--------	2.170E-04	4.060E-04	2.570E+00
CS-135	4.570E-07	1.642E-06	3.500E-05	1.188E-06	--------	3.288E-05	2.284E-06	1.682E-04	0.000E+00	1.682E-04	1.168E-05	0.000E+00	1.168E-05	--------	2.900E-04	5.570E-04	3.530E+00
CS-136	8.413E-04	9.952E-04	8.585E-04	5.810E-04	--------	8.865E-04	6.131E-05	2.118E-03	0.000E+00	2.118E-03	1.464E-04	0.000E+00	1.464E-04	--------	1.600E-05	3.030E-05	1.920E-01
CS-137	2.748E-04	3.354E-04	5.179E-04	1.995E-04	--------	5.245E-04	3.645E-05	6.661E-02	0.000E+00	6.661E-02	4.629E-03	0.000E+00	4.629E-03	--------	6.550E-04	1.230E-03	7.790E+00
BA-133	2.156E-04	3.059E-04	2.060E-04	1.459E-04	--------	2.780E-04	1.933E-05	2.894E-02	0.000E+00	2.894E-02	2.011E-03	0.000E+00	2.011E-03	--------	2.460E-04	4.310E-04	2.730E+00
BA-140	6.617E-04	7.347E-04	6.778E-04	6.466E-04	--------	6.724E-04	4.784E-05	7.661E-04	0.000E+00	7.661E-04	5.442E-05	0.000E+00	5.442E-05	--------	6.400E-06	1.110E-05	7.050E-02
LA-137	1.238E-05	2.137E-05	7.444E-05	8.323E-06	--------	1.080E-04	7.500E-06	5.227E-03	0.000E+00	5.227E-03	3.632E-04	0.000E+00	3.632E-04	--------	1.440E-04	2.380E-04	1.510E+00
LA-138	5.669E-04	6.139E-04	1.135E-03	5.027E-04	--------	2.199E-03	1.528E-04	2.273E-01	0.000E+00	2.273E-01	1.579E-02	0.000E+00	1.579E-02	--------	4.400E+02	5.460E+02	3.460E+06
LA-140	3.415E-04	3.682E-04	4.946E-04	4.300E-04	--------	3.441E-04	2.296E-05	5.092E-04	0.000E+00	5.092E-04	3.394E-05	0.000E+00	3.394E-05	--------	4.430E-06	7.100E-06	4.500E-02
CE-144	2.917E-05	2.770E-05	1.813E-02	8.710E-04	--------	4.277E-04	2.969E-05	1.494E-03	0.000E+00	1.494E-03	1.038E-04	0.000E+00	1.038E-04	--------	1.910E-04	2.220E-05	1.410E-01
PM-145	1.731E-05	3.126E-05	3.250E-04	1.389E-05	--------	7.501E-05	5.211E-06	3.441E-03	0.000E+00	3.441E-03	2.391E-04	0.000E+00	2.391E-04	--------	6.840E-05	5.500E-05	3.500E-01
PM-146	3.712E-04	4.550E-04	2.930E-03	3.436E-04	--------	7.642E-04	5.311E-05	3.143E-02	0.000E+00	3.143E-02	2.184E-03	0.000E+00	2.184E-03	--------	3.220E-04	4.520E-04	2.860E+00
SM-146	3.736E-04	8.000E-04	2.725E-01	2.092E-04	--------	1.786E-01	1.240E-02	9.032E-01	0.000E+00	9.032E-01	6.276E-02	0.000E+00	6.276E-02	--------	3.470E+02	5.500E+01	3.530E+05
SM-147	3.384E-04	7.270E-04	2.470E-01	2.620E-04	--------	1.617E-01	1.123E-02	8.187E-01	0.000E+00	8.187E-01	5.688E-02	0.000E+00	5.688E-02	--------	3.240E+05	5.200E+04	3.290E+08
SM-151	1.460E-07	3.217E-07	1.064E-04	1.160E-05	--------	6.367E-05	4.424E-06	3.193E-04	0.000E+00	3.193E-04	2.219E-05	0.000E+00	2.219E-05	--------	2.870E-05	4.620E-06	3.100E-02
EU-150	7.622E-04	9.531E-04	1.353E-03	5.853E-04	--------	2.112E-03	1.468E-04	2.027E-01	0.000E+00	2.027E-01	1.408E-02	0.000E+00	1.408E-02	--------	2.160E-03	3.940E-03	2.560E+01
EU-152	5.041E-04	6.453E-04	1.556E-03	4.851E-04	--------	1.490E-03	1.035E-04	8.665E-02	0.000E+00	8.665E-02	6.020E-03	0.000E+00	6.020E-03	--------	7.570E-04	1.320E-03	8.370E+00
EU-154	5.779E-04	6.737E-04	2.399E-03	6.012E-04	--------	1.637E-03	1.137E-04	6.963E-02	0.000E+00	6.963E-02	4.839E-03	0.000E+00	4.839E-03	--------	6.490E-04	1.020E-03	6.450E+00
GD-148	4.764E-04	1.037E-03	3.516E-01	3.745E-04	--------	1.732E-01	1.203E-02	8.692E-01	0.000E+00	8.692E-01	6.038E-02	0.000E+00	6.038E-02	--------	9.100E-02	1.260E-02	8.400E+01
GD-150	4.079E-04	8.878E-04	3.015E-01	3.209E-04	--------	1.653E-01	1.148E-02	8.365E-01	0.000E+00	8.365E-01	5.812E-02	0.000E+00	5.812E-02	--------	6.800E+00	9.150E-01	5.800E+03
TB-157	2.433E-06	4.600E-06	2.615E-05	2.081E-06	--------	2.049E-05	1.420E-06	9.213E-04	0.000E+00	9.213E-04	6.401E-05	0.000E+00	6.401E-05	--------	2.180E-05	2.730E-05	1.730E-01
TB-158	3.668E-04	4.434E-04	1.134E-03	3.119E-04	--------	1.384E-03	9.615E-05	1.317E-01	0.000E+00	1.317E-01	9.150E-03	0.000E+00	9.150E-03	--------	2.230E-03	4.030E-03	2.550E+01
DY-154	4.209E-04	1.230E-03	3.135E-01	3.326E-04	--------	1.602E-01	9.742E-03	1.612E-01	0.000E+00	1.612E-01	9.800E-03	0.000E+00	9.800E-03	--------	1.850E-02	1.960E-03	1.700E+01
HO-166	2.095E-04	2.643E-04	1.508E-03	2.703E-04	--------	2.627E-03	1.711E-04	2.752E-03	0.000E+00	2.752E-03	1.793E-04	0.000E+00	1.793E-04	--------	4.760E-05	3.540E-05	2.990E-01
LU-176	2.793E-04	4.024E-04	6.797E-03	3.861E-04	--------	1.199E-03	8.329E-05	1.090E-01	0.000E+00	1.090E-01	7.576E-03	0.000E+00	7.576E-03	--------	1.020E+03	1.230E+02	7.790E+05
LU-177	1.527E-05	2.278E-05	1.371E-04	9.075E-05	3.765E-06	1.685E-05	1.159E-06	2.970E-05	1.013E-04	1.311E-04	2.045E-06	6.965E-06	9.009E-06	3.938E-06	6.600E-05	5.900E-06	3.700E-02
LU-177m	4.850E-04	6.925E-04	2.124E-03	3.051E-04	3.355E-05	5.639E-04	3.919E-05	6.267E-03	7.843E-04	7.050E-03	4.354E-04	5.468E-05	4.900E-04	1.709E-03	3.220E-04	1.420E-04	9.010E-01
LU-178	3.874E-07	3.666E-07	4.392E-06	2.515E-07	--------	3.874E-07	7.462E-10	4.681E-07	2.663E-08	4.947E-07	8.898E-10	4.738E-11	9.372E-10	--------	4.330E-09	2.790E-09	1.770E-05
LU-178m	2.430E-06	3.317E-06	4.672E-06	1.095E-06	--------	2.430E-06	2.032E-09	3.018E-06	1.921E-08	3.038E-06	2.481E-09	1.463E-11	2.495E-09	--------	8.010E-09	1.210E-08	7.660E-05
HF-175	1.677E-04	2.279E-04	2.923E-04	1.346E-04	1.159E-05	1.708E-04	1.258E-05	1.179E-03	9.199E-04	2.099E-03	8.184E-05	6.384E-05	1.457E-04	3.001E-04	1.130E-03	2.580E-04	1.630E+00
HF-178m	1.248E-03	1.662E-03	3.006E-03	1.032E-03	8.991E-05	3.049E-03	2.674E-04	3.141E-01	1.162E-01	4.303E-01	2.183E-02	8.072E-03	2.990E-02	9.474E-02	1.140E-01	4.190E-02	2.650E+02
HF-181	2.600E-04	3.480E-04	7.471E-04	2.949E-04	2.301E-05	2.791E-04	1.937E-05	1.298E-03	1.615E-03	2.912E-03	9.003E-05	1.120E-04	2.020E-04	3.075E-04	3.060E-03	4.050E-04	2.570E+00
HF-182	1.820E-04	2.477E-04	1.175E-03	1.773E-04	--------	3.809E-03	2.146E-04	7.994E-02	1.349E-06	7.994E-02	5.554E-03	9.512E-07	5.555E-03	--------	2.370E-01	5.320E-02	3.370E+02
HF-183	4.707E-06	5.922E-06	1.253E-05	4.200E-06	--------	4.738E-06	1.239E-07	6.098E-06	1.064E-06	7.162E-06	1.838E-07	3.152E-07	4.982E-07	--------	6.440E-06	7.170E-07	4.540E-03
TA-179	1.941E-05	3.732E-05	1.706E-04	1.296E-05	--------	3.042E-05	2.113E-06	6.747E-04	5.320E-05	7.279E-04	4.688E-03	3.696E-06	5.058E-05	--------	7.290E-05	2.320E-05	1.470E-01
TA-180m	4.105E-07	5.765E-07	4.806E-06	1.582E-06	2.107E-07	4.114E-07	2.321E-08	5.537E-07	1.001E-06	1.555E-06	3.170E-08	5.619E-08	8.739E-08	2.335E-08	7.650E-07	1.490E-07	9.450E-04
TA-182	5.868E-04	6.621E-04	2.965E-03	5.984E-04	4.309E-05	6.737E-04	4.680E-05	5.971E-03	1.963E-02	2.560E-02	4.146E-04	1.343E-03	1.778E-03	1.589E-03	3.840E-02	6.410E-03	4.060E+01
TA-182m	4.502E-07	6.846E-07	1.138E-06	2.602E-07	1.895E-07	4.506E-07	4.521E-09	8.031E-07	9.740E-07	1.778E-06	3.969E-08	1.303E-07	1.700E-07	1.405E-09	2.930E-06	4.910E-07	3.110E-03
TA-183	1.140E-04	1.763E-04	3.057E-04	2.240E-04	1.326E-05	1.170E-04	8.022E-06	2.013E-04	6.243E-04	8.256E-04	1.379E-05	4.276E-05	5.655E-05	2.368E-05	1.480E-03	1.550E-04	9.780E-01
TA-184	5.821E-05	7.155E-05	1.011E-04	5.575E-05	--------	5.822E-05	3.342E-06	8.367E-05	2.039E-05	1.041E-04	4.790E-06	1.160E-06	5.950E-06	--------	1.150E-05	4.020E-06	2.550E-02
TA-185	7.422E-07	1.020E-06	8.643E-06	3.689E-07	--------	7.479E-07	6.567E-09	9.563E-07	1.283E-07	1.085E-06	8.334E-09	9.565E-09	1.790E-08	--------	5.230E-08	1.520E-08	9.600E-05
TA-186	1.243E-06	1.535E-06	2.033E-06	8.178E-07	--------	1.243E-06	4.923E-12	1.429E-06	3.060E-09	1.432E-06	5.368E-12	9.862E-14	5.579E-12	--------	1.850E-09	2.910E-09	1.040E-05
W-179	1.918E-07	3.529E-07	2.606E-07	7.233E-08	--------	1.920E-07	9.976E-10	2.627E-07	4.017E-09	2.667E-07	3.099E-09	1.653E-10	3.264E-09	--------	2.980E-09	2.130E-09	1.350E-05
W-179m	5.428E-08	9.633E-08	1.053E-07	2.208E-08	--------	5.435E-08	1.995E-10	7.044E-08	8.567E-10	7.129E-08	5.780E-10	2.959E-11	6.076E-10	--------	7.040E-10	4.680E-10	2.970E-06
W-181	2.327E-05	4.459E-05	1.835E-05	1.106E-05	1.142E-06	2.361E-05	1.641E-06	2.415E-04	7.306E-05	3.145E-04	1.677E-05	5.074E-06	2.184E-05	6.533E-05	1.580E-05	7.970E-06	5.040E-02
W-185	5.447E-07	2.551E-07	1.434E-05	2.216E-05	1.185E-06	1.807E-06	1.254E-07	3.116E-06	3.071E-04	3.102E-04	2.162E-07	2.132E-05	2.153E-05	3.483E-07	1.510E-04	1.880E-05	1.190E-01
W-187	4.929E-05	6.132E-05	6.470E-05	5.170E-05	8.285E-06	4.933E-05	3.198E-06	7.182E-05	2.788E-05	9.969E-05	4.651E-06	1.801E-06	6.452E-06	4.644E-06	9.960E-06	2.520E-06	1.600E-02

ISOTOPE	PROMPT DOSE AT 1 KM WB	BM	Lung	LLI	Fetter WB	WB EARLY DOSE 1 km	10 km	WB CHRONIC DOSE AT 1 KM Inh+ord	Ingestion Total	WB CHRONIC DOSE AT 10 KM Inh+ord	Ingestion Total	Fetter WB at 10 km	CANCERS Bone organs	CANCERS WB	WB Non-rems
W-188	2.035E-05	4.197E-05	7.085E-05	1.208E-04	6.232E-06	3.590E-05	2.548E-06	4.771E-05	1.385E-03	1.433E-03	3.377E-06	9.660E-05	9.998E-05	1.089E-05	7.530E-04	8.550E-05	5.420E-01
RE-186	1.022E-05	1.550E-05	1.670E-04	3.067E-05	6.386E-06	1.241E-05	8.467E-07	1.777E-05	3.397E-04	3.574E-04	1.212E-06	2.316E-05	2.437E-05	1.928E-06	1.290E-04	6.390E-05	4.050E-01
RE-186m	1.553E-05	2.857E-05	1.919E-03	2.550E-05	--------	4.806E-05	3.355E-06	3.469E-03	7.210E-07	3.470E-03	2.411E-04	4.967E-07	2.416E-04	--------	5.050E-04	1.890E-04	1.200E+00
RE-187	4.905E-09	4.720E-09	3.569E-06	7.955E-08	2.821E-08	6.268E-08	4.354E-09	3.170E-07	0.000E+00	3.174E-07	2.205E-08	0.000E+00	2.205E-08	2.312E-08	1.450E-01	1.420E-02	8.970E+01
RE-188	7.215E-06	7.212E-06	1.213E-04	1.942E-05	4.722E-06	7.502E-06	4.716E-07	9.600E-06	6.255E-05	7.215E-05	6.033E-07	3.921E-06	4.523E-06	6.705E-07	2.010E-05	1.010E-05	6.400E-02
RE-188m	2.612E-07	3.205E-07	2.514E-06	4.098E-07	1.480E-07	2.466E-07	8.903E-09	2.904E-07	5.431E-07	8.335E-07	1.138E-08	7.362E-08	8.500E-08	7.027E-09	2.870E-07	1.440E-07	9.140E-04
RE-189	7.749E-06	9.913E-06	6.839E-05	1.433E-05	--------	8.054E-06	5.229E-07	1.102E-05	4.942E-05	6.044E-05	7.146E-07	3.200E-06	3.915E-06	--------	1.730E-05	8.480E-06	5.370E-02
OS-189m	4.221E-08	1.165E-09	1.853E-06	3.440E-07	--------	4.230E-08	2.167E-09	4.540E-08	1.879E-07	2.333E-07	2.330E-09	9.622E-09	1.195E-08	--------	5.650E-08	1.330E-08	8.440E-05
OS-194	3.969E-05	4.556E-05	2.075E-02	6.103E-04	--------	9.316E-04	6.477E-05	4.087E-03	4.902E-07	4.088E-03	2.840E-04	3.310E-07	2.840E-04	--------	6.760E-04	6.020E-05	3.840E-01
IR-192	4.185E-04	5.481E-04	2.041E-03	4.482E-04	3.278E-05	4.657E-04	3.235E-05	3.090E-03	1.288E-03	4.377E-03	2.145E-04	8.939E-05	3.039E-04	7.895E-04	7.790E-04	1.730E-04	1.100E+00
IR-192m	1.523E-05	1.856E-05	6.738E-03	1.121E-04	--------	9.019E-04	6.270E-05	4.642E-03	1.393E-07	4.642E-03	3.227E-04	9.670E-08	3.228E-04	--------	5.170E-04	7.290E-05	4.980E-01
IR-194	9.813E-06	8.888E-06	1.447E-04	1.090E-04	--------	1.015E-05	6.462E-07	1.330E-05	4.944E-03	6.277E-05	8.483E-07	3.138E-06	3.986E-06	--------	3.670E-05	4.300E-06	2.750E-02
PT-190	4.325E-04	6.118E-04	9.142E-03	1.424E-04	--------	4.361E-03	3.029E-04	2.208E-02	0.000E+00	2.208E-02	1.534E-03	0.000E+00	1.534E-03	--------	8.050E+03	1.480E+04	9.360E+07
PT-193	2.536E-07	6.443E-08	3.258E-07	1.178E-07	--------	3.732E-07	2.593E-08	6.962E-05	0.000E+00	6.962E-05	4.835E-06	0.000E+00	4.835E-06	--------	1.300E-07	1.520E-06	9.640E-03
PT-193m	6.000E-06	9.302E-06	9.417E-06	1.005E-05	--------	6.457E-06	4.015E-07	1.036E-05	3.218E-05	4.254E-05	7.080E-07	2.199E-06	2.907E-06	--------	2.700E-05	3.260E-06	2.060E-02
AU-194	1.594E-04	1.893E-04	1.651E-04	1.345E-04	--------	1.601E-04	1.067E-05	2.371E-04	0.000E+00	2.371E-04	1.579E-05	0.000E+00	1.579E-05	--------	1.040E-06	3.300E-06	2.090E-02
AU-198	9.970E-05	1.255E-04	2.300E-04	1.906E-04	--------	1.014E-04	6.867E-06	1.556E-04	1.514E-04	3.070E-04	1.053E-05	1.020E-05	2.077E-05	--------	1.140E-04	1.660E-05	1.050E-01
HG-194	3.648E-04	4.588E-04	7.328E-04	2.897E-04	--------	5.684E-04	3.998E-05	1.360E-02	0.000E+00	1.360E-02	9.457E-04	0.000E+00	9.457E-04	--------	3.310E-04	5.040E-04	3.210E+00
HG-203	1.198E-04	1.659E-04	4.141E-04	1.393E-04	1.173E-05	1.301E-04	9.029E-06	6.379E-04	1.435E-03	2.073E-03	4.476E-05	9.957E-05	1.438E-04	1.531E-04	2.450E-03	3.850E-04	2.440E+00
HG-205	3.089E-09	2.711E-09	8.678E-08	1.019E-09	5.129E-10	3.089E-09	4.850E-19	3.263E-09	9.826E-11	3.361E-09	5.106E-19	1.404E-20	5.247E-19	1.041E-19	1.340E-11	6.670E-12	4.230E-08
TL-202	1.956E-04	2.591E-04	1.875E-04	1.349E-04	1.543E-05	2.004E-04	1.385E-05	4.703E-04	1.477E-03	1.947E-03	3.249E-05	1.020E-04	1.345E-04	7.966E-05	1.840E-04	2.850E-04	1.810E+00
TL-204	2.237E-06	6.626E-06	3.873E-05	4.948E-06	1.533E-05	1.532E-05	1.060E-06	8.069E-05	1.154E-02	1.162E-02	5.605E-06	8.020E-04	8.076E-04	1.065E-05	1.410E-03	2.590E-03	1.640E+01
TL-206	8.111E-10	1.871E-11	4.638E-08	7.027E-12	1.573E-10	8.111E-10	1.031E-21	8.121E-10	0.000E+00	8.121E-10	1.032E-21	0.000E+00	1.032E-21	1.313E-19	6.060E-12	6.090E-13	3.860E-09
PB-202	4.159E-05	5.591E-05	7.709E-05	2.909E-05	--------	8.066E-04	5.611E-05	4.014E-03	9.712E-07	4.015E-03	2.790E-04	6.729E-07	2.797E-04	--------	6.570E-04	5.020E-04	3.240E+00
PB-203	5.732E-05	8.177E-05	5.564E-05	4.092E-05	6.507E-06	5.791E-05	3.897E-06	8.733E-05	3.197E-05	1.193E-04	5.875E-06	2.188E-06	8.023E-06	7.503E-06	8.200E-06	3.080E-06	1.950E-02
PB-205	3.291E-07	2.935E-07	1.045E-06	1.004E-06	5.511E-07	3.060E-05	2.126E-06	2.606E-04	8.203E-15	2.606E-04	1.810E-05	5.699E-16	1.810E-05	5.237E-05	9.110E-04	8.360E-04	5.300E+00
PB-209	1.574E-07	1.566E-07	4.051E-06	6.908E-07	9.539E-08	1.574E-07	6.404E-09	1.576E-07	4.450E-07	6.026E-07	6.413E-09	1.810E-08	2.452E-08	4.953E-09	5.130E-08	2.140E-08	1.350E-04
PB-210	3.178E-06	2.842E-05	1.447E-03	3.222E-05	2.692E-04	2.645E-01	1.838E-02	1.291E+00	3.072E+01	3.201E+01	8.968E-02	2.135E+00	2.224E+00	1.615E-01	1.070E+00	1.880E+00	1.190E+04
BI-207	7.232E-04	8.515E-04	1.710E-03	6.106E-04	4.690E-05	7.718E-04	5.366E-05	1.882E-01	0.000E+00	1.882E-01	1.308E-02	0.000E+00	1.308E-02	5.536E-02	2.010E-03	3.760E-03	2.380E+01
BI-208	1.047E-03	1.056E-03	1.598E-03	9.492E-04	5.956E-05	1.104E-03	7.678E-05	4.039E-01	0.000E+00	4.039E-01	2.806E-02	0.000E+00	2.806E-02	1.246E-01	9.500E-03	1.830E-02	1.160E+02
BI-210	5.709E-06	8.678E-07	1.389E-02	1.625E-04	8.957E-05	2.124E-04	1.498E-05	2.246E-04	1.586E-03	1.811E-03	1.630E-05	7.384E-04	7.547E-04	2.919E-05	6.610E-04	1.950E-03	1.240E+01
BI-210m	8.335E-04	2.415E-04	5.425E-01	9.750E-04	3.058E-03	8.748E-03	6.076E-04	9.861E-02	0.000E+00	9.861E-02	6.851E-03	0.000E+00	6.851E-03	1.993E-02	1.620E+00	1.480E-01	9.390E+02
PO-209	7.548E-04	3.342E-04	5.415E-01	5.204E-04	--------	1.627E-02	1.129E-03	8.216E-02	1.285E-26	8.216E-02	5.707E-03	8.931E-27	5.707E-03	--------	7.180E-03	1.220E-03	7.740E+00
PO-210	8.052E-04	3.463E-04	4.307E-01	5.564E-04	4.821E-03	1.231E-02	8.544E-04	2.582E-02	1.757E+01	1.760E+01	1.793E-03	1.221E+00	1.223E+00	2.585E-03	1.440E+00	5.740E+00	3.630E+04

Appendix E

INVESTIGATION OF THE EFFECT OF GROUNDSHINE EXPOSURE TIME ON THE CRITICAL DOSE

As was mentioned in Section 4.2.2, the effect of groundshine exposure time was investigated for 10 isotopes, which were of interest due to their large contributions to the overall dose (mobility categories I–V) for one or more of the seven designs. The motivation behind this analysis was the discovery of the large difference in groundshine exposure times used by FUSEDOSE (10 hours) and FUSCRAC3 (7 days = 168 hours). Consequently, FUSCRAC3 was re–run for a 1 Ci release of each of the 10 isotopes, using a groundshine exposure time of 10 hours. The results of these runs are presented in Table E.1. As can be seen from the data in the table for each isotope, a 10–hour groundshine exposure time yielded overall critical doses less than a factor of 2 greater than those generated by FUSEDOSE, while the original doses calculated using a seven–day exposure period were up to factors of 15 and 16 greater than Fetter's FUSEDOSE numbers. As a result, the critical–dose TDRFs for mobility categories III–V (the majority of the dose in categories I and II comes from inhalation–dominated isotopes) are significantly greater than the original values. In fact, as can be seen in Table E.2, the new TDRFs are only approximately a factor of 2 lower than those calculated by Fetter for the majority of cases. The only significant differences occur in the mobility category summation I–IV for the first wall for Case 4, where FUSEDOSE's TDRF is still $\approx$ 23 times greater than FUSCRAC3's, and for Case 7, where FUSEDOSE's TDRF is still $\approx$ 13 times greater than FUSCRAC3's. This is easily explained by the fact that the major isotope of interest in categories I–IV for the first wall for Cases 4 and 7 is Cr–51, which is also groundshine–dominated. But because Cr–51 is not a large contributor to the total overall dose (i.e., I–V) for any of the designs, its total critical dose was not recalculated. It is certain that such a recalculation would yield a much lower dose from Cr–51 and hence a much larger TDRF value from FUSCRAC3 for Cases 4 and 7, mobility categories I–IV, first wall.

In examining Table E–1, one sees a slightly disturbing result: the total critical dose for Mn–56 *increases* slightly with the decreased exposure time. This apparent inconsistency is explained by the fact that Mn–56 has a relatively short half–life (0.11 days), which is about 5 times less than the next shortest half–life of the 10 isotopes in the table. (Cu–64 has a half–life of roughly 0.53 days.) This factor is important because the interpolation routine used by FUSCRAC3 is non–linear. FUSCRAC3 interpolates between the values given in the health file (FUSDOS3); that is, the 8–hour integrated groundshine dose conversion factor and the 7–day integrated groundshine dose conversion factor. For Mn–56, the total groundshine dose is an extremely slowly increasing function of exposure time, since most of it has decayed away after 8 hours. Hence, it is most likely that the non–linear interpolation routine used by FUSCRAC3 over–estimates the dose for exposure times between 8 hours and 7 days for short–lived isotopes.

Table E.1. THE EFFECT OF GROUNDSHINE EXPOSURE TIME ON THE PROMPT DOSE FOR GROUNDSHINE-DOMINATED ISOTOPES

Isotope	10-hr Groundshine Exposure Time Total Prompt Dose Rem/Ci	10-hr Exposure Dose/ Fetter's Critical Dose	7-day Groundshine Exposure Time Total Prompt Dose Rem/Ci	7-day Exposure Dose/ Fetter's Critical Dose
Na-24	9.303e-05	1.92	2.243e-04	4.62
Sc-48	9.498e-05	1.64	5.322e-04	9.17
Mn-54	2.660e-05	0.997	3.871e-04	14.5
Mn-56	1.957e-05	1.91	1.849e-05	1.81
Fe-59	3.775e-05	0.909	5.140e-04	12.4
Co-60	7.814e-05	1.07	1.136e-03	15.5
Cu-64	5.681e-06	1.66	1.192e-05	3.48
W-187	1.405e-05	1.70	4.929e-05	5.95
Tl-202	1.598e-05	1.04	1.956e-04	12.7
Pb-203	9.054e-06	1.39	5.732e-05	8.81

Table E.2. THE EFFECT OF GROUNDSHINE EXPOSURE TIME ON THE CRITICAL TDRFs

Case and Mobility Category	Release Fraction that Would Produce			
	200 rem prompt dose from plume at 1 km based on 7–day groundshine exposure		200 rem prompt dose from plume at 1 km based on 10–hr groundshine exposure	
	First Wall	BOFC	First Wall	BOFC
Case 1: V–Li/TOK				
I	350	1.8e+04	350	1.8e+04
I–II	7.1	9.1	7.1	9.1
I–III	3.0	0.0042	4.4	0.017
I–IV	1.0	0.0041	1.2	0.015
I–V	0.0039	0.0020	0.014	0.006
Case 2: RAF–He/TOK				
I	1000	3700	1000	3700
I–II	4.1	1.5	4.1	1.5
I–III	0.0047	0.0044	0.025	0.022
I–IV	0.0046	0.0039	0.023	0.018
I–V	0.0043	0.0036	0.017	0.015
Case 3: RAF–PbLi/RFP				
I	3400	1100	3400	1100
I–II	1.2	0.44	1.2	0.44
I–III	0.0080	0.0036	0.020	0.011
I–IV	0.0061	0.0031	0.018	0.0082
I–V	0.0059	0.0027	0.016	0.0062

Case and Mobility Category	Release Fraction that Would Produce			
	200 rem prompt dose from plume at 1 km based on 7–day groundshine exposure		200 rem prompt dose from plume at 1 km based on 10–hr groundshine exposure	
	First Wall	BOFC	First Wall	BOFC
Case 4: V–Li/RFP				
I	340	1.8e+04	340	1.8e+04
I–II	18	11	18	11
I–III	8.0	0.0034	12	0.011
I–IV	0.36	0.0032	0.36	0.0093
I–V	0.010	0.0018	0.033	0.0055
Case 5: SiC–He/TOK				
I	1000	830	1000	830
I–II	49	13	49	13
I–III	13	0.71	22	1.7
I–IV	13	0.022	22	0.073
I–V	4.2	0.022	4.9	0.072
Case 6: V–FLIBE/TOK				
I	8900	2.5e+05	8900	2.5e+05
I–II	39	54	39	54
I–III	17	7.8	24	19
I–IV	3.9	2.3	4.1	3.3
I–V	0.022	0.023	0.082	0.077
Case 7: V–D^{3}He/TOK				
I	3500	4.9e+04	3500	4.9e+04
I–II	130	1400	130	1400
I–III	54	2.3	78	14
I–IV	2.0	2.0	2.0	8.7
I–V	0.061	0.47	0.22	1.9