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TRANSPORTATION SYSTEM RISK ASSESSMENT (TSRA) BOUNDING RELEASE MODEL

J. C. Anderson

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**Lockheed Martin Energy Systems, Inc., Central Engineering Services
Specialty Engineering Services**

TRANSPORTATION SYSTEM RISK ASSESSMENT (TSRA) BOUNDING RELEASE MODEL

Prepared by J. C. Anderson

October 1997

Prepared for the Oak Ridge Y-12 Plant
Nuclear Packaging Systems
Y-12 Defense Programs Division

Prepared by
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ABSTRACT

Transportation System Risk Assessments (TSRAs) document the compliance of proposed shipments of nuclear components with applicable federal regulations as well as the associated risks involved. If a relatively simple bounding analysis can show that the consequences resulting from a worst case scenario are acceptably low, a more time intensive and costly risk analysis can be avoided. Therefore, a bounding release FORTRAN model has been developed to determine the consequences of a worst case non-criticality transportation accident. The consequences of three conservative bounding accidents are determined by the model: 1) direct radiation exposure, 2) airborne release of radiological and/or hazardous solid material, and 3) release of radiological and/or hazardous solid material into a waterway and subsequent uptake by an individual through drinking water. Program output includes the direct radiation exposure (mrem), maximum downwind concentration (mg/m^3), radiation dose (mrem) received as a result of the postulated airborne release of radiological material, intake (mg) due to inhalation, radiation dose (mrem) received by an individual resulting from a release of radiological material into a waterway and uptake into drinking water, and uptake (mg) due to ingestion. This report documents the methodologies and correlations used in the numerical model to perform the bounding consequence calculations.

1. INTRODUCTION

The Nuclear Explosive Safety Division (NESD) of the Department of Energy, Albuquerque Area Office (DOE-AL) is responsible for evaluating Transportation System Risk Assessments (TSRAs). TSRAs document the compliance of proposed shipments of nuclear components with applicable federal regulations as well as the associated risks involved. If a relatively simple bounding analysis can show that the consequences resulting from a worst case scenario are acceptably low, a more time intensive and costly risk analysis can be avoided. Therefore, the purpose of this project is to develop a model which will determine the consequences of a worst case non-criticality transportation accident. It is expected that if a criticality accident is credible, modifications will be required prior to shipment to prevent this from occurring. Therefore, analysis of a postulated criticality incident is not considered in this model.

The consequences of the following three conservative bounding accidents are determined by the model:

- (1) Direct radiation exposure,
- (2) Airborne release of radiological and/or hazardous solid material,
- (3) Release of radiological and/or hazardous solid material into a waterway and subsequent uptake by an individual through drinking water.

Historically, the Nuclear Regulatory Commission has considered only radiological hazards in licensing the transport of radiological material because the U. S. Department of Transportation considers licensing requirements of nonradiological (i.e., chemically toxic) materials. A TSRA is prepared when it is not possible to meet the licensing requirements of 10 CFR 71. These requirements are based primarily on consideration of radiological hazards. For completeness, this report provides information for assessing the effects of chemical toxicity.

For the direct radiation calculation, it is assumed that 100% of the potentially hazardous material is exposed and unshielded. Excluding a criticality event, a fire or explosion are the only plausible mechanisms identified for dispersing significant amounts of solid hazardous materials into the atmosphere. At the present time, the model only calculates the consequences resulting from a fire. The fire is assumed to be fueled by the gasoline or diesel fuel present in the transport vehicle. Both radiological and chemical effects are determined. The third accident scenario involves the spill or release of hazardous material into a waterway and the subsequent uptake by an individual. Both radiological and chemical consequences will be determined for this scenario. The model conservatively neglects any mitigative or emergency response actions such as notification of possible danger, efforts to extinguish the fire, actions to prevent people from drinking contaminated water, etc. The model also assumes that an individual remains at a given location throughout the duration of the exposure.

A FORTRAN model has been constructed to evaluate the accident scenarios described above. Output from the program includes:

- (1) Direct radiation exposure (mrem) to the Maximally Exposed Individual,
- (2) Maximum downwind concentration (mg/m^3) and the product of concentration and exposure time ($\text{mg}\cdot\text{hr}/\text{m}^3$),
- (3) Maximum radiation dose (mrem) to the Maximally Exposed Individual as a result of the postulated airborne release of radiological material,

- (4) Maximum intake (mg) the Maximally Exposed Individual receives as a result of the postulated airborne release of toxic material,
- (5) Radiation dose (mrem) received by an individual resulting from a release of radiological material into a waterway and uptake into drinking water,
- (6) Uptake (mg) received by an individual resulting from the release of toxic material into a waterway.

This report presents the correlations, assumptions and other background information required to perform the bounding consequence calculations. In addition, a brief discussion is presented regarding the construction and use of the numerical model. Results from sample runs for all the materials of interest are also presented and discussed.

2. DESCRIPTION OF NUMERICAL MODEL

A FORTRAN model has been constructed to perform bounding analysis calculations for a worst case non-criticality transportation accident. A complete listing of the FORTRAN model is presented in Appendix A. The model consists of the following program units:

- (1) A **MAIN** program in which variables are initialized, the user is given the opportunity to change default program values, and the input is read. Calls to the various subroutines used to calculate the consequences of the accident scenarios are made from the **MAIN** program.
- (2) **SUBROUTINE DRAD** performs the direct radiation calculations. Output from this subroutine includes the radiological dose received (mrem) due to direct exposure.
- (3) **SUBROUTINE DISPERSE** performs the atmospheric dispersion calculations for stability classes A-G. Output from this subroutine includes the highest value of concentration (mg/m^3) at a given downwind distance along with the stability class which results in this maximum concentration.
- (4) **SUBROUTINE INHAL** determines the radiological and/or chemical consequences of inhalation due to the airborne release of hazardous material. Output from this subroutine includes the radiation dose (mrem) and the uptake (mg) received due to inhalation.
- (5) **SUBROUTINE WATER** calculates the amount of contaminant which reaches the public drinking supply due to a spill into a waterway. Output from this subroutine includes the mass of contaminant (mg) present in an individual's daily water uptake.
- (6) **SUBROUTINE INGST** determines the radiological and/or chemical consequences of ingestion resulting from a spill of material into a waterway. Output from this subroutine includes the radiation dose (mrem) and intake (mg) received due to ingestion.
- (7) **DATABASE** is the block data subprogram containing the pre-defined material data.

2.1 PROGRAM DEFAULT VALUES

Several variables which are given default values in the program can easily be changed by the user. The user is interactively given the opportunity to change any or all of the values shown in Table 2.1. The bases for selecting these default values are discussed in Chapters 4-6 as the variables are introduced in relation to the calculations.

2.2 PROGRAM INPUT

The FORTRAN program operates in an interactive mode. Upon program execution, the user will be prompted to enter the name of the output file. The extension .OUT will automatically be added to the file name. The default output file name is TSRA.OUT. Next, the user will be given the opportunity to change the default values presented in Table 2.1. At this point, any user-defined material data will be read

Table 2.1. Program Default Values

Variable	Value
Direct Radiation Calculations	
Distance from the source	152.4 m (500 ft)
Exposure time	3 hr
Atmospheric Dispersion Calculations	
Minimum downwind distance	100 m
Maximum downwind distance	2000 m
Downwind distance increment	100 m
Elevation of receptor	0
Ambient temperature	298 K
Initial plume radius	0.5 m
Wind velocity at elevation of 2 m	1 m/s
Inhalation Calculations	
Breathing rate	1.2 m ³ /hr
Exposure time	Fire duration
Water Transport Calculations	
Volume of water tank	473 m ³
Individual's daily uptake of water	0.002 m ³

from the file TSRA.DAT created by the user (see following discussion for file format). Next, the user will be presented with a list of available materials (see Chapter 3 for a complete list and discussion of the available materials). The user will be asked to choose the materials of interest for the bounding calculations. Next, the user will be asked to enter the total mass present of each material chosen. For standard program execution, this is the only input required. The screen output from two sample runs (one without and one with user-supplied materials) is presented in Appendix B which shows everything printed to the screen during execution of the program.

Currently, a total of 18 materials are defined in the material database (see Chapter 3 for a discussion of the materials included). For all of these pre-defined materials, properties required for the bounding release calculations are contained in data statements in the block data subprogram (see Appendix A). A total of 32 additional materials may be defined by the user, as required. If the user wishes to analyze a material that is not contained in the database, a file named TSRA.DAT must be created to contain the required material data. The remainder of this section describes the process of adding a material to the database. All user-defined entries in the database are free format. All entries in each card should be separated by either a comma or a space. Character variables, such as Material Name and Isotope Name, should be enclosed in single quotes if the string contains any embedded spaces (i.e., 'Depleted Uranium'). The single quote character is obtained in WordPerfect by using character (0,39) from the ASCII character set. If the character string contains no spaces (i.e., Th-232), single quotes are not required. Each user-defined material entry has the following format:

CARD 1

Material ID, Material Name, Number of Isotopes

The **Material ID** is simply an integer (19-50) which identifies the material. Material IDs 1-18 are used for the materials already in the database; therefore, any new materials being added should have a Material ID of 19 or greater. Material IDs should be numbered consecutively without skipping any integer values.

The **Material Name** is a character string of up to 30 characters which identifies the material (i.e., Lithium Hydride, Uranium, etc.).

Number of Isotopes is an integer (0-10) that indicates the number of radionuclides of the particular element to be considered in the radiation calculations. For example, Natural Uranium has three radionuclides (U-234, U-235, U-238) which are considered in the radiation calculations. Therefore, an entry of 3 is entered for **Number of Isotopes** for Natural Uranium. If the material does not pose a radiological hazard, a value of 0 should be entered for this variable.

CARD 2

Molecular Weight of Plume, Burn Rate of Material, Flame Temperature

Molecular Weight of Plume is the initial molecular weight of the plume in kg/kmole (lbm/lbmole).

Burn Rate of Material is the rate at which the material burns in %/s.

Flame Temperature is the fire temperature in degrees Kelvin .

If **Number of Isotopes** is given a value of 0 (no radiological hazard) in Card 1, Cards 3-8 should be omitted.

CARD 3

Isotope Name, Mass Fraction of Isotope

Isotope Name is a character string of up to 6 characters which identifies the radionuclide (i.e., U-234, Th-232, etc.).

Mass Fraction of Isotope is the mass fraction of the isotope which is present in the material. It should be noted that the mass fractions of all isotopes of a material should sum to 1.0. If this is not the case, the program will print a warning message.

CARD 4

Molecular Weight of Isotope, Half Life of Isotope, Density of Isotope, Inhalation Dose Factor, Ingestion Dose Factor

Molecular Weight of Isotope is the molecular weight in kg/kmole (or lbm/lbmole) of the radionuclide.

Half Life of Isotope is the half life (in years) of the radionuclide.

Density of Isotope is the density in g/cm³ of the radionuclide.

Representative values for the molecular weight, half life and density of various radionuclides may be found in the *CRC Handbook of Chemistry and Physics*.

Inhalation Dose Factor is the dose factor (e.g., 50-year C.E.D.E.) in rem/Ci for inhalation.

Ingestion Dose Factor is the dose factor (e.g., 50-year C.E.D.E) in rem/Ci for ingestion.

Values of the inhalation and ingestion dose factors for various radionuclides may be found in *Internal Dose Conversion Factors for Calculation of Dose to the Public* (DOE/EH-0071).

CARD 5

Direct Radiation Flag, Direct Radiation Constant

Direct Radiation Flag is given an integer value of either 1 or 2. A value of 2 indicates that the source data for direct radiation calculations is given as a constant ($\sum R_j S_{ij}$). A value of 1 indicates that the source data (S_{ij}) are given individually and the program performs the summation.

Direct Radiation Constant is required if the **Direct Radiation Flag** above is given a value of 2. This constant is given by $\sum R_j S_{ij}$ and has units of mrem/hr-cm. Although this entry is not used in the calculations if the **Direct Radiation Flag** has a value of 1, it must still be given a value (a value of 0 is recommended).

Cards 6-8 should be omitted if the **Direct Radiation Flag** has a value of 2.

CARD 6

$S_1, S_2, S_3, S_4, S_5, S_6$

$S_1 - S_6$ are the source terms for the radionuclide in $\gamma/\text{cm}^3/\text{s}$. These values should be obtained from a computer code such as ORIGEN.¹

CARD 7

$S_7, S_8, S_9, S_{10}, S_{11}, S_{12}$

$S_7 - S_{12}$ are the source terms for the radionuclide in $\gamma/\text{cm}^3/\text{s}$. These values should be obtained from a computer code such as ORIGEN.¹

CARD 8

$S_{13}, S_{14}, S_{15}, S_{16}, S_{17}, S_{18}$

$S_{13} - S_{18}$ are the source terms for the radionuclide in $\gamma/\text{cm}^3/\text{s}$. These values should be obtained from a computer code such as ORIGEN.¹

Cards 3-8 should be repeated for each radionuclide. In other words, there should be n sets of Cards 3-8 where n is the number of isotopes entered in Card 1.

An end of file card is required to indicate the termination of material data. This card should have the following format:

0,'END OF FILE', 0

A sample input file (TSRA.DAT) containing user-defined materials is presented in Appendix B.

2.3 PROGRAM OUTPUT

For each material chosen, the following output is provided:

- (1) Radiological dose in rem received from direct exposure,
- (2) Maximum downwind concentration in mg/m^3 and the product of concentration and exposure time in $\text{mg}\cdot\text{hr}/\text{m}^3$,
- (3) Maximum radiological dose in rem received from inhalation,
- (4) Maximum uptake in mg due to inhalation,
- (5) Radiological dose in rem received from ingestion,
- (6) Intake in mg due to ingestion.

An extensive listing of program output is provided in the file TSRA.OUT. In addition to the final output listed above, values of intermediate calculated variables as well as the input values used in the calculations are given in this output file for each material analyzed. All user-defined material data is also echoed to the output file. Sample output files are presented in Appendix B for cases with and without user-supplied materials.

3. MATERIALS CONSIDERED IN MODEL

Table 3.1 contains the materials used in weapons packages that are included in the TSRA Bounding Release Model database. The list of materials selected for inclusion in the model was based on consideration of typical materials associated with weapons components and consultation with DOE/AL Nuclear Explosives Safety Division. A comprehensive treatment of components in a fire is outside the scope of this evaluation.

Since magnesium, polyethylene, polyethylpentene, silicone, tungsten and urethane are assumed to be standard industrial hazards, no consequence calculations will be performed for these materials, although they are included in the model database. The only materials which pose a radiological hazard are thorium, uranium and the alloys containing uranium. The isotopes of these elements considered in the radiation dose calculations are also shown in Table 3.1.

Isotopic compositions are needed for those materials which pose a radiological hazard. Table 3.2 contains the assumed radionuclide mass fractions for the radiological materials contained in the database. Thorium is assumed to consist of 100% Th-232. If compositions other than those shown in Table 3.2 are desired, a new material would need to be added to the database as described in Section 2.2.

Table 3.1. Materials Included in the Database

Material	Radionuclides Considered in Radiation Dose Calculations
Beryllium	
Beryllium Oxide [BeO]	
Boron	
Lithium Deuteride [LiD]	
Lithium Hydride [LiH]	
Magnesium	
Polyethylene	
Polyethylpentene	
Silicone [SiO(CH ₃) ₂]	
Tantalum	
Thorium	Th-232
Tungsten	
Highly Enriched Uranium	U-232, U-234, U-235, U-236, and U-238
Natural Uranium	U-234, U-235 and U-238
Depleted Uranium	U-235 and U-238
Uranium-Niobium Alloy	U-235 and U-238
Uranium-Niobium-Zirconium Alloy	U-235 and U-238
Urethane [C ₃ H ₇ NO ₂]	

Table 3.2. Isotopic Compositions of Radiological Materials

Compound	Mass Fraction				
	U-232	U-234	U-235	U-236	U-238
Highly Enriched Uranium ^a	4.0E-08	0.012	0.94	0.0048	0.04319996
Natural Uranium ^b	-	5.6E-05	0.00705	-	0.992894
Depleted Uranium ^b	-	-	0.00195	-	0.99805
Uranium -Niobium Alloy [94.8% U (Depleted), 5.2% Nb]	-	-	0.0018486	-	0.9461514
Uranium-Niobium-Zirconium Alloy [90% U (Depleted), 7.5% Nb, 2.5% Zr]	-	-	0.001755	-	0.898245

- Sources:
- a. Internal memorandum to R. A. Just from J. F. DeClue and D. A. Tollefson, October 11, 1995.
 - b. Internal memorandum to R. A. Just from J. F. DeClue and D. A. Tollefson, October 20, 1995.

4. DIRECT RADIATION EXPOSURE

If all of the material is conservatively assumed to be exposed and unshielded and all the radiation emanates from a single point source, the dose rate for a specific material may be calculated as

$$D = \frac{1}{4 \pi r^2} \sum_{i=1}^N \sum_{j=1}^{18} \frac{m_i}{\rho_i} S_{ij} R_j, \quad (4.1)$$

where D = dose rate (mrem/hr),
 r = distance from source (cm),
 N = number of isotopes being considered,
 m_i = mass present of isotope i (g),
 ρ_i = density of isotope i (g/cm³),
 S_{ij} = source term for isotope i and group j (γ/cm³/s),
 R_j = response term for group j [(mrem/hr)/(γ/cm²/s)].

Guidance from DOE-AL indicates that in the event of an accident which does not involve high energy explosives, the security force will establish a perimeter of 500 ft around the accident site. Therefore, the Maximally Exposed Individual is assumed to be located a minimum of 152.4 m (500 ft) from the postulated point source. This default value may be easily changed if direct dose calculations are desired at other distances (e.g., to evaluate the dose to security forces moving the SST contents). The radiological dose received in mrem is simply the product of the dose rate (D) and the exposure time. In the event of a major accident, it might take several hours to restore the hazardous material to a proper environment. Although there is no definitive basis for predicting the exposure time, a value of 3 hours is assumed as the default.

The response terms (R_j) needed in the direct radiation calculations are independent of the material or nuclide and are presented in Table 4.1. The densities of the radionuclides of interest in this study are presented in Table 4.2. The nuclide densities in Table 4.2 were calculated as the product of the density of the most abundant nuclide and the molecular weight ratio between the isotope of interest and the most abundant isotope. S. N. Cramer of the Radiation Shielding Information Center in the Computational Physics and Engineering Division used the ORIGEN computer code to predict the source terms (S_{ij}) for the various isotopes.¹ B. L. Broadhead of the Nuclear Engineering Applications Section in the Computational Physics and Engineering Division performed an independent verification of Cramer's analyses. Results of both analyses as well as the assumed decay times are presented in Table 4.3. The decay times listed in Table 4.3 indicate the time at which the dose rate is a maximum. In general, Cramer and Broadhead's results are fairly consistent. Cramer's results were used in the FORTRAN code.

Bremsstrahlung, which is the electromagnetic radiation produced by a charged particle subjected to a change in velocity, was included in the direct dose calculations. Including the Bremsstrahlung should result in conservative results. The determination as to whether or not the Bremsstrahlung are included usually depends on the medium. For instance, if an oxide or water medium is assumed, the Bremsstrahlung should definitely be included. Usually the effect of neglecting the Bremsstrahlung on total dose rate is insignificant; however, for some isotopes such as U-238, it has a very significant effect (i.e., 32.06 mrem/hr-cm without Bremsstrahlung and 134.9 with Bremsstrahlung).

Table 4.1. Response Terms for All Nuclides

<i>J</i>	R_j [(mrem/hr)/($\gamma/\text{cm}^2/\text{s}$)]
1	8.771E-03
2	7.478E-03
3	6.374E-03
4	5.413E-03
5	4.622E-03
6	3.959E-03
7	3.468E-03
8	3.019E-03
9	2.627E-03
10	2.205E-03
11	1.832E-03
12	1.522E-03
13	1.172E-03
14	8.759E-04
15	6.306E-04
16	3.833E-04
17	2.669E-04
18	9.347E-04

Source: ANSI/ANS-6.1.1-1977, *Neutron and Gamma-Ray Flux-to-Dose-Rate Factors*, American Nuclear Society, 1977.

Table 4.2. Properties of the Nuclides

Nuclide	Molecular Weight ^a	Half Life ^a (years)	Density ^b (g/cm ³)
Th-232	232.038054	1.4E10	11.7
U-232	232.03713	68.9	18.57
U-234	234.040946	2.450E05	18.72
U-235	235.043924	7.04E08	18.81
U-236	236.045562	2.34E07	18.89
U-238	238.050784	4.46E09	19.05

- Sources:
- CRC Handbook of Chemistry and Physics*, 73rd ed., CRC Press, Inc., 1993.
 - Uranium radionuclide densities calculated as the product of the density of the most abundant nuclide (U-238) and the molecular weight ratio between the isotope of interest and U-238.

Table 4.3. Source Terms for the Nuclides

Nuclide	$\sum S_y R_y$ (mrem/hr-cm)			Decay Time for Maximum Dose (yr)	
	Cramer	Broadhead	Percent Difference	Cramer	Broadhead
Th-232	2.628E02*	2.620E02	0.30	100	100
U-232	4.342E10*	4.438E10	2.15	10	10
U-234	1.841E05*	1.831E05	0.53	100	10
U-235	1.131E03*	1.122E03	0.73	100	10
U-236	2.478E00*	2.557E00	3.11	10	10
U-238	1.349E02*	1.346E02	0.28	10	10

* Note Dose rates based on gammas only [dose rates from neutrons are several orders of magnitude (2-6) smaller than dose rates from gammas].

5. AIRBORNE RELEASES

One of the accident scenarios which must be considered involves the airborne release of material resulting from a fire. Both the radiological and chemical hazards due to inhalation to an individual downwind of the fire must be calculated.

5.1 RELEASE RATES

Information or data regarding oxidation or burning rates of metals and other materials considered in this analysis is scarce. In the absence of a better model, the release factor value of $8.9 \times 10^{-3} \text{ %/s}$ recommended by R. A. Just is used for all the metals.⁷ This value is based on data presented in the *Nuclear Fuel Cycle Facility Accident Analysis Handbook*² and information provided in J. M. Napier's *Release of Uranium to Air During Oxidation of Uranium Chips*³. It should be noted that this value results in burn durations of 3.12 hr regardless of the initial mass of the material present. Although unrealistic, this release rate represents an average rate throughout the process and should lead to reasonable results for relatively small quantities of metal. Although this model is very crude, it is believed to be conservative since test data for pyrophoric metals indicate significantly longer burn times. Experimental data were available for the combustion of lithium hydride.⁴ In order to be consistent with the other values, this data was converted into units of %/s. It is assumed that the release rate for lithium deuteride is equal to that of lithium hydride.

The release rates assumed for the analyses are presented in Table 5.1. Since it is assumed that beryllium oxide will not oxidize further, no burning rate is presented in Table 5.1 for this material. Available information and comments regarding the flammability of the materials considered in this analysis are also presented in Table 5.1

These analyses conservatively assume that 100% of the burned material becomes airborne. This assumption insures conservative results given the inherent uncertainties in dispersion analysis and to account for the possibility that a receptor may be at an elevated location. If this assumption results in unfavorable consequences, the analysis should be refined by choosing a more realistic value for the the airborne release fraction.

5.2 ATMOSPHERIC DISPERSION

The concentration may be evaluated using the standard Gaussian dispersion equation.⁵ The concentration at coordinates X, Y, Z is

$$C = \left(\frac{Q}{2\pi\sigma_y\sigma_zU} \right) \exp\left(\frac{-Y^2}{2\sigma_y^2}\right) \left[\exp\left(\frac{-(Z-h)^2}{2\sigma_z^2}\right) + \exp\left(\frac{-(Z+h)^2}{2\sigma_z^2}\right) \right], \quad (5.1)$$

where

C = concentration (mg/m^3),
 Q = release rate (mg/s),
 σ_y = crosswind dispersion coefficient (m),
 σ_z = vertical dispersion coefficient (m),

Table 5.1 Burning Rates of Materials

Material	Notes Regarding Flammability	Burn Rate (%/s)
Beryllium	Moderate fire hazard in dust or powder form ^a	8.9E-03
Beryllium Oxide	Not expected to oxidize further	
Boron	Flammable in dust form ^a	8.9E-03
Lithium Deuteride	Highly flammable ^a	6.846E-01
Lithium Hydride	Highly flammable ^a	6.846E-01
Tantalum	Dry powder ignites spontaneously in air ^a	8.9E-03
Thorium	Powder may ignite spontaneously in air ^a	8.9E-03
Uranium	Flammable in the solid or dust form when exposed to heat or flame ^a	8.9E-03
Uranium-Niobium Alloy	Niobium is flammable in dust form ^a	8.9E-03
Uranium-Niobium-Zirconium Alloy	Zirconium is very dangerous fire hazard in dust form ^a	8.9E-03

Sources: a. Lewis, R. J. Sr., *Sax's Dangerous Properties of Industrial Materials (Vol. I-III)*, Eighth edition, Van Nostrand Reinhold, N.Y., 1992.

U = average ambient wind velocity between elevations 0 and h (m/s),
 Y = crosswind distance (m),
 Z = elevation (m),
 h = plume height (m).

Centerline, ground level air concentrations are predicted by assuming $Y = 0$ and $Z = 0$. The release rate is assumed to be equal to the burning rate of the material (see Table 5.1). The crosswind dispersion coefficient is calculated as⁶

$$\sigma_y = y_1 X (1.0 + 0.0001 X)^{-1/2}, \quad (5.2)$$

where X = downwind distance (m).

The values of the constant y_1 are given in Table 5.2 for stability classes A-G. The vertical dispersion coefficient is calculated as⁶

$$\sigma_z = z_1 X (z_2 + z_3 X)^{z_4}. \quad (5.3)$$

The values of the constants z_1 - z_4 are given in Table 5.2 for stability classes A-G. Equations 5.2 and 5.3 are valid for $100 \leq X \leq 10,000$ m.

The equilibrium or maximum plume rise (h_{max}) may be estimated by⁷

$$h_{max} = 2.6 \frac{3}{3+p} \left[\frac{g(p+1) \left(1 - \frac{T_a M_o}{T_o M_a} \right) w_o r_o^2}{\frac{u_2 s}{2^p}} \right]^{\frac{1}{3+p}}, \quad (5.4)$$

where p = constant,
 g = acceleration due to gravity (m/s²),
 T_a = ambient temperature (K),
 M_o = initial molecular weight of the plume,
 T_o = flame temperature (K),
 M_a = molecular weight of ambient air,
 w_o = initial vertical velocity of the plume (m/s),
 r_o = initial plume radius (m),
 u_2 = wind velocity at an elevation of 2 m (m/s),
 s = stability parameter (s⁻²).

Values of 298 K (77°F) and 28.964 kg/kmole may be assumed for the ambient temperature and molecular weight of ambient air, respectively. The ambient temperature has an effect on the plume rise and the initial plume temperature. As the ambient temperature increases, the plume rise and the initial plume temperature

increase. However, the effects of varying the ambient temperature from -25 to 50°C on the plume rise and

Table 5.2. Dispersion Coefficient Constants

Stability Class	y_1	z_1	z_2	z_3	z_4
A ^a	0.22	0.2	1	0	0
B ^a	0.16	0.12	1	0	0
C ^a	0.11	0.08	1	0.0002	-0.5
D ^a	0.08	0.06	1	0.0015	-0.5
E ^a	0.06	0.03	1	0.0003	-1
F ^a	0.04	0.016	1	0.0003	-1
G ^b	0.67(0.04) = 0.0268	0.6(0.016) = 0.0096	1	0.0003	-1

- Sources:
- Hanna, S. R., Briggs, G. A. And Hosker, R. P. Jr., *Handbook on Atmospheric Diffusion*, DOE/TIC-11223, U. S. Department of Energy, Office of Energy Research, Washington, D. C., 1982.
 - U. S. Nuclear Regulatory Commission, *On-Site Meteorological Programs*, Regulatory Guide 1.23, 1972.

initial plume temperature are estimated to be less than 6%.⁷ Values of the constant (p) and stability parameter (s) are given in Table 5.3 for stability classes A-G. Since a value of p is not defined for G stability, the analysis will use the value of 0.55 associated with F stability. Details regarding the determination of the stability parameter are provided in R. A. Just's report.⁷ Hydrocarbon pool fires typically have initial upward velocities ranging from 1 to 4 m/s.⁸ Since lower initial vertical plume velocities result in lower plume rise and subsequently higher downwind concentrations, it is conservative to assume a value of 1 m/s for the initial plume velocity. Since a significant fire would more than likely be at least 1 m in diameter, an initial plume radius of 0.5 m is assumed to be reasonable. Since this analysis is intended for an arbitrary location, site specific wind velocity data is unobtainable. For most situations, ground level concentrations increase with decreasing wind velocities. Since the Gaussian dispersion coefficients are valid for wind velocities of 1 m/s or greater, a wind velocity of 1 m/s should provide conservative results.

The plume height at any downwind distance may be calculated by⁷

$$h = \left[\frac{1.6(p+1) \left[g \left(1 - \frac{T_a M_o}{T_o M_a} \right) w_o r_o^2 \right]^{1/3} \left(\frac{1}{1+p} \right)}{\frac{u_2}{2^p}} \right] X^{\frac{2}{3+3p}} \quad (5.5)$$

Since the plume height predicted by Eq. 5.5 should not exceed the maximum plume rise predicted by Eq. 5.4, the smaller of these two values should be used as the plume height in the calculation of the downwind concentration (Eq. 5.1).

The general form of the vertical velocity profile is given in Reference 9. The following form is written specifically for an elevation of 2 meters:

$$u = u_2 \left(\frac{h}{2} \right)^p \quad (5.6)$$

The average ambient wind velocity may be obtained by integrating Eq. 5.6 from $h = 0$ to $h = h_{max}$. This yields

$$U = \frac{\left[u_2 \left(\frac{h_{max}}{2} \right)^p \right]}{p+1} \quad (5.7)$$

Table 5.3. Constants Required for Plume Rise Calculations

Stability Class	P (Rural terrain)	s (s ²)
A	0.07 ^a	1.6E-04 ^b
B	0.07 ^a	1.6E-04 ^b
C	0.1 ^a	1.6E-04 ^b
D	0.15 ^a	1.6E-04 ^b
E	0.35 ^a	8.2E-04 ^b
F	0.55 ^a	1.6E-03 ^b
G	0.55 ^b	1.6E-03 ^b

- Sources: a. Hanna, S. R., Briggs, G. A. And Hosker, R. P. Jr., *Handbook on Atmospheric Diffusion*, DOE/TIC-11223, U. S. Department of Energy, Office of Energy Research, Washington, D. C., 1982.
- b. Just, R. A., *Support for Nuclear Explosive Safety Division, Department of Energy, Albuquerque Operations - Effects of a Postulated Uranium Transportation Accident*, Y/LF-504, January 1996.

5.3 RADIOLOGICAL CONSEQUENCES OF INHALATION

The radiological exposure received due to inhalation resulting from the fire may be calculated as

$$D_{fire} = \frac{(C) \left[\sum_{i=1}^N (A_i)(DF_{inhale,i})(F_i) \right] (b)(t)}{1 \times 10^3} \quad (5.8)$$

- where D_{fire} = radiological dose received from inhalation (rem),
 C = downwind concentration (mg/m³),
 N = number of isotopes considered for the material,
 A_i = activity of isotope i (Ci/g),
 $DF_{inhale,i}$ = inhalation dose conversion factor for isotope i (rem/Ci),
 F_i = mass fraction of isotope i ,
 b = breathing rate (m³/hr),
 t = exposure time (hr).

Equation 5.8 gives the radiological dose received due to the burning of a single material containing N isotopes. If the postulated fire involves several materials, the doses for each material should be calculated by Eq. 5.8 and then summed to obtain the total radiation dose received.

The activity is calculated as⁹

$$A_i = \frac{3.578 \times 10^5}{(MW_i)(\tau_i)}, \quad (5.9)$$

where MW_i = molecular weight of isotope i ,
 τ_i = half life of isotope i (years).

The inhalation dose conversion factors for the radionuclides of interest in this study are presented in Table 5.4. The values in Table 5.4 represent 50-year committed effective dose equivalents (C.E.D.E.). A typical value of breathing rate is approximately 1.2 m³/hr. As a default, the exposure time is assumed to be equal to the duration of the fire, which is calculated as

$$t = \frac{m}{3600Q}, \quad (5.10)$$

where t = exposure time (hr),
 m = initial mass of material (mg),
 Q = release rate (mg/s).

5.4 CHEMICAL CONSEQUENCES OF INHALATION

The uptake in mg due to inhalation is calculated as

$$Uptake = (C)(b)(t). \quad (5.11)$$

Table 5.4. Dose Conversion Factors

Nuclide	Inhalation Dose Conversion Factor (rem/Ci)	Ingestion Dose Conversion Factor (rem/Ci)
Th-232	1.6E09	2.8E06
U-232	6.7E08	1.3E06
U-234	1.3E08	2.6E05
U-235	1.2E08	2.5E05
U-236	1.2E08	2.5E05
U-238	1.2E08	2.3E05

Source: *Internal Dose Conversion Factors for Calculation of Dose to the Public*, DOE/EH-0071, U.S. Department of Energy, Washington, D.C., July 1988.

6. WATER TRANSPORT SCENARIO

Another accident scenario which must be considered involves a transportation accident which results in loss of containment and release of the hazardous material into a waterway. Subsequently, the material is assumed to be transported downstream, taken into a municipal water supply, and ingested by the public through drinking water. One possible mechanism for such a release would be runoff from a fire where water is applied to the burning material. Direct ingestion from a waterway is not considered due to low probability of a person drinking water directly downstream of a major highway following a transportation accident.

The amount of contaminant which is available to be ingested by an individual is calculated as

$$m_{cont} = \frac{(m)(f)(V_{drink})}{V_{tank}}, \quad (6.1)$$

where m_{cont} = amount of contaminant ingested (kg),
 m = initial mass of material released (kg),
 f = fraction of contaminant which reaches public drinking supply,
 V_{drink} = individual daily uptake of water (m^3),
 V_{tank} = volume of water tank (m^3).

A significant fraction of the small particles generated by the fire would likely become airborne. Those particles that remain on the ground and are available to be washed into the waterway would tend to be significantly larger than those that become airborne. In addition, fire fighting actions would probably extinguish the fire before combustion of the material is complete. Therefore, only a portion of the initial material would be expected to wash into the waterway. However, this analysis assumes that 100% of the material is released in a dispersible form to the waterway, either directly or due to runoff from a fire extinguishing stream.

Once the material reaches the waterway, advection and convection phenomena dilute the contaminated water and soil and sediment interaction will remove some of the contaminant from the waterway. Furthermore, the municipal water supply system will remove a significant portion of the contaminant through filtration and settling prior to public distribution. Information received from the Knoxville Utilities Board and ETMC/Johnson Controls (see Appendix C) indicates that only 0.29-0.6% of the particles (in the 2-15 micron size range) at the water intake will pass through the filtration system. These data also indicate that no particles greater than 15 micron pass through the filtration system. If the material reaches a municipal water supply and is detected at an unacceptably high level, actions would be taken to prevent people from drinking the contaminated water. The Clean Water Act specifies disinfectant contact values for public water supplies. Required contact time is based on these values and determined by water temperature, Ph, and disinfectant values. Since no notification is assumed, the material reaching the public is dependent on the effectiveness of the municipal system.

Although 500,000 to 2,000,000 gallon tanks are typical for main water systems, managers at local water treatment facilities indicated that 125,000 to 250,000 gallon tanks were also in use. Therefore, a minimum tank size of 125,000 gallons is assumed in the analysis. The analysis also assumes that an individual drinks an entire days supply of water (estimated to be two liters) from the contaminated source. Public ingestion through drinking is the only exposure pathway considered in the model; absorption through bodily contact and ingestion due to contaminated food are neglected.

Taking into account these dilution and depletion mechanisms, the analysis conservatively assumes that 0.01 (1%) of the initial quantity of hazardous material initially released passes through the municipal water system and is available for public ingestion. Neglecting emergency response actions, assuming a minimum tank size, and assuming an individual drinks an entire days supply of water from the contaminated source adds additional conservatism. It should be noted that the value of 0.01 is valid only for insoluble materials. Since lithium deuteride and lithium hydride are assumed to be completely water soluble, the analysis assumes that 100% of the initial material is available for public ingestion for these two compounds.

6.1 RADIOLOGICAL CONSEQUENCES OF INGESTION

The radiological dose received by an individual resulting from a spill into a waterway and subsequent uptake of the contaminated water may be calculated as

$$D_{spill} = m_{cont} \left[\sum_{i=1}^N (A_i)(DF_{ingest,i})(F_i) \right] (1 \times 10^3) , \quad (6.2)$$

where D_{spill} = radiological dose received from ingestion (rem),
 N = number of isotopes considered for the material,
 A_i = activity of isotope i (Ci/g),
 $DF_{ingest,i}$ = ingestion dose conversion factor for isotope i (rem/Ci),
 F_i = mass fraction of isotope i .

Equation 6.2 gives the radiological dose received due to the ingestion of a single material containing N isotopes. If the postulated release involves several materials, the doses for each material should be calculated by Eq. 6.2 and then summed to obtain the total radiation dose received. The activity is calculated as⁹

$$A_i = \frac{3.578 \times 10^5}{(MW_i)(\tau_i)} , \quad (6.3)$$

where MW_i = molecular weight of isotope i ,
 τ_i = half life of isotope i (years).

The ingestion dose conversion factors for the radionuclides of interest in this study are presented in Table 5.4. The values in Table 5.4 represent 50-year committed effective dose equivalents (C.E.D.E.).

6.2 CHEMICAL CONSEQUENCES OF INGESTION

The intake in mg due to a spill into a waterway is

$$Intake = (1 \times 10^6) m_{cont} . \quad (6.4)$$

7. SAMPLE RUNS AND RESULTS

Sample runs were performed by arbitrarily assuming that 10 kg of each material was exposed for each of the accident scenarios (direct exposure, fire and spill into waterway). Since magnesium, polyethylene, polyethylpentene, silicone, tungsten and urethane are assumed to be standard industrial hazards, they were not analyzed. Since it is assumed that beryllium oxide will not oxidize further, calculations for this compound were not performed for the fire accident. The results of the sample runs are presented in Table 7.1. The initial molecular weight of the plume and the flame temperature were assumed to have values of 28.964 (molecular weight of air) and 1200 K, respectively, for all the materials considered in the sample runs. Since an open flame is assumed, excess oxygen will probably be available for combustion. Therefore, an initial plume molecular weight equal to the molecular weight of air is assumed. Typical flame temperatures of hydrocarbon pool fires range from approximately 1200 to 1400 K.¹⁰ Assuming a flame temperature of 1200 K should lead to conservative values of plume rise and, subsequently, concentration.

As mentioned in Chapter 3, the only materials which pose a radiological hazard are thorium, uranium and the alloys containing uranium. As evident from the results presented in Table 7.1, of the materials considered, Highly Enriched Uranium presents the worst radiological hazard. As seen from Table 7.1, the values of uptake due to inhalation resulting from a fire predicted by the model were identical regardless of the material. This implies that the uptake is independent of the burn rate. The explanation for this is related to the way in which the default exposure time is calculated by the model. As explained in Section 5.3, as the default, the exposure time is assumed to be equal to the fire duration which is inversely proportional to the burn rate (Eq. 5.10). Since the concentration is directly proportional to the burn rate (Eq. 5.1), the uptake, which is the product of the concentration, exposure time and breathing rate, is independent of the burn rate. Although the default values for exposure time were used for these sample runs, the exposure time for the fire accident is included as a user input so that values less than the fire duration may be used if desired. Using the fire duration for the exposure time will, however, result in the worst case scenario.

The intake due to ingestion resulting from a spill into a waterway is also the same for all the materials considered in this study with the exception of lithium hydride and lithium deuteride. This occurs since the fraction of material which reaches the public drinking system is assumed to be the same (0.01) for all the materials except the lithium compounds. In reality, this value is probably a function of the material solubility, size of the particles, etc.

Table 7.1. Model Results

Material	Direct Exposure	Fire Accident (Inhalation)				Spill into Waterway (Ingestion)	
	Direct Radiation Dose (rem)	Concentration (mg/m ³)	Concentration *Exposure Time (mg-hr/m ³)	Radiation Dose (rem)	Uptake (mg)	Radiation Dose (rem)	Intake (mg)
Beryllium	0	1.0325E-01	3.2224E-01	0	3.8669E-01	0	4.2268E-01
Beryllium Oxide	0	not calculated	not calculated	0	not calculated	0	4.2268E-01
Boron	0	1.0325E-01	3.2224E-01	0	3.8669E-01	0	4.2268E-01
Lithium Deuteride	0	7.9418	3.2224E-01	0	3.8669E-01	0	42.268
Lithium Hydride	0	7.9418	3.2224E-01	0	3.8669E-01	0	42.268
Tantalum	0	1.0325E-01	3.2224E-01	0	3.8669E-01	0	4.2268E-01
Thorium	2.3088E-07	1.0325E-01	3.2224E-01	6.8145E-02	3.8669E-01	1.3035E-04	4.2268E-01
Uranium							
Highly Enriched	2.7582E-06	1.0325E-01	3.2224E-01	4.1055	3.8669E-01	8.9699E-03	4.2268E-01
Natural	8.2306E-08	1.0325E-01	3.2224E-01	3.3800E-02	3.8669E-01	7.2542E-05	4.2268E-01
Depleted	7.3871E-08	1.0325E-01	3.2224E-01	1.5803E-02	3.8669E-01	3.3144E-05	4.2268E-01
Uranium-Niobium Alloy	7.0029E-08	1.0325E-01	3.2224E-01	1.4981E-02	3.8669E-01	3.1420E-05	4.2268E-01
Uranium-Niobium -Zirconium Alloy	6.6484E-08	1.0325E-01	3.2224E-01	1.4223E-02	3.8669E-01	2.9829E-05	4.2268E-01

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APPENDIX A
FORTRAN Code Listing


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C*****
C*
C*          TSRA.FOR
C*
C*          J. C. ANDERSON
C*
C*          LOCKHEED MARTIN ENERGY SYSTEMS, INC.
C*          OAK RIDGE NATIONAL LABORATORY
C*          BUILDING 1000, MS-6332
C*          OAK RIDGE, TN 37831
C*
C*          (615) 576-2910
C*
C*          OCTOBER 1997
C*
C*  THIS FORTRAN PROGRAM DETERMINES THE CONSEQUENCES OF WORST CASE
C*  NON-CRITICALITY TRANSPORTATION ACCIDENTS INCLUDING DIRECT
C*  EXPOSURE, AIRBORNE RELEASES OF HAZARDOUS MATERIALS AND SPILLS
C*  INTO WATERWAYS.  BOTH RADIOLOGICAL AND CHEMICAL CONSEQUENCES
C*  ARE DETERMINED.
C*
C*****
C
  IMPLICIT REAL*8(A-H,K-Z)
  REAL*8 ACT(50,10),CONC(50,7),DIRECT(50)
  REAL*8 INGEST(50)
  REAL*8 INHALE(50),INTAKE(50)
  REAL*8 MCONT(50),Q(50)
  REAL*8 UPTAKE(50)
  INTEGER CLASS,DRFLAG,INHFLAG,NISOTOPE,RESPONSE
  CHARACTER*1 SCLASS,WSCLASS
  CHARACTER*6 ISOTOP
  CHARACTER*8 OUT
  CHARACTER*12 OUTPUT
  CHARACTER*30 MATL
C
C  COMMON BLOCKS
C
  COMMON/DEFAULT/DIST,EXPTIME,X,Z,TA,RO,U2,BREATHE,EPTIME
  @,VTANK,VDRINK,INHFLAG
  COMMON/DIRECT/DRFLAG(50,10),DRCONST(50,10),S(50,10,18)
  COMMON/CONSTANT/G,PI
  COMMON/ISOTOPE/FRACTION(50,10),HLIFE(50,10),INGCEDE(50,10),
  @INHCEDE(50,10),ISOTOP(50,10),MW(50,10),NISOTOPE(50),RHO(50,10)
  COMMON/MATERIAL/IJ,MATL(50),MASS(50)
  COMMON/PLUME/BRATE(50),FLMTEMP(50),MWPLUME(50)
  COMMON/SPILL/FRACT(50)
C
C  OPEN OUTPUT FILE
C
  WRITE(*,150)
  WRITE(*,160)
  WRITE(*,170)
  WRITE(*,*)
  WRITE(*,180)
  WRITE(*,*)
  READ(*,*) OUT
  IF (OUT .EQ. '0') OUT = 'TSRA'
  OUTPUT = OUT//''.OUT'
  OPEN(UNIT = 200, FILE = OUTPUT)
C
C  INITIALIZE VALUES
C
  TDIRECT = 0.
  TINHALE = 0.
  TINGEST = 0.
  INHFLAG = 2
C

```

```

C SET DEFAULT VALUES
C
C ENTER THE DISTANCE FROM THE SOURCE FOR DIRECT RADIATION CALCULATIONS
C (m)
    DIST = 152.4
C ENTER THE EXPOSURE TIME FOR DIRECT RADIATION CALCULATIONS (hr)
    EXPTIME = 3.
C ENTER THE MINIMUM DOWNWIND DISTANCE FOR DISPERSION CALCULATIONS (m)
    XMIN = 100.
C ENTER THE MAXIMUM DOWNWIND DISTANCE FOR DISPERSION CALCULATIONS (m)
    XMAX = 2000.
C ENTER THE DOWNWIND DISTANCE INCREMENT (m)
    XSTEP = 100.
C ENTER THE ELEVATION TO BE USED IN DISPERSION CALCULATIONS (m)
    Z = 0.
C ENTER THE AMBIENT TEMPERATURE (K)
    TA = 298.
C ENTER THE INITIAL PLUME RADIUS (m)
    RO = 0.5
C ENTER THE WIND VELOCITY AT AN ELEVATION OF 2 m (m/s)
    U2 = 1.
C ENTER THE BREATHING RATE (m3/hr)
    BREATHE = 1.2
C ENTER THE VOLUME OF THE WATER TANK (m3)
    VTANK = 473.175
C ENTER THE INDIVIDUALS DAILY UPTAKE OF WATER (m3)
    VDRINK = 0.002
C
C ALLOW USER TO CHANGE DEFAULT VALUES
C
    WRITE(*,*) 'DEFAULT VALUES ASSUMED BY PROGRAM:'
    WRITE(*,*)
    WRITE(*,220) DIST
    WRITE(*,230) EXPTIME
    WRITE(*,240) XMIN
    WRITE(*,242) XMAX
    WRITE(*,244) XSTEP
    WRITE(*,250) Z
    WRITE(*,260) TA
    WRITE(*,270) RO
    WRITE(*,280) U2
    WRITE(*,290) BREATHE
    WRITE(*,300)
    WRITE(*,310) VTANK
    WRITE(*,320) VDRINK
    WRITE(*,*)
    WRITE(*,*) 'DO YOU WISH TO CHANGE ANY OF THESE VALUES?'
    WRITE(*,*) '1 = YES OR 2 = NO'
    WRITE(*,*)
    READ(*,*) RESPONSE
    IF (RESPONSE .EQ. 2) GOTO 5
    IF (RESPONSE .EQ. 1) THEN
2    CONTINUE
    WRITE(*,*) 'ENTER NUMBER OF VARIABLE YOU WISH TO CHANGE'
    WRITE(*,*)
    READ(*,*) INUM
    WRITE(*,*) 'ENTER NEW VALUE'
    WRITE(*,*)
    IF (INUM .EQ. 1) READ(*,*) DIST
    IF (INUM .EQ. 2) READ(*,*) EXPTIME
    IF (INUM .EQ. 3) READ(*,*) XMIN
    IF (INUM .EQ. 4) READ(*,*) XMAX
    IF (INUM .EQ. 5) READ(*,*) XSTEP
    IF (INUM .EQ. 6) READ(*,*) Z
    IF (INUM .EQ. 7) READ(*,*) TA
    IF (INUM .EQ. 8) READ(*,*) RO
    IF (INUM .EQ. 9) READ(*,*) U2
    IF (INUM .EQ. 10) READ(*,*) BREATHE

```

```

IF (INUM .EQ. 11) THEN
  INHFLAG = 1
  READ(*,*) EPTIME
ENDIF
IF (INUM .EQ. 12) READ(*,*) VTANK
IF (INUM .EQ. 13) READ(*,*) VDRINK
WRITE(*,*) 'DO YOU WISH TO CHANGE ANOTHER VALUE?'
WRITE(*,*) '1 = YES OR 2 = NO'
WRITE(*,*)
READ(*,*) RESPONSE
IF (RESPONSE .EQ. 2) GOTO 4
IF (RESPONSE .EQ. 1) THEN
  WRITE(*,*) 'DEFAULT VALUES ASSUMED BY PROGRAM:'
  WRITE(*,*)
  WRITE(*,220) DIST
  WRITE(*,230) EXPTIME
  WRITE(*,240) XMIN
  WRITE(*,242) XMAX
  WRITE(*,244) XSTEP
  WRITE(*,250) Z
  WRITE(*,260) TA
  WRITE(*,270) RO
  WRITE(*,280) U2
  WRITE(*,290) BREATHE
  IF (INHFLAG .EQ. 1) WRITE(*,301) EPTIME
  IF (INHFLAG .NE. 1) WRITE(*,300)
  WRITE(*,310) VTANK
  WRITE(*,320) VDRINK
  WRITE(*,*)
  GOTO 2
ENDIF
ENDIF
4 CONTINUE
C PRINT REVISED SET OF VALUES TO SCREEN
WRITE(*,*) 'CURRENT VALUES TO BE USED IN PROGRAM:'
WRITE(*,*)
WRITE(*,220) DIST
WRITE(*,230) EXPTIME
WRITE(*,240) XMIN
WRITE(*,242) XMAX
WRITE(*,244) XSTEP
WRITE(*,250) Z
WRITE(*,260) TA
WRITE(*,270) RO
WRITE(*,280) U2
WRITE(*,290) BREATHE
IF (INHFLAG .EQ. 1) WRITE(*,301) EPTIME
IF (INHFLAG .NE. 1) WRITE(*,300)
WRITE(*,310) VTANK
WRITE(*,320) VDRINK
WRITE(*,*)
5 CONTINUE
C
C ENTER VALUES FOR CONSTANTS
C
C PI
  PI = 3.14159265
C ACCELERATION DUE TO GRAVITY (m/s2)
  G = 9.8
C
C INITIALIZE MATERIAL COUNTER
  IMATL = 18
C DETERMINE WHETHER THERE ARE ANY USER-DEFINED MATERIALS
  WRITE(*,*) 'DO YOU WISH TO ANALYZE MATERIALS OTHER THAN THOSE'
  WRITE(*,*) 'CURRENTLY IN THE DATABASE?'
  WRITE(*,*) '1 = YES, 2 = NO'
  WRITE(*,*)
  READ(*,*) RESPONSE

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```

      IF (RESPONSE .EQ. 2) GOTO 15
      IF (RESPONSE .EQ. 1) THEN
        WRITE(*,*) 'ADDITIONAL MATERIALS SHOULD BE DEFINED IN FILE'
        WRITE(*,*) 'TSRA.DAT'
        OPEN(UNIT = 100, FILE = 'TSRA.DAT', STATUS = 'OLD')
        WRITE(200,*) 'ECHO OF USER-SUPPLIED MATERIAL DATA:'
        WRITE(200,*)

C
C READ USER-DEFINED MATERIAL DATA
C
10  CONTINUE
    READ(100,*) IDMATL,MATL(IDMATL),NISOTOPE(IDMATL)
    IF (IDMATL .EQ. 0) GOTO 50
    WRITE(200,420) IDMATL,MATL(IDMATL),NISOTOPE(IDMATL)
    READ(100,*) MWPLUME(IDMATL), BRATE(IDMATL), FLMTMP(IDMATL),
@FRACT(IDMATL)
    WRITE(200,430) MWPLUME(IDMATL), BRATE(IDMATL), FLMTMP(IDMATL),
@FRACT(IDMATL)
    IF (NISOTOPE(IDMATL) .EQ. 0) GOTO 40
    SUM = 0
    DO 30 I = 1, NISOTOPE(IDMATL)
      READ(100,*) ISOTOP(IDMATL,I),FRACTION(IDMATL,I)
      WRITE(200,440) ISOTOP(IDMATL,I),FRACTION(IDMATL,I)
      SUM = SUM + FRACTION(IDMATL,I)
      READ(100,*) MW(IDMATL,I),HLIFE(IDMATL,I),RHO(IDMATL,I),
@INHCEDE(IDMATL,I),INGCEDE(IDMATL,I)
      WRITE(200,450) MW(IDMATL,I),HLIFE(IDMATL,I),RHO(IDMATL,I),
@INHCEDE(IDMATL,I),INGCEDE(IDMATL,I)
      READ(100,*) DRFLAG(IDMATL,I),DRCONST(IDMATL,I)
      WRITE(200,460) DRFLAG(IDMATL,I),DRCONST(IDMATL,I)
      IF (DRFLAG(IDMATL,I) .EQ. 2) GOTO 20
      READ(100,*) (S(IDMATL,I,J),J = 1,6)
      WRITE(200,470) (S(IDMATL,I,J),J = 1,6)
      READ(100,*) (S(IDMATL,I,J),J = 7,12)
      WRITE(200,470) (S(IDMATL,I,J),J = 7,12)
      READ(100,*) (S(IDMATL,I,J),J = 13,18)
      WRITE(200,470) (S(IDMATL,I,J),J = 13,18)
20  CONTINUE
30  CONTINUE
    IF (DABS(SUM - 1.0) .GT. 1.0D-04) THEN
      WRITE(*,*) MATL(IDMATL)
      WRITE(*,*) 'MASS FRACTIONS DO NOT SUM TO 1.0'
      WRITE(*,*) 'DO YOU WANT TO CONTINUE ANYWAY?'
      WRITE(*,*) '1 = YES OR 2 = NO'
      WRITE(*,*)
      READ(*,*) RESPONSE
      IF (RESPONSE .EQ. 1) GOTO 40
      IF (RESPONSE .EQ. 2) GOTO 130
    ENDIF
40  CONTINUE
    WRITE(200,*)

C
C INCREMENT MATERIAL COUNTER
    IMATL = IMATL + 1
    GOTO 10
50  CONTINUE
    WRITE(200,410)
    WRITE(200,*)
    ENDIF

C
15  CONTINUE
C
C PROMPT USER FOR MATERIAL MASSES
    DO 55 IJ = 1,IMATL
      WRITE(*,330) IJ,MATL(IJ)
55  CONTINUE
    WRITE(*,*)
    WRITE(*,*) 'ENTER THE NUMBER OF THE MATERIAL OF INTEREST'

```

```

WRITE(*,*)
READ(*,*) IJ
WRITE(*,*) 'ENTER MASS OF ',MATL(IJ),'IN kg'
WRITE(*,*)
READ(*,*) MASS(IJ)
C
C CALCULATE CONSEQUENCES OF ACCIDENT SCENARIOS
C
WRITE(200,200) MATL(IJ),MASS(IJ)
WRITE(200,210)
WRITE(200,*)
C DIRECT RADIATION
IF (NISOTOPE(IJ) .EQ. 0) THEN
DIRECT(IJ) = 0.
WRITE(200,500)
WRITE(200,*)
WRITE(200,501) DIST
WRITE(200,505) EXPTIME
WRITE(200,506) DIRECT(IJ)
WRITE(200,*)
WRITE(200,507)
WRITE(200,*)
GOTO 70
ENDIF
CALL DRAD(DIRECT)
TDIRECT = TDIRECT + DIRECT(IJ)
70 CONTINUE
C ATMOSPHERIC DISPERSION CALCULATIONS
WCONC = 0.
IFLAG = 1
DO 120 X = XMIN,XMAX,XSTEP
CALL DISPERSE(IFLAG,Q,CONC,CLASS)
IF (IFLAG .EQ. 1) THEN
WRITE(200,340)
WRITE(200,345)
WRITE(200,350)
WRITE(200,360)
WRITE(200,*)
WRITE(200,*)
ENDIF
IFLAG = 2
C INHALATION CALCULATIONS
CALL INHAL(IFLAG,Q,CONC,CLASS,ACT,INHALE,UPTAKE)
IF (CLASS .EQ. 1) SCLASS = 'A'
IF (CLASS .EQ. 2) SCLASS = 'B'
IF (CLASS .EQ. 3) SCLASS = 'C'
IF (CLASS .EQ. 4) SCLASS = 'D'
IF (CLASS .EQ. 5) SCLASS = 'E'
IF (CLASS .EQ. 6) SCLASS = 'F'
IF (CLASS .EQ. 7) SCLASS = 'G'
WRITE(200,370) X,SCLASS,CONC(IJ,CLASS)*1.0D06,CONC(IJ,CLASS)
@*EPTIME*1.0D06,INHALE(IJ),UPTAKE(IJ)
IF (CONC(IJ,CLASS) .GT. WCONC) THEN
WCONC = CONC(IJ,CLASS)
WX = X
WSCLASS = SCLASS
WINHALE = INHALE(IJ)
WUPTAKE = UPTAKE(IJ)
ENDIF
120 CONTINUE
WRITE(200,*)
WRITE(200,405)
WRITE(200,*)
WRITE(200,370) WX,WSCLASS,WCONC*1.0D06,WCONC*EPTIME*1.0D06,
@WINHALE,WUPTAKE
WRITE(200,*)
X = WX
CALL DISPERSE(IFLAG,Q,CONC,CLASS)

```

```

IFLAG = 1
CALL INHAL(IFLAG,Q,CONC,CLASS,ACT,INHALE,UPTAKE)
TINHALE = TINHALE+WINHALE
C INGESTION CALCULATIONS
CALL WATER(MCONT)
CALL INGST(ACT,MCONT,INGEST,INTAKE)
TINGEST = TINGEST + INGEST(IJ)
C
WRITE(*,*) 'DO YOU WISH TO CHOOSE ANOTHER MATERIAL?'
WRITE(*,*) '1 = YES OR 2 = NO'
WRITE(*,*)
READ(*,*) RESPONSE
IF (RESPONSE .EQ. 2) GOTO 130
IF (RESPONSE .EQ. 1) GOTO 15
130 CONTINUE
C
C WRITE TOTAL RADIOLOGICAL DOSES TO OUTPUT FILE
WRITE(200,*)
WRITE(200,375)
WRITE(200,380) TDIRECT
WRITE(200,390) TINHALE
WRITE(200,400) TINGEST
C
C FORMAT STATEMENTS
C
150 FORMAT(
@' ENTER THE NAME (UP TO 8 CHARACTERS) OF THE OUTPUT FILE. DO')
160 FORMAT(
@' NOT PROVIDE AN EXTENSION. THE FILE WILL AUTOMATICALLY BE')
170 FORMAT(
@' GIVEN THE EXTENSION .OUT')
180 FORMAT(' ENTER A 0 IF YOU WISH TO ACCEPT THE DEFAULT OUTPUT')
190 FORMAT(' NAME OF TSRA.OUT')
200 FORMAT(A30,' [',1P,E10.4,' kg]')
210 FORMAT(' ')
220 FORMAT(' 1. DISTANCE FROM THE SOURCE = ',F6.2,' m')
230 FORMAT(' 2. EXPOSURE TIME FOR DIRECT RADIATION = ',F5.2,' hr')
240 FORMAT(' 3. MINIMUM DOWNWIND DISTANCE = ',F6.1,' m')
242 FORMAT(' 4. MAXIMUM DOWNWIND DISTANCE = ',F6.1,' m')
244 FORMAT(' 5. DOWNWIND DISTANCE INCREMENT = ',F6.1,' m')
250 FORMAT(' 6. ELEVATION = ',F6.1,' m')
260 FORMAT(' 7. AMBIENT TEMPERATURE = ',F6.2,' K')
270 FORMAT(' 8. INITIAL PLUME RADIUS = ',F5.2,' m')
280 FORMAT(' 9. WIND VELOCITY AT AN ELEVATION OF 2 m = ',F5.2,' m/s')
290 FORMAT(' 10. BREATHING RATE = ',F5.2,' m3/hr')
300 FORMAT(' 11. EXPOSURE TIME FOR INHALATION = BURN DURATION')
301 FORMAT(' 11. EXPOSURE TIME FOR INHALATION = ',F5.2,' hr')
310 FORMAT(' 12. VOLUME OF THE WATER TANK = ',F6.2,' m3')
320 FORMAT(' 13. INDIVIDUAL DAILY UPTAKE OF WATER = ',F6.4,' m3')
330 FORMAT(1X,12,'. 'A30)
340 FORMAT('Downwind',2X,'Stability',2X,'Concentration',1X,
@'Concentration',1X,'Inhalation',4X,'Uptake')
345 FORMAT('Distance',4X,'Class',18X,'*Exposure Time',3X,'Dose')
350 FORMAT(3X,'(m)',18X,'(mg/m3)',6X,'(mg-hr/m3)',5X,'(rem)',7X,
@'(mg)')
360 FORMAT(
@' ')
370 FORMAT(1X,F6.1,7X,A1,8X,1P,E10.4,4X,1P,E10.4,2X,1P,E10.4,2X,1P,
@E10.4)
375 FORMAT('TOTAL RADIOLOGICAL DOSES FOR SHIPMENT:')
380 FORMAT(5X,'TOTAL RADIOLOGICAL DOSE DUE TO DIRECT RADIATION = ',
@1P,E10.4,' rem')
390 FORMAT(5X,'TOTAL RADIOLOGICAL DOSE DUE TO INHALATION = ',
@1P,E10.4,' rem')
400 FORMAT(5X,'TOTAL RADIOLOGICAL DOSE DUE TO INGESTION = ',
@1P,E10.4,' rem')
405 FORMAT(5X,'WORST CASE VALUES:')
410 FORMAT('*****')

```

```

420  FORMAT(5X, I2, 2X, A30, 2X, I2)
430  FORMAT(5X, 1P, E10.4, 2X, 1P, E10.4, 2X, 1P, E10.4, 2X, 1P, E10.4)
440  FORMAT(5X, A6, 2X, 1P, E10.4)
450  FORMAT(5X, 1P, E10.4, 2X, 1P, E10.4, 2X, 1P, E10.4, 2X, 1P, E10.4, 2X, 1P,
    @E10.4)
460  FORMAT(5X, I1, 2X, 1P, E10.4)
470  FORMAT(5X, 1P, E10.4, 2X, 1P, E10.4, 2X, 1P, E10.4, 2X, 1P, E10.4, 2X, 1P,
    @E10.4, 2X, 1P, E10.4)
500  FORMAT('DIRECT RADIATION EXPOSURE:')
501  FORMAT(5X, 'DISTANCE FROM SOURCE = ', F6.2, ' m')
505  FORMAT(5X, 'EXPOSURE TIME = ', F5.2, ' hours')
506  FORMAT(5X, 'DOSE DUE TO DIRECT RADIATION = ', 1P, E10.4, ' rem')
507  FORMAT('*****')
C
    END

```

```

C*****
C*
C*          SUBROUTINE DRAD          *
C*          J. C. ANDERSON          *
C*
C* THIS SUBROUTINE PERFORMS THE DIRECT RADIATION CALCULATIONS. *
C*
C*****
C
C      SUBROUTINE DRAD(DIRECT)
C      IMPLICIT REAL*8(A-H,K-Z)
C
C      CHARACTER*6 ISOTOP
C      CHARACTER*30 MATL
C      INTEGER DRFLAG,INHFLAG,NISOTOPE
C      REAL*8 DDOSE(50,10),DIRECT(50),MASSI(50,10),R(18)
C
C COMMON BLOCKS
C
C      COMMON/CONSTANT/G,PI
C      COMMON/DEFAULT/DIST,EXPTIME,X,Z,TA,RO,U2,BREATHE,EPTIME
C      @,VTANK,VDRINK,INHFLAG
C      COMMON/DIRECT/DRFLAG(50,10),DRCONST(50,10),S(50,10,18)
C      COMMON/ISOTOPE/FRACTION(50,10),HLIFE(50,10),INGCEDE(50,10),
C      @INHCEDE(50,10),ISOTOP(50,10),MW(50,10),NISOTOPE(50),RHO(50,10)
C      COMMON/MATERIAL/IJ,MATL(50),MASS(50)
C
C
C ENTER RESPONSE TERM DATA
C      DATA R/8.771D-03, 7.478D-03, 6.374D-03, 5.413D-03, 4.622D-03,
C      @3.959D-03, 3.468D-03, 3.019D-03, 2.627D-03, 2.205D-03, 1.832D-03
C      @,1.522D-03, 1.172D-03, 8.759D-04, 6.306D-04, 3.833D-04, 2.669D-04
C      @,9.347D-04/
C
C
C CALCULATE THE DOSE RATE (mrem/hr)
C      D = 0
C      DO 110 I = 1,NISOTOPE(IJ)
C      MASSI(IJ,I) = MASS(IJ)*FRACTION(IJ,I)
C      IF (DRFLAG(IJ,I).EQ. 1) THEN
C      DRCONST(IJ,I) = 0.
C      DO 100 J = 1,18
C      DRCONST(IJ,I) = DRCONST(IJ,I) + S(IJ,I,J)*R(J)
C 100 CONTINUE
C      ENDIF
C
C CALCULATE THE DOSE RATE FOR THE CURRENT ISOTOPE (mrem/hr)
C      DDOSE(IJ,I) = 1./(4.*PI*(DIST*100.)**2.)*(MASSI(IJ,I)*
C      @ 1000.)/RHO(IJ,I)*DRCONST(IJ,I)
C
C CALCULATE THE TOTAL CUMMULATIVE DOSE RATE (mrem/hr)
C      D = D + 1./(4.*PI*(DIST*100.)**2.)*(MASSI(IJ,I)*1000.)/
C      @ RHO(IJ,I)*DRCONST(IJ,I)
C 110 CONTINUE
C
C CALCULATE THE DOSE RECEIVED DUE TO DIRECT EXPOSURE (rem)
C      DIRECT(IJ) = D*EXPTIME/1000.
C
C
C WRITE RESULTS TO OUTPUT FILE
C
C      WRITE(200,500)
C      WRITE(200,*)
C      WRITE(200,501) DIST
C      WRITE(200,502)
C      DO 111 I = 1,NISOTOPE(IJ)
C      WRITE(200,503) ISOTOP(IJ,I),DDOSE(IJ,I)/1000.
C 111 CONTINUE
C      WRITE(200,504) D/1000.
C      WRITE(200,505) EXPTIME
C      WRITE(200,506) DIRECT(IJ)
C      WRITE(200,*)
C      WRITE(200,507)
C      WRITE(200,*)

```



```

C
C FORMAT STATEMENTS
C
500  FORMAT('DIRECT RADIATION EXPOSURE:')
501  FORMAT(5X,'DISTANCE FROM SOURCE = ',F6.2,' m')
502  FORMAT(5X,'DOSE RATES:')
503  FORMAT(10X,'CONTRIBUTION DUE TO ',A6,' = ',1P,E10.4,' rem/hr')
504  FORMAT(10X,'TOTAL = ',1P,E10.4,' rem/hr')
505  FORMAT(5X,'EXPOSURE TIME = ',F5.2,' hours')
506  FORMAT(5X,'DOSE DUE TO DIRECT RADIATION = ',1P,E10.4,' rem')
507  FORMAT('*****')
C
      RETURN
      END

```

```

C*****
C*
C*          SUBROUTINE DISPERSE
C*          J. C. ANDERSON
C*
C* THIS SUBROUTINE PERFORMS THE ATMOSPHERIC DISPERSION
C* CALCULATIONS.
C*
C*****
C
C      SUBROUTINE DISPERSE(IFLAG,Q,CONC,CLASS)
C      IMPLICIT REAL*8(A-H,K-Z)
C
C      CHARACTER*30 MATL
C      INTEGER CLASS,INHFLAG
C      REAL*8 CONC(50,7),H(50,7),MAXRISE(50,7),P(7),PLMRISE(50,7)
C      REAL*8 Q(50),SIGMAY(7),SIGMAZ(7),SS(7),SY1(7),SZ1(7),SZ2(7)
C      REAL*8 SZ3(7),SZ4(7),U(50,7)
C
C COMMON BLOCKS
C
C      COMMON/CONSTANT/G,PI
C      COMMON/DEFAULT/DIST,EXPTIME,X,Z,TA,RO,U2,BREATHE,EPTIME
C      @,VTANK,VDRINK,INHFLAG
C      COMMON/MATERIAL/IJ,MATL(50),MASS(50)
C      COMMON/PLUME/BRATE(50),FLMTEMP(50),MWPLUME(50)
C
C ENTER DATA REQUIRED FOR ATMOSPHERIC DISPERSION CALCULATIONS
C      DATA P/0.07, 0.07, 0.10, 0.15, 0.35, 0.55, 0.55/
C      DATA SS/1.6D-04, 1.6D-04, 1.6D-04, 1.6D-04, 8.2D-04, 1.6D-03,
C      @1.6D-03/
C      DATA SY1/0.22, 0.16, 0.11, 0.08, 0.06, 0.04, 0.0268/
C      DATA SZ1/0.2, 0.12, 0.08, 0.06, 0.03, 0.016, 0.0096/
C      DATA SZ2/1., 1., 1., 1., 1., 1., 1./
C      DATA SZ3/0., 0., 0.0002, 0.0015, 0.0003, 0.0003, 0.0003/
C      DATA SZ4/0., 0., -0.5, -0.5, -1., -1., -1./
C
C ENTER THE CROSSWIND DISTANCE TO BE USED IN CONCENTRATION CALCULATIONS
C (m)
C      Y = 0.
C ENTER THE DENSITY OF THE AMBIENT AIR (kg/m3)
C      RHOA = 1.1614
C ENTER THE MOLECULAR WEIGHT OF THE AMBIENT AIR
C      MA = 28.964
C ENTER THE INITIAL MOLECULAR WEIGHT OF THE PLUME
C      MO = MWPLUME(IJ)
C ENTER THE FLAME TEMPERATURE (K)
C      TO = FLMTEMP(IJ)
C ENTER THE INITIAL VERTICAL PLUME VELOCITY (m/s)
C      WO = 1.
C ENTER THE BURN (RELEASE) RATE (%/s)
C      BRNRATE = BRATE(IJ)
C CALCULATE THE RELEASE RATE (kg/s)
C      Q(IJ) = BRNRATE/100.*MASS(IJ)
C CALCULATE THE EQUILIBRIUM PLUME RISE (m) FOR ALL STABILITY CLASSES
C      DO 100 ISC = 1,7
C CALCULATE THE MAXIMUM PLUME RISE (m)
C      MAXRISE(IJ,ISC) = 2.6**((3./(3. + P(ISC)))*(G*(P(ISC) +1.)*(1.
C      @ - (TA*MO)/(TO*MA))*WO*RO**2)/((U2*SS(ISC))/(2.**P(ISC))))**
C      @ (1./(3. + P(ISC)))
C CALCULATE THE PLUME RISE AT THE DOWNWIND DISTANCE OF INTEREST (m)
C      PLMRISE(IJ,ISC) = ((1.6*(P(ISC) +1.)*(G*(1. - (TA*MO)/(TO*MA))
C      @ *WO*RO**2)**(1./3.))/(U2/(2.**P(ISC))))**((1./(1. + P(ISC)))X
C      @ **((2./(3. + 3.*P(ISC))))
C ENTER THE PLUME HEIGHT
C      H(IJ,ISC) = PLMRISE(IJ,ISC)
C      IF (PLMRISE(IJ,ISC) .GE. MAXRISE(IJ,ISC))THEN
C      H(IJ,ISC) = MAXRISE(IJ,ISC)

```

```

ENDIF
C CALCULATE THE AVERAGE AMBIENT WIND VELOCITY (m/s)
  U(IJ,ISC) = U2*(H(IJ,ISC)/2.)*P(ISC)/(P(ISC) + 1.)
C CALCULATE THE CROSSWIND DISPERSION COEFFICIENT (m)
  SIGMAZ(ISC) = SY1(ISC)*X*(1. + 0.0001*X)**(-0.5)
C CALCULATE THE VERTICAL DISPERSION COEFFICIENT
  SIGMAZ(ISC) = SZ1(ISC)*X*(SZ2(ISC) + SZ3(ISC)*X)**(SZ4(ISC))
C CALCULATE THE CONCENTRATION USING THE STANDARD GAUSSIAN DISPERSION
C EQUATION (kg/m3)
  CONC(IJ,ISC) = Q(IJ)/(2.*PI*SIGMAZ(ISC)*SIGMAZ(ISC)*U(IJ,ISC))
  @ *DEXP(-Y**2./(2.*SIGMAZ(ISC)**2.))*DEXP(-(Z - H(IJ,ISC))**2./
  @ (2.*SIGMAZ(ISC)**2.)) + DEXP(-(Z + H(IJ,ISC))**2./(2.*SIGMAZ
  @ (ISC)**2.)))
100 CONTINUE
C DETERMINE THE WORST CASE CONCENTRATION AND THE ASSOCIATED STABILITY
C CLASS
  WORST = 0
  DO 110 ISC = 1,7
    IF (CONC(IJ,ISC) .GT. WORST) THEN
      WORST = CONC(IJ,ISC)
      CLASS = ISC
    ENDIF
110 CONTINUE
C
C WRITE RESULTS TO OUTPUT FILE
C
  IF (IFLAG .EQ. 1) THEN
    WRITE(200,600)
    WRITE(200,*)
    WRITE(200,602) TA
    WRITE(200,605) MA
    WRITE(200,608) RHOA
    WRITE(200,610) U2
    WRITE(200,*)
    WRITE(200,603) MO
    WRITE(200,604) TO
    WRITE(200,606) RO
    WRITE(200,607) Q(IJ)
    WRITE(200,609) WO
    WRITE(200,*)
    WRITE(200,613) Y
    WRITE(200,614) Z
    WRITE(200,615) EPTIME
    WRITE(200,616) BREATHE
    WRITE(200,*)
  ENDIF
C
C FORMAT STATEMENTS
C
600 FORMAT('ATMOSPHERIC DISPERSION CALCULATIONS:')
602 FORMAT(5X,'Ambient Properties:',6X,'AMBIENT TEMPERATURE = '
  @,F6.1,' K')
603 FORMAT(5X,'Plume Properties:',8X,'MOLECULAR WEIGHT OF PLUME = '
  @,F6.2)
604 FORMAT(30X,'FLAME TEMPERATURE = ',F6.1,' K')
605 FORMAT(30X,'MOLECULAR WEIGHT OF AMBIENT AIR = ',F6.2)
606 FORMAT(30X,'INITIAL PLUME RADIUS = ',F5.2,' m')
607 FORMAT(30X,'BURN RATE = ',1P,E10.4,' kg/s')
608 FORMAT(30X,'DENSITY OF AMBIENT AIR = ',1P,E10.4,' kg/m3')
609 FORMAT(30X,'INITIAL VERTICAL PLUME VELOCITY = ',F5.2,' m/s')
610 FORMAT(30X,'WIND VELOCITY AT 2 m = ',F5.2,' m/s')
612 FORMAT(30X,'BURN TIME = ',1P,E10.4,' s')
613 FORMAT(5X,'Receptor Information:',4X,'CROSSWIND DISTANCE = '
  @,1P,E10.4,' m')
614 FORMAT(30X,'ELEVATION OF RECEPTOR = ',1P,E10.4,' m')
615 FORMAT(30X,'EXPOSURE TIME = ',1P,E10.4,' hr')
616 FORMAT(30X,'BREATHING RATE = ',F5.2,' m3/hr')
C

```

RETURN
END

```

C*****
C*
C*          SUBROUTINE INHAL
C*          J. C. ANDERSON
C*
C*  THIS SUBROUTINE CALCULATES THE RADIOLOGICAL AND CHEMICAL
C*  CONSEQUENCES OF INHALATION.
C*
C*****
C
C  SUBROUTINE INHAL(IFLAG,Q,CONC,CLASS,ACT,INHALE,UPTAKE)
C  IMPLICIT REAL*8(A-H,K-Z)
C
C  CHARACTER*6 ISOTOP
C  CHARACTER*30 MATL
C  INTEGER CLASS,INHFLAG,NISOTOPE
C  REAL*8 ACT(50,10),BTIME(50),CONC(50,7),DOSE(50,10),INHALE(50)
C  REAL*8 Q(50),UPTAKE(50)
C
C  COMMON BLOCKS
C
C  COMMON/CONSTANT/G,PI
C  COMMON/DEFAULT/DIST,EXPTIME,X,Z,TA,RO,U2,BREATHE,EPTIME
C  @,VTANK,VDRINK,INHFLAG
C  COMMON/ISOTOPE/FRACTION(50,10),HLIFE(50,10),INGCEDE(50,10),
C  @INHCEDE(50,10),ISOTOP(50,10),MW(50,10),NISOTOPE(50),RHO(50,10)
C  COMMON/MATERIAL/IJ,MATL(50),MASS(50)
C
C  C CALCULATE THE TOTAL BURN TIME (s)
C  BTIME(IJ) = MASS(IJ)/Q(IJ)
C  C CALCULATE THE EXPOSURE TIME (hr)
C  EXPTIM2 = BTIME(IJ)/3600.
C  IF (INHFLAG .EQ. 1) THEN
C    IF (EPTIME .GT. EXPTIM2) EPTIME = EXPTIM2
C  ENDIF
C  IF (INHFLAG .NE. 1) EPTIME = EXPTIM2
C
C  C DETERMINE RADIOLOGICAL CONSEQUENCES OF INHALATION
C
C  IF (NISOTOPE(IJ) .EQ. 0) THEN
C    INHALE(IJ) = 0.
C    GOTO 105
C  ENDIF
C  TDOSE = 0
C  DO 100 I = 1,NISOTOPE(IJ)
C  C CALCULATE THE ACTIVITY OF THE MATERIAL (Ci/g)
C  ACT(IJ,I) = 3.578D5/(MW(IJ,I)*HLIFE(IJ,I))
C  C CALCULATE THE TOTAL RADIOLOGICAL DOSE (rem/g)
C  DOSE(IJ,I) = ACT(IJ,I)*INHCEDE(IJ,I)*FRACTION(IJ,I)
C  TDOSE = TDOSE + ACT(IJ,I)*INHCEDE(IJ,I)*FRACTION(IJ,I)
100  CONTINUE
C  C CALCULATE THE RADIATION DOSE RECEIVED FROM INHALATION (rem)
C  INHALE(IJ) = CONC(IJ,CLASS)*TDOSE*1.0D03*BREATHE*EPTIME
105  CONTINUE
C
C  C DETERMINE CHEMICAL CONSEQUENCES OF INHALATION
C
C  C CALCULATE THE UPTAKE DUE TO INHALATION (mg)
C  UPTAKE(IJ) = CONC(IJ,CLASS)*BREATHE*EPTIME*1.0D06
C
C  C WRITE RESULTS TO OUTPUT FILE
C
C  IF (IFLAG .EQ. 1) THEN
C    WRITE(200,700)
C    WRITE(200,*)
C    WRITE(200,703)
C    DO 110 I = 1,NISOTOPE(IJ)
C      WRITE(200,704) ISOTOP(IJ,I),DOSE(IJ,I)

```

```

110      CONTINUE
        WRITE(200,705) TDOSE
        WRITE(200,706) INHALE(IJ)
        WRITE(200,*)
        WRITE(200,707)
        WRITE(200,*)
        WRITE(200,708) UPTAKE(IJ)
        WRITE(200,*)
        WRITE(200,709)
        WRITE(200,*)
        ENDIF
C
C FORMAT STATEMENTS
C
700  FORMAT('MAXIMUM RADIOLOGICAL CONSEQUENCES OF INHALATION:')
703  FORMAT(5X,'RADIOLOGICAL DOSES:')
704  FORMAT(10X,'CONTRIBUTION DUE TO ',A6,' = ',1P,E10.4,' rem/g')
705  FORMAT(10X,'TOTAL = ',1P,E10.4,' rem/g')
706  FORMAT(5X,'DOSE DUE TO INHALATION = ',1P,E10.4,' rem')
707  FORMAT('MAXIMUM CHEMICAL CONSEQUENCES OF INHALATION:')
708  FORMAT(5X,'UPTAKE DUE TO INHALATION = ',1P,E10.4,' mg')
709  FORMAT('*****')
C
      RETURN
      END

```

```

C*****
C*
C*          SUBROUTINE WATER          *
C*          J. C. ANDERSON            *
C*
C* THIS SUBROUTINE CALCULATES THE AMOUNT OF CONTAMINANT WHICH *
C* REACHES THE PUBLIC DRINKING SUPPLY. *
C*
C*****
C
C      SUBROUTINE WATER(MCONT)
C      IMPLICIT REAL*8(A-H,K-Z)
C
C      CHARACTER*30 MATL
C      REAL*8 MCONT(50)
C      INTEGER INHFLAG
C
C COMMON BLOCKS
C
C      COMMON/CONSTANT/G,PI
C      COMMON/DEFAULT/DIST,EXPTIME,X,Z,TA,RO,U2,BREATHE,EPTIME
C      @,VTANK,VDRINK,INHFLAG
C      COMMON/MATERIAL/IJ,MATL(50),MASS(50)
C      COMMON/SPILL/FRACT(50)
C
C CALCULATE THE MASS OF CONTAMINANT WHICH ENTERS MUNICIPAL WATER
C SYSTEM (kg)
C      MCONT(IJ) = MASS(IJ)*FRACT(IJ)*VDRINK/VTANK
C
C WRITE RESULTS TO OUTPUT FILE
C
C      WRITE(200,800)
C      WRITE(200,*)
C      WRITE(200,801) FRACT(IJ)
C      WRITE(200,802) VTANK
C      WRITE(200,803) VDRINK
C      WRITE(200,804) MCONT(IJ)
C      WRITE(200,*)
C
C      FORMAT STATEMENTS
C
C      800 FORMAT('WATER TRANSPORT CALCULATIONS:')
C      801 FORMAT(5X,'FRACTION REACHING PUBLIC DRINKING SUPPLY = ',1P,E10.4)
C      802 FORMAT(5X,'TANK VOLUME = ',1P,E10.4,' m3')
C      803 FORMAT(5X,'DAILY WATER UPTAKE = ',1P,E10.4,' m3')
C      804 FORMAT(5X,'MASS AVAILABLE FOR UPTAKE = ',1P,E10.4,' kg')
C
C      RETURN
C      END

```

```

C*****
C*
C*          SUBROUTINE INGST
C*          J. C. ANDERSON
C*
C* THIS SUBROUTINE CALCULATES THE RADIOLOGICAL AND CHEMICAL
C* CONSEQUENCES OF INGESTION.
C*
C*****
C
C      SUBROUTINE INGST(ACT,MCONT,INGEST,INTAKE)
C      IMPLICIT REAL*8(A-H,K-Z)
C
C      CHARACTER*6 ISOTOP
C      CHARACTER*30 MATL
C      INTEGER INHFLAG,NISOTOPE
C      REAL*8 ACT(50,10),DOSE(50,10),INGEST(50),INTAKE(50),MCONT(50)
C
C COMMON BLOCKS
C      COMMON/CONSTANT/G,PI
C      COMMON/DEFAULT/DIST,EXPTIME,X,Z,TA,RO,U2,BREATHE,EPTIME
C      @,VTANK,VDRINK,INHFLAG
C      COMMON/ISOTOPE/FRACTION(50,10),HLIFE(50,10),INGCEDE(50,10),
C      @INHCEDE(50,10),ISOTOP(50,10),MW(50,10),NISOTOPE(50),RHO(50,10)
C      COMMON/MATERIAL/IJ,MATL(50),MASS(50)
C
C DETERMINE RADIOLOGICAL CONSEQUENCES OF INGESTION
C
C      IF (NISOTOPE(IJ) .EQ. 0) THEN
C      INGEST(IJ) = 0.
C      GOTO 105
C      ENDIF
C      TDOSE = 0
C      DO 100 I = 1,NISOTOPE(IJ)
C      C CALCULATE THE TOTAL RADIOLOGICAL DOSE FROM INGESTION (rem/g)
C      DOSE(IJ,I) = ACT(IJ,I)*INGCEDE(IJ,I)*FRACTION(IJ,I)
C      TDOSE = TDOSE + ACT(IJ,I)*INGCEDE(IJ,I)*FRACTION(IJ,I)
100  CONTINUE
C      C CALCULATE THE RADIOLOGICAL DOSE FROM INGESTION (rem)
C      INGEST(IJ) = TDOSE*MCONT(IJ)*1.0D03
105  CONTINUE
C
C DETERMINE CHEMICAL CONSEQUENCES OF INGESTION
C
C      C CALCULATE THE INTAKE DUE TO INGESTION (mg)
C      INTAKE(IJ) = MCONT(IJ)*1.0D6
C
C      C WRITE RESULTS TO OUTPUT FILE
C
C      WRITE(200,900)
C      WRITE(200,*)
C      WRITE(200,901)
C      DO 110 I = 1,NISOTOPE(IJ)
C      WRITE(200,902) ISOTOP(IJ,I),DOSE(IJ,I)
110  CONTINUE
C      WRITE(200,903) TDOSE
C      WRITE(200,904) INGEST(IJ)
C      WRITE(200,*)
C      WRITE(200,905)
C      WRITE(200,*)
C      WRITE(200,906) INTAKE(IJ)
C      WRITE(200,*)
C
C      C FORMAT STATEMENTS
C
900  FORMAT('RADIOLOGICAL CONSEQUENCES OF INGESTION:')
901  FORMAT(5X,'RADIOLOGICAL DOSES:')
902  FORMAT(10X,'CONTRIBUTION DUE TO ',A6,' = ',1P,E10.4,' rem/g')

```



```
903  FORMAT(10X,'TOTAL = ',1P,E10.4,' rem/g')
904  FORMAT(5X,'DOSE DUE TO INGESTION = ',1P,E10.4,' rem')
905  FORMAT('CHEMICAL CONSEQUENCES OF INGESTION:')
906  FORMAT(5X,'INTAKE DUE TO INGESTION = ',1P,E10.4,' mg')
C
  RETURN
  END
```

```

C*****
C*
C*          DATABASE
C*          J. C. ANDERSON
C*
C*  THIS SUBPROGRAM CONSISTS OF THE DATABASE CONTAINING MATERIAL
C*  PROPERTIES NEEDED FOR THE BOUNDING RELEASE CALCULATIONS.
C*
C*****
C
C  BLOCK DATA
C  IMPLICIT REAL*8(A-H,K-Z)
C  INTEGER DRFLAG,NISOTOPE
C  CHARACTER*6 ISOTOP
C  CHARACTER*30 MATL
C
C  COMMON/DIRECT/DRFLAG(50,10),DRCONST(50,10),S(50,10,18)
C  COMMON/ISOTOPE/FRACTION(50,10),HLIFE(50,10),INGCEDE(50,10),
C  @INHCEDE(50,10),ISOTOP(50,10),MW(50,10),NISOTOPE(50),RHO(50,10)
C  COMMON/MATERIAL/IJ,MATL(50),MASS(50)
C  COMMON/PLUME/BRATE(50),FLMTEMP(50),MWPLUME(50)
C  COMMON/SPILL/FRACT(50)
C
C  DATA MATL(1)/'Beryllium'/
C  DATA NISOTOPE(1)/0/
C  DATA MWPLUME(1)/28.964/
C  DATA BRATE(1)/8.90-03/
C  DATA FLMTEMP(1)/1200./
C  DATA FRACT(1)/0.01/
C
C  DATA MATL(2)/'Beryllium Oxide'/
C  DATA NISOTOPE(2)/0/
C  DATA MWPLUME(2)/28.964/
C  DATA BRATE(2)/8.90-03/
C  DATA FLMTEMP(2)/1200./
C  DATA FRACT(2)/0.01/
C
C  DATA MATL(3)/'Boron'/
C  DATA NISOTOPE(3)/0/
C  DATA MWPLUME(3)/28.964/
C  DATA BRATE(3)/8.90-03/
C  DATA FLMTEMP(3)/1200./
C  DATA FRACT(3)/0.01/
C
C  DATA MATL(4)/'Lithium Deuteride'/
C  DATA NISOTOPE(4)/0/
C  DATA MWPLUME(4)/28.964/
C  DATA BRATE(4)/6.8460-01/
C  DATA FLMTEMP(4)/1200./
C  DATA FRACT(4)/1.0/
C
C  DATA MATL(5)/'Lithium Hydride'/
C  DATA NISOTOPE(5)/0/
C  DATA MWPLUME(5)/28.964/
C  DATA BRATE(5)/6.8460-01/
C  DATA FLMTEMP(5)/1200./
C  DATA FRACT(5)/1.0/
C
C  DATA MATL(6)/'Magnesium'/
C  DATA NISOTOPE(6)/0/
C  DATA MWPLUME(6)/28.964/
C  DATA BRATE(6)/8.90-03/
C  DATA FLMTEMP(6)/1200./
C  DATA FRACT(6)/0.01/
C
C  DATA MATL(7)/'Polyethylene'/
C  DATA NISOTOPE(7)/0/
C  DATA MWPLUME(7)/28.964/

```

DATA BRATE(7)/8.90-03/
 DATA FLMTEMP(7)/1200./
 DATA FRACT(7)/0.01/

C

DATA MATL(8)/'Polyethylpentene'/
 DATA NISOTOPE(8)/0/
 DATA MWPLUME(8)/28.964/
 DATA BRATE(8)/8.90-03/
 DATA FLMTEMP(8)/1200./
 DATA FRACT(8)/0.01/

C

DATA MATL(9)/'Silicone'/
 DATA NISOTOPE(9)/0/
 DATA MWPLUME(9)/28.964/
 DATA BRATE(9)/8.90-03/
 DATA FLMTEMP(9)/1200./
 DATA FRACT(9)/0.01/

C

DATA MATL(10)/'Tantalum'/
 DATA NISOTOPE(10)/0/
 DATA MWPLUME(10)/28.964/
 DATA BRATE(10)/8.90-03/
 DATA FLMTEMP(10)/1200./
 DATA FRACT(10)/0.01/

C

DATA MATL(11)/'Thorium'/
 DATA NISOTOPE(11)/1/
 DATA MWPLUME(11)/28.964/
 DATA BRATE(11)/8.90-03/
 DATA FLMTEMP(11)/1200./
 DATA FRACT(11)/0.01/
 DATA ISOTOP(11,1)/'Th-232'/
 DATA FRACTION(11,1)/1.0/
 DATA MW(11,1)/232.038054/
 DATA HLIFE(11,1)/1.4010/
 DATA RHO(11,1)/11.7/
 DATA INHCEDE(11,1)/1.6009/
 DATA INGCEDE(11,1)/2.8006/
 DATA DRFLAG(11,1)/2/
 DATA DRCONST(11,1)/262.8/

C

DATA MATL(12)/'Tungsten'/
 DATA NISOTOPE(12)/0/
 DATA MWPLUME(12)/28.964/
 DATA BRATE(12)/8.90-03/
 DATA FLMTEMP(12)/1200./
 DATA FRACT(12)/0.01/

C

DATA MATL(13)/'Highly Enriched Uranium'/
 DATA NISOTOPE(13)/5/
 DATA MWPLUME(13)/28.964/
 DATA BRATE(13)/8.90-03/
 DATA FLMTEMP(13)/1200./
 DATA FRACT(13)/0.01/
 DATA (ISOTOP(13,J),J=1,5)/'U-232','U-234','U-235','U-236',
 @'U-238'/
 DATA (FRACTION(13,J),J=1,5)/4.00-08,0.012,0.94,0.0048,0.04319996/
 DATA (MW(13,J),J=1,5)/232.03713,234.040946,235.043924,236.045562,
 @238.050784/
 DATA (HLIFE(13,J),J=1,5)/68.9,2.45005,7.04008,2.34007,4.46009/
 DATA (RHO(13,J),J=1,5)/18.57,18.72,18.81,18.89,19.05/
 DATA (INHCEDE(13,J),J=1,5)/6.7008,1.3008,1.2008,1.2008,1.2008/
 DATA (INGCEDE(13,J),J=1,5)/1.3006,2.6005,2.5005,2.5005,2.3005/
 DATA (DRFLAG(13,J),J=1,5)/5*1/
 DATA (DRCONST(13,J),J=1,5)/5*0/
 DATA (SC(13,1,J),J=1,18)/1.744001,1.306002,1.027003,3.562003,
 @1.408004,4.563012,4.517006,4.378010,4.770011,1.502011,7.149011,
 @2.080012,6.026012,3.518011,7.191012,7.405011,6.771012,5.533012/

```

DATA (S(13,2,J),J=1,18)/1.008D-03,7.359D-03,5.696D-02,
a1.961D-01,2.786D01,1.190D02,7.181D03,1.880D04,1.126D04,
a2.218D04,5.088D03,4.300D04,5.580D03,3.415D04,2.899D04,
a1.401D06,3.652D06,1.950D08/
DATA (S(13,3,J),J=1,18)/6.573D-06,3.188D-05,1.693D-04,
a4.409D-04,1.373D-03,1.594D-03,2.846D-03,4.881D-03,3.447D-05
a,2.862D00,6.911D01,3.932D01,3.289D02,3.037D03,7.224D04,
a1.318D06,3.044D05,5.301D05/
DATA (S(13,4,J),J=1,18)/9.642D-05,4.815D-04,2.658D-03,7.190D-03,
a2.329D-02,5.754D-02,5.100D-02,9.078D-02,1.348D-02,2.065D-01,
a6.182D-02,4.755D-01,4.843D-02,1.773D-02,7.087D-01,6.457D03,
a5.182D-02,6.614D-02/
DATA (S(13,5,J),J=1,18)/1.929D-04,9.087D-04,4.632D-03,
a1.154D-02,3.420D-02,3.806D-02,4.075D-01,1.600D02,1.616D02,
a9.743D02,1.772D03,2.360D03,3.240D03,4.756D03,6.656D03,
a2.009D04,5.291D04,9.742D04/

```

C

```

DATA MATL(14)/'Natural Uranium'/
DATA NISOTOPE(14)/3/
DATA MWPLUME(14)/28.964/
DATA BRATE(14)/8.9D-03/
DATA FLMTMP(14)/1200./
DATA FRACT(14)/0.01/
DATA (ISOTOP(14,J),J=1,3)/'U-234','U-235','U-238'/
DATA (FRACTION(14,J),J=1,3)/0.000056,0.007050,0.992894/
DATA (MW(14,J),J=1,3)/234.040946,235.043924,238.050784/
DATA (HLIFE(14,J),J=1,3)/2.45D05,7.04D08,4.46D09/
DATA (RHO(14,J),J=1,3)/18.72,18.81,19.05/
DATA (INHCEDE(14,J),J=1,3)/1.3D08,1.2D08,1.2D08/
DATA (INGCEDE(14,J),J=1,3)/2.6D05,2.5D05,2.3D05/
DATA (DRFLAG(14,J),J=1,3)/3*1/
DATA (DRCONST(14,J),J=1,3)/3*0/
DATA (S(14,1,J),J=1,18)/1.008D-03,7.359D-03,5.696D-02,
a1.961D-01,2.786D01,1.190D02,7.181D03,1.880D04,1.126D04,
a2.218D04,5.088D03,4.300D04,5.580D03,3.415D04,2.899D04,
a1.401D06,3.652D06,1.950D08/
DATA (S(14,2,J),J=1,18)/6.573D-06,3.188D-05,1.693D-04,
a4.409D-04,1.373D-03,1.594D-03,2.846D-03,4.881D-03,3.447D-05
a,2.862D00,6.911D01,3.932D01,3.289D02,3.037D03,7.224D04,
a1.318D06,3.044D05,5.301D05/
DATA (S(14,3,J),J=1,18)/1.929D-04,9.087D-04,4.632D-03,
a1.154D-02,3.420D-02,3.806D-02,4.075D-01,1.600D02,1.616D02,
a9.743D02,1.772D03,2.360D03,3.240D03,4.756D03,6.656D03,
a2.009D04,5.291D04,9.742D04/

```

C

```

DATA MATL(15)/'Depleted Uranium'/
DATA NISOTOPE(15)/2/
DATA MWPLUME(15)/28.964/
DATA BRATE(15)/8.9D-03/
DATA FLMTMP(15)/1200./
DATA FRACT(15)/0.01/
DATA (ISOTOP(15,J),J=1,2)/'U-235','U-238'/
DATA (FRACTION(15,J),J=1,2)/0.00195,0.99805/
DATA (MW(15,J),J=1,2)/235.043924,238.050784/
DATA (HLIFE(15,J),J=1,2)/7.04D08,4.46D09/
DATA (RHO(15,J),J=1,2)/18.81,19.05/
DATA (INHCEDE(15,J),J=1,2)/1.2D08,1.2D08/
DATA (INGCEDE(15,J),J=1,2)/2.5D05,2.3D05/
DATA (DRFLAG(15,J),J=1,2)/2*1/
DATA (DRCONST(15,J),J=1,2)/2*0/
DATA (S(15,1,J),J=1,18)/6.573D-06,3.188D-05,1.693D-04,
a4.409D-04,1.373D-03,1.594D-03,2.846D-03,4.881D-03,3.447D-05
a,2.862D00,6.911D01,3.932D01,3.289D02,3.037D03,7.224D04,
a1.318D06,3.044D05,5.301D05/
DATA (S(15,2,J),J=1,18)/1.929D-04,9.087D-04,4.632D-03,
a1.154D-02,3.420D-02,3.806D-02,4.075D-01,1.600D02,1.616D02,
a9.743D02,1.772D03,2.360D03,3.240D03,4.756D03,6.656D03,
a2.009D04,5.291D04,9.742D04/

```

C

```

DATA MATL(16)/'Uranium-Niobium Alloy'/
DATA NISOTOPE(16)/2/
DATA MWPLUME(16)/28.964/
DATA BRATE(16)/8.9D-03/
DATA FLMTMP(16)/1200./
DATA FRACT(16)/0.01/
DATA (ISOTOP(16,J),J=1,2)/'U-235','U-238'/
DATA (FRACTION(16,J),J=1,2)/0.0018486,0.9461514/
DATA (MW(16,J),J=1,2)/235.043924,238.050784/
DATA (HLIFE(16,J),J=1,2)/7.04D08,4.46D09/
DATA (RHO(16,J),J=1,2)/18.81,19.05/
DATA (INHCEDE(16,J),J=1,2)/1.2D08,1.2D08/
DATA (INGCEDE(16,J),J=1,2)/2.5D05,2.3D05/
DATA (DRFLAG(16,J),J=1,2)/2*1/
DATA (DRCONST(16,J),J=1,2)/2*0/
DATA (S(16,1,J),J=1,18)/6.573D-06,3.188D-05,1.693D-04,
a4.409D-04,1.373D-03,1.594D-03,2.846D-03,4.881D-03,3.447D-05
a,2.862D00,6.911D01,3.932D01,3.289D02,3.037D03,7.224D04,
a1.318D06,3.044D05,5.301D05/
DATA (S(16,2,J),J=1,18)/1.929D-04,9.087D-04,4.632D-03,
a1.154D-02,3.420D-02,3.806D-02,4.075D-01,1.600D02,1.616D02,
a9.743D02,1.772D03,2.360D03,3.240D03,4.756D03,6.656D03,
a2.009D04,5.291D04,9.742D04/

```

C

```

DATA MATL(17)/'Uranium-Niobium-Zirconium Alloy'/
DATA NISOTOPE(17)/2/
DATA MWPLUME(17)/28.964/
DATA BRATE(17)/8.9D-03/
DATA FLMTMP(17)/1200./
DATA FRACT(17)/0.01/
DATA (ISOTOP(17,J),J=1,2)/'U-235','U-238'/
DATA (FRACTION(17,J),J=1,2)/1.755D-03,8.98245D-01/
DATA (MW(17,J),J=1,2)/235.043924,238.050784/
DATA (HLIFE(17,J),J=1,2)/7.04D08,4.46D09/
DATA (RHO(17,J),J=1,2)/18.81,19.05/
DATA (INHCEDE(17,J),J=1,2)/1.2D08,1.2D08/
DATA (INGCEDE(17,J),J=1,2)/2.5D05,2.3D05/
DATA (DRFLAG(17,J),J=1,2)/2*1/
DATA (DRCONST(17,J),J=1,2)/2*0/
DATA (S(17,1,J),J=1,18)/6.573D-06,3.188D-05,1.693D-04,
a4.409D-04,1.373D-03,1.594D-03,2.846D-03,4.881D-03,3.447D-05
a,2.862D00,6.911D01,3.932D01,3.289D02,3.037D03,7.224D04,
a1.318D06,3.044D05,5.301D05/
DATA (S(17,2,J),J=1,18)/1.929D-04,9.087D-04,4.632D-03,
a1.154D-02,3.420D-02,3.806D-02,4.075D-01,1.600D02,1.616D02,
a9.743D02,1.772D03,2.360D03,3.240D03,4.756D03,6.656D03,
a2.009D04,5.291D04,9.742D04/

```

C

```

DATA MATL(18)/'Urethane'/
DATA NISOTOPE(18)/0/
DATA MWPLUME(18)/28.964/
DATA BRATE(18)/8.9D-03/
DATA FLMTMP(18)/1200./
DATA FRACT(18)/0.01/

```

C

END

APPENDIX B
Sample Input and Output

Screen Dump for Run without User-Supplied Materials

C:\TSRA\TSRA

32-bit Power for Lahey Computer Systems
Phar Lap's 386|DOS-Extender(tm) Version 5.1
Copyright (C) 1986-93 Phar Lap Software, Inc.
Available Memory = 14580 Kb

ENTER THE NAME (UP TO 8 CHARACTERS) OF THE OUTPUT FILE. DO NOT PROVIDE AN EXTENSION. THE FILE WILL AUTOMATICALLY BE GIVEN THE EXTENSION .OUT

ENTER A 0 IF YOU WISH TO ACCEPT THE DEFAULT OUTPUT REPORT

DEFAULT VALUES ASSUMED BY PROGRAM:

1. DISTANCE FROM THE SOURCE = 152.40 m
2. EXPOSURE TIME FOR DIRECT RADIATION = 3.00 hr
3. MINIMUM DOWNWIND DISTANCE = 100.0 m
4. MAXIMUM DOWNWIND DISTANCE = 2000.0 m
5. DOWNWIND DISTANCE INCREMENT = 100.0 m
6. ELEVATION = 0.0 m
7. AMBIENT TEMPERATURE = 298.00 K
8. INITIAL PLUME RADIUS = 0.50 m
9. WIND VELOCITY AT AN ELEVATION OF 2 m = 1.00 m/s
10. BREATHING RATE = 1.20 m³/hr
11. EXPOSURE TIME FOR INHALATION = BURN DURATION
12. VOLUME OF THE WATER TANK = 473.17 m³
13. INDIVIDUAL DAILY UPTAKE OF WATER = 0.0020 m³

DO YOU WISH TO CHANGE ANY OF THESE VALUES?

1 = YES OR 2 = NO

2

DO YOU WISH TO ANALYZE MATERIALS OTHER THAN THOSE CURRENTLY IN THE DATABASE?

1 = YES, 2 = NO

2

1. Beryllium
2. Beryllium Oxide
3. Boron
4. Lithium Deuteride
5. Lithium Hydride

6. Magnesium
7. Polyethylene
8. Polyethylpentene
9. Silicone
10. Tantalum
11. Thorium
12. Tungsten
13. Highly Enriched Uranium
14. Natural Uranium
15. Depleted Uranium
16. Uranium-Niobium Alloy
17. Uranium-Niobium-Zirconium Allo
18. Urethane

ENTER THE NUMBER OF THE MATERIAL OF INTEREST

13

ENTER MASS OF Highly Enriched Uranium IN kg

10

DO YOU WISH TO CHOOSE ANOTHER MATERIAL?

1 = YES OR 2 = NO

1

1. Beryllium
2. Beryllium Oxide
3. Boron
4. Lithium Deuteride
5. Lithium Hydride
6. Magnesium
7. Polyethylene
8. Polyethylpentene
9. Silicone
10. Tantalum
11. Thorium
12. Tungsten
13. Highly Enriched Uranium
14. Natural Uranium
15. Depleted Uranium
16. Uranium-Niobium Alloy
17. Uranium-Niobium-Zirconium Allo
18. Urethane

ENTER THE NUMBER OF THE MATERIAL OF INTEREST

14

ENTER MASS OF Natural Uranium IN kg

10

DO YOU WISH TO CHOOSE ANOTHER MATERIAL?

1 = YES OR 2 = NO

1

1. Beryllium
2. Beryllium Oxide
3. Boron
4. Lithium Deuteride
5. Lithium Hydride
6. Magnesium
7. Polyethylene
8. Polyethylpentene
9. Silicone
10. Tantalum
11. Thorium
12. Tungsten
13. Highly Enriched Uranium
14. Natural Uranium
15. Depleted Uranium
16. Uranium-Niobium Alloy
17. Uranium-Niobium-Zirconium Alloy
18. Urethane

ENTER THE NUMBER OF THE MATERIAL OF INTEREST

15

ENTER MASS OF Depleted Uranium IN kg

10

DO YOU WISH TO CHOOSE ANOTHER MATERIAL?

1 = YES OR 2 = NO

2

C:\TSRA>

Output File for Run without User-Supplied Materials

Highly Enriched Uranium [1.0000E+01 kg]

DIRECT RADIATION EXPOSURE:

DISTANCE FROM SOURCE = 152.40 m

DOSE RATES:

CONTRIBUTION DUE TO U-232 = 3.2048E-07 rem/hr

CONTRIBUTION DUE TO U-234 = 4.0427E-07 rem/hr

CONTRIBUTION DUE TO U-235 = 1.9360E-07 rem/hr

CONTRIBUTION DUE TO U-236 = 2.1572E-12 rem/hr

CONTRIBUTION DUE TO U-238 = 1.0484E-09 rem/hr

TOTAL = 9.1941E-07 rem/hr

EXPOSURE TIME = 3.00 hours

DOSE DUE TO DIRECT RADIATION = 2.7582E-06 rem

ATMOSPHERIC DISPERSION CALCULATIONS:

AMBIENT PROPERTIES:

AMBIENT TEMPERATURE = 298.0 K

MOLECULAR WEIGHT OF AMBIENT AIR = 28.96

DENSITY OF AMBIENT AIR = 1.1614E+00 kg/m³

WIND VELOCITY AT 2 m = 1.00 m/s

PLUME PROPERTIES:

MOLECULAR WEIGHT OF PLUME = 28.96

FLAME TEMPERATURE = 1200.0 K

INITIAL PLUME RADIUS = 0.50 m

BURN RATE = 8.9000E-04 kg/s

INITIAL VERTICAL PLUME VELOCITY = 1.00 m/s

EQUILIBRIUM PLUME RISE = 3.6867E+01 m

RECEPTOR INFORMATION:

CROSSWIND DISTANCE = 0.0000E+00 m

ELEVATION OF RECEPTOR = 0.0000E+00 m

EXPOSURE TIME = 0.0000E+00 hr

BREATHING RATE = 1.20 m³/hr

Downwind Distance (m)	Stability Class	Concentration (mg/m ³)	Concentration *Exposure Time (mg-hr/m ³)	Inhalation Dose (rem)	Uptake (mg)
100.0	A	1.0325E-01	3.2224E-01	4.1055E+00	3.8669E-01
200.0	A	5.2527E-02	1.6394E-01	2.0887E+00	1.9673E-01
300.0	B	4.2874E-02	1.3382E-01	1.7049E+00	1.6058E-01
400.0	B	4.0805E-02	1.2736E-01	1.6226E+00	1.5283E-01
500.0	E	4.1906E-02	1.3079E-01	1.6664E+00	1.5695E-01
600.0	E	5.4997E-02	1.7165E-01	2.1869E+00	2.0598E-01
700.0	E	6.0561E-02	1.8902E-01	2.4082E+00	2.2682E-01
800.0	E	6.1264E-02	1.9121E-01	2.4361E+00	2.2945E-01
900.0	F	6.0137E-02	1.8769E-01	2.3913E+00	2.2523E-01
1000.0	F	6.4247E-02	2.0052E-01	2.5547E+00	2.4062E-01
1100.0	F	6.5887E-02	2.0564E-01	2.6199E+00	2.4677E-01
1200.0	F	6.5847E-02	2.0552E-01	2.6184E+00	2.4662E-01
1300.0	F	6.4727E-02	2.0202E-01	2.5738E+00	2.4242E-01
1400.0	F	6.2949E-02	1.9647E-01	2.5031E+00	2.3576E-01
1500.0	F	6.0798E-02	1.8976E-01	2.4176E+00	2.2771E-01
1600.0	F	5.8464E-02	1.8247E-01	2.3248E+00	2.1897E-01
1700.0	F	5.6071E-02	1.7500E-01	2.2296E+00	2.1000E-01
1800.0	F	5.3695E-02	1.6759E-01	2.1351E+00	2.0110E-01
1900.0	F	5.1384E-02	1.6037E-01	2.0433E+00	1.9245E-01
2000.0	F	4.9167E-02	1.5345E-01	1.9551E+00	1.8414E-01

WORST CASE VALUES:

100.0 A 1.0325E-01 3.2224E-01 4.1055E+00 3.8669E-01

MAXIMUM RADIOLOGICAL CONSEQUENCES OF INHALATION:

RADIOLOGICAL DOSES:

CONTRIBUTION DUE TO U-232 = 5.9979E+02 rem/g
CONTRIBUTION DUE TO U-234 = 9.7344E+03 rem/g
CONTRIBUTION DUE TO U-235 = 2.4391E+02 rem/g
CONTRIBUTION DUE TO U-236 = 3.7312E+01 rem/g
CONTRIBUTION DUE TO U-238 = 1.7470E+00 rem/g
TOTAL = 1.0617E+04 rem/g

DOSE DUE TO INHALATION = 4.1055E+00 rem

MAXIMUM CHEMICAL CONSEQUENCES OF INHALATION:

UPTAKE DUE TO INHALATION = 3.8669E-01 mg

WATER TRANSPORT CALCULATIONS:

FRACTION REACHING PUBLIC DRINKING SUPPLY = 1.0000E-02
TANK VOLUME = 4.7317E+02 m³
DAILY WATER UPTAKE = 2.0000E-03 m³
MASS AVAILABLE FOR UPTAKE = 4.2268E-07 kg

RADIOLOGICAL CONSEQUENCES OF INGESTION:

RADIOLOGICAL DOSES:

CONTRIBUTION DUE TO U-232 = 1.1638E+00 rem/g
CONTRIBUTION DUE TO U-234 = 1.9469E+01 rem/g
CONTRIBUTION DUE TO U-235 = 5.0814E-01 rem/g
CONTRIBUTION DUE TO U-236 = 7.7734E-02 rem/g
CONTRIBUTION DUE TO U-238 = 3.3485E-03 rem/g
TOTAL = 2.1222E+01 rem/g

DOSE DUE TO INGESTION = 8.9699E-03 rem

CHEMICAL CONSEQUENCES OF INGESTION:

INTAKE DUE TO INGESTION = 4.2268E-01 mg

Natural Uranium

[1.0000E+01 kg]

DIRECT RADIATION EXPOSURE:

DISTANCE FROM SOURCE = 152.40 m

DOSE RATES:

CONTRIBUTION DUE TO U-234 = 1.8866E-09 rem/hr

CONTRIBUTION DUE TO U-235 = 1.4520E-09 rem/hr

CONTRIBUTION DUE TO U-238 = 2.4097E-08 rem/hr

TOTAL = 2.7435E-08 rem/hr

EXPOSURE TIME = 3.00 hours

DOSE DUE TO DIRECT RADIATION = 8.2306E-08 rem

ATMOSPHERIC DISPERSION CALCULATIONS:

AMBIENT PROPERTIES:

AMBIENT TEMPERATURE = 298.0 K

MOLECULAR WEIGHT OF AMBIENT AIR = 28.96

DENSITY OF AMBIENT AIR = 1.1614E+00 kg/m³

WIND VELOCITY AT 2 m = 1.00 m/s

PLUME PROPERTIES:

MOLECULAR WEIGHT OF PLUME = 28.96

FLAME TEMPERATURE = 1200.0 K

INITIAL PLUME RADIUS = 0.50 m

BURN RATE = 8.9000E-04 kg/s

INITIAL VERTICAL PLUME VELOCITY = 1.00 m/s

EQUILIBRIUM PLUME RISE = 3.6867E+01 m

RECEPTOR INFORMATION:

CROSSWIND DISTANCE = 0.0000E+00 m

ELEVATION OF RECEPTOR = 0.0000E+00 m

EXPOSURE TIME = 3.1211E+00 hr

BREATHING RATE = 1.20 m³/hr

Downwind Distance (m)	Stability Class	Concentration (mg/m ³)	Concentration *Exposure Time (mg-hr/m ³)	Inhalation Dose (rem)	Uptake (mg)
100.0	A	1.0325E-01	3.2224E-01	3.3800E-02	3.8669E-01
200.0	A	5.2527E-02	1.6394E-01	1.7196E-02	1.9673E-01
300.0	B	4.2874E-02	1.3382E-01	1.4036E-02	1.6058E-01
400.0	B	4.0805E-02	1.2736E-01	1.3358E-02	1.5283E-01
500.0	E	4.1906E-02	1.3079E-01	1.3719E-02	1.5695E-01
600.0	E	5.4997E-02	1.7165E-01	1.8005E-02	2.0598E-01
700.0	E	6.0561E-02	1.8902E-01	1.9826E-02	2.2682E-01
800.0	E	6.1264E-02	1.9121E-01	2.0056E-02	2.2945E-01
900.0	F	6.0137E-02	1.8769E-01	1.9687E-02	2.2523E-01
1000.0	F	6.4247E-02	2.0052E-01	2.1033E-02	2.4062E-01
1100.0	F	6.5887E-02	2.0564E-01	2.1570E-02	2.4677E-01
1200.0	F	6.5847E-02	2.0552E-01	2.1557E-02	2.4662E-01
1300.0	F	6.4727E-02	2.0202E-01	2.1190E-02	2.4242E-01
1400.0	F	6.2949E-02	1.9647E-01	2.0608E-02	2.3576E-01
1500.0	F	6.0798E-02	1.8976E-01	1.9904E-02	2.2771E-01
1600.0	F	5.8464E-02	1.8247E-01	1.9140E-02	2.1897E-01
1700.0	F	5.6071E-02	1.7500E-01	1.8356E-02	2.1000E-01
1800.0	F	5.3695E-02	1.6759E-01	1.7578E-02	2.0110E-01
1900.0	F	5.1384E-02	1.6037E-01	1.6822E-02	1.9245E-01
2000.0	F	4.9167E-02	1.5345E-01	1.6096E-02	1.8414E-01

WORST CASE VALUES:

100.0 A 1.0325E-01 3.2224E-01 3.3800E-02 3.8669E-01

MAXIMUM RADIOLOGICAL CONSEQUENCES OF INHALATION:

RADIOLOGICAL DOSES:

CONTRIBUTION DUE TO U-234 = 4.5427E+01 rem/g
CONTRIBUTION DUE TO U-235 = 1.8293E+00 rem/g
CONTRIBUTION DUE TO U-238 = 4.0153E+01 rem/g
TOTAL = 8.7409E+01 rem/g

DOSE DUE TO INHALATION = 3.3800E-02 rem

MAXIMUM CHEMICAL CONSEQUENCES OF INHALATION:

UPTAKE DUE TO INHALATION = 3.8669E-01 mg

WATER TRANSPORT CALCULATIONS:

FRACTION REACHING PUBLIC DRINKING SUPPLY = 1.0000E-02
TANK VOLUME = 4.7317E+02 m³
DAILY WATER UPTAKE = 2.0000E-03 m³
MASS AVAILABLE FOR UPTAKE = 4.2268E-07 kg

RADIOLOGICAL CONSEQUENCES OF INGESTION:

RADIOLOGICAL DOSES:

CONTRIBUTION DUE TO U-234 = 9.0854E-02 rem/g
CONTRIBUTION DUE TO U-235 = 3.8111E-03 rem/g
CONTRIBUTION DUE TO U-238 = 7.6960E-02 rem/g
TOTAL = 1.7163E-01 rem/g
DOSE DUE TO INGESTION = 7.2542E-05 rem

CHEMICAL CONSEQUENCES OF INGESTION:

INTAKE DUE TO INGESTION = 4.2268E-01 mg

Depleted Uranium

[1.0000E+01 kg]

DIRECT RADIATION EXPOSURE:

DISTANCE FROM SOURCE = 152.40 m

DOSE RATES:

CONTRIBUTION DUE TO U-235 = 4.0162E-10 rem/hr

CONTRIBUTION DUE TO U-238 = 2.4222E-08 rem/hr

TOTAL = 2.4624E-08 rem/hr

EXPOSURE TIME = 3.00 hours

DOSE DUE TO DIRECT RADIATION = 7.3871E-08 rem

ATMOSPHERIC DISPERSION CALCULATIONS:

AMBIENT PROPERTIES:

AMBIENT TEMPERATURE = 298.0 K

MOLECULAR WEIGHT OF AMBIENT AIR = 28.96

DENSITY OF AMBIENT AIR = 1.1614E+00 kg/m³

WIND VELOCITY AT 2 m = 1.00 m/s

PLUME PROPERTIES:

MOLECULAR WEIGHT OF PLUME = 28.96

FLAME TEMPERATURE = 1200.0 K

INITIAL PLUME RADIUS = 0.50 m

BURN RATE = 8.9000E-04 kg/s

INITIAL VERTICAL PLUME VELOCITY = 1.00 m/s

EQUILIBRIUM PLUME RISE = 3.6867E+01 m

RECEPTOR INFORMATION:

CROSSWIND DISTANCE = 0.0000E+00 m

ELEVATION OF RECEPTOR = 0.0000E+00 m

EXPOSURE TIME = 3.1211E+00 hr

BREATHING RATE = 1.20 m³/hr

Downwind Distance (m)	Stability Class	Concentration (mg/m ³)	Concentration *Exposure Time (mg-hr/m ³)	Inhalation Dose (rem)	Uptake (mg)
100.0	A	1.0325E-01	3.2224E-01	1.5803E-02	3.8669E-01
200.0	A	5.2527E-02	1.6394E-01	8.0400E-03	1.9673E-01
300.0	B	4.2874E-02	1.3382E-01	6.5625E-03	1.6058E-01
400.0	B	4.0805E-02	1.2736E-01	6.2457E-03	1.5283E-01
500.0	E	4.1906E-02	1.3079E-01	6.4143E-03	1.5695E-01
600.0	E	5.4997E-02	1.7165E-01	8.4179E-03	2.0598E-01
700.0	E	6.0561E-02	1.8902E-01	9.2696E-03	2.2682E-01
800.0	E	6.1264E-02	1.9121E-01	9.3772E-03	2.2945E-01
900.0	F	6.0137E-02	1.8769E-01	9.2047E-03	2.2523E-01
1000.0	F	6.4247E-02	2.0052E-01	9.8338E-03	2.4062E-01
1100.0	F	6.5887E-02	2.0564E-01	1.0085E-02	2.4677E-01
1200.0	F	6.5847E-02	2.0552E-01	1.0079E-02	2.4662E-01
1300.0	F	6.4727E-02	2.0202E-01	9.9073E-03	2.4242E-01
1400.0	F	6.2949E-02	1.9647E-01	9.6351E-03	2.3576E-01
1500.0	F	6.0798E-02	1.8976E-01	9.3059E-03	2.2771E-01
1600.0	F	5.8464E-02	1.8247E-01	8.9487E-03	2.1897E-01
1700.0	F	5.6071E-02	1.7500E-01	8.5823E-03	2.1000E-01
1800.0	F	5.3695E-02	1.6759E-01	8.2186E-03	2.0110E-01
1900.0	F	5.1384E-02	1.6037E-01	7.8650E-03	1.9245E-01
2000.0	F	4.9167E-02	1.5345E-01	7.5256E-03	1.8414E-01

WORST CASE VALUES:

100.0 A 1.0325E-01 3.2224E-01 1.5803E-02 3.8669E-01

MAXIMUM RADIOLOGICAL CONSEQUENCES OF INHALATION:

RADIOLOGICAL DOSES:

CONTRIBUTION DUE TO U-235 = 5.0598E-01 rem/g
CONTRIBUTION DUE TO U-238 = 4.0362E+01 rem/g
TOTAL = 4.0868E+01 rem/g
DOSE DUE TO INHALATION = 1.5803E-02 rem

MAXIMUM CHEMICAL CONSEQUENCES OF INHALATION:

UPTAKE DUE TO INHALATION = 3.8669E-01 mg

WATER TRANSPORT CALCULATIONS:

FRACTION REACHING PUBLIC DRINKING SUPPLY = 1.0000E-02
TANK VOLUME = 4.7317E+02 m³
DAILY WATER UPTAKE = 2.0000E-03 m³
MASS AVAILABLE FOR UPTAKE = 4.2268E-07 kg

RADIOLOGICAL CONSEQUENCES OF INGESTION:

RADIOLOGICAL DOSES:
CONTRIBUTION DUE TO U-235 = 1.0541E-03 rem/g
CONTRIBUTION DUE TO U-238 = 7.7360E-02 rem/g
TOTAL = 7.8414E-02 rem/g
DOSE DUE TO INGESTION = 3.3144E-05 rem

CHEMICAL CONSEQUENCES OF INGESTION:

INTAKE DUE TO INGESTION = 4.2268E-01 mg

TOTAL RADIOLOGICAL DOSES FOR SHIPMENT:

TOTAL RADIOLOGICAL DOSE DUE TO DIRECT RADIATION = $2.9144\text{E}-06$ rem

TOTAL RADIOLOGICAL DOSE DUE TO INHALATION = $4.1551\text{E}+00$ rem

TOTAL RADIOLOGICAL DOSE DUE TO INGESTION = $9.0756\text{E}-03$ rem

Screen Dump for Run with User-Supplied Materials

C:\TSRA\TSRA

32-bit Power for Lahey Computer Systems
Phar Lap's 386|DOS-Extender(tm) Version 5.1
Copyright (C) 1986-93 Phar Lap Software, Ince
Available Memory = 14580 Kb

ENTER THE NAME (UP TO 8 CHARACTERS) OF THE OUTPUT FILE. DO NOT PROVIDE AN EXTENSION. THE FILE WILL AUTOMATICALLY BE GIVEN THE EXTENSION .OUT

ENTER A 0 IF YOU WISH TO ACCEPT THE DEFAULT OUTPUT

0

DEFAULT VALUES ASSUMED BY PROGRAM:

1. DISTANCE FROM THE SOURCE = 152.40 m
2. EXPOSURE TIME FOR DIRECT RADIATION = 3.00 hr
3. MINIMUM DOWNWIND DISTANCE = 100.0 m
4. MAXIMUM DOWNWIND DISTANCE = 2000.0 m
5. DOWNWIND DISTANCE INCREMENT = 100.0 m
6. ELEVATION = 0.0 m
7. AMBIENT TEMPERATURE = 298.00 K
8. INITIAL PLUME RADIUS = 0.50 m
9. WIND VELOCITY AT AN ELEVATION OF 2 m = 1.00 m/s
10. BREATHING RATE = 1.20 m³/hr
11. EXPOSURE TIME FOR INHALATION = BURN DURATION
12. VOLUME OF THE WATER TANK = 473.17 m³
13. INDIVIDUAL DAILY UPTAKE OF WATER = 0.0020 m³

DO YOU WISH TO CHANGE ANY OF THESE VALUES?

1 = YES OR 2 = NO

2

DO YOU WISH TO ANALYZE MATERIALS OTHER THAN THOSE CURRENTLY IN THE DATABASE?

1 = YES, 2 = NO

1

ADDITIONAL MATERIALS SHOULD BE DEFINED IN FILE
TSRA.DAT

1. Beryllium
2. Beryllium Oxide
3. Boron

4. Lithium Deuteride
5. Lithium Hydride
6. Magnesium
7. Polyethylene
8. Polyethylpentene
9. Silicone
10. Tantalum
11. Thorium
12. Tungsten
13. Highly Enriched Uranium
14. Natural Uranium
15. Depleted Uranium
16. Uranium-Niobium Alloy
17. Uranium-Niobium-Zirconium Allo
18. Urethane
19. H E U
20. N U
21. D U

ENTER THE NUMBER OF THE MATERIAL OF INTEREST
19

ENTER MASS OF H E U IN kg
10

DO YOU WISH TO CHOOSE ANOTHER MATERIAL?
1 = YES OR 2 = NO
1

1. Beryllium
2. Beryllium Oxide
3. Boron
4. Lithium Deuteride
5. Lithium Hydride
6. Magnesium
7. Polyethylene
8. Polyethylpentene
9. Silicone
10. Tantalum
11. Thorium
12. Tungsten
13. Highly Enriched Uranium
14. Natural Uranium
15. Depleted Uranium
16. Uranium-Niobium Alloy
17. Uranium-Niobium-Zirconium Allo
18. Urethane
19. H E U

20. N U

21. D U

ENTER THE NUMBER OF THE MATERIAL OF INTEREST

20

ENTER MASS OF N U IN kg

10

DO YOU WISH TO CHOOSE ANOTHER MATERIAL?

1 = YES OR 2 = NO

1

1. Beryllium
2. Beryllium Oxide
3. Boron
4. Lithium Deuteride
5. Lithium Hydride
6. Magnesium
7. Polyethylene
8. Polyethylpentene
9. Silicone
10. Tantalum
11. Thorium
12. Tungsten
13. Highly Enriched Uranium
14. Natural Uranium
15. Depleted Uranium
16. Uranium-Niobium Alloy
17. Uranium-Niobium-Zirconium Allo
18. Urethane
19. H E U
20. N U
21. D U

ENTER THE NUMBER OF THE MATERIAL OF INTEREST

21

ENTER MASS OF D U IN kg

10

DO YOU WISH TO CHOOSE ANOTHER MATERIAL?

1 = YES OR 2 = NO

2

C:\TSRA

TSRA.DAT (User-Supplied Material File)

19,'F E U',5
28.964,8.9D-03,1200.,0.01
U-232,4.0D-08
232.032,72,19.0,6.7D08,1.3D06
1,0
17.84157,133.6308,1050.339,3644.77,14408.46,4.67D12
4621940,4.48D10,4.88D11,1.54D11,7.31D11,2.13D12
6.17D12,3.6D11,7.36D12,7.58D11,6.93D12,5.66D12
U-234,0.012
234.041,2.45D05,18.6,1.3D08,2.6D05
1,0
1.0011D-03,7.3114D-03,5.6593D-02,1.9480D-01,2.7678D01,1.1820D02
7.1351D03,1.8679D04,1.1191D04,2.2034D04,5.0551D03,4.2723D04
5.5443D03,3.3934D04,2.8801D04,1.3923D06,3.6286D06,1.9378D08
U-235,0.94
235.044,7.04D08,18.7,1.2D08,2.5D05
1,0
6.5349D-06,3.1690D-05,1.6833D-04,4.3831D-04,1.3648D-03,1.5844D-03
2.8297D-03,4.8525D-03,3.4272D-05,2.8456D00,6.8704D01,3.9091D01
3.2702D02,3.0189D03,7.1816D04,1.3098D06,3.0265D05,5.2699D05
U-236,0.0048
236.0455,2.34D07,19.0,1.2D08,2.5D05
1,0
9.7D-05,4.84D-04,2.674D-03,7.232D-03,2.3427D-02,5.787D-02
5.13D-02,9.1312D-02,1.356D-02,2.07746D-01,6.2183D-02,4.78306D-01
4.8708D-02,1.7832D-02,7.12861D-01,6494.58,5.2117D-02,6.6527D-02
U-238,0.04319996
238.051,4.47D09,19.0,1.2D08,2.3D05
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1.9242D-04,9.0632D-04,4.6203D-03,1.1513D-02,3.4106D-02,3.7964D-02
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Output File for Run with User-Supplied Materials

ECHO OF USER-SUPPLIED MATERIAL DATA:

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U-232 4.0000E-08
2.3204E+02 6.8900E+01 1.8570E+01 6.7000E+08 1.3000E+06
1 0.0000E+00
1.7440E+01 1.3060E+02 1.0270E+03 3.5620E+03 1.4080E+04 4.5630E+12
4.5170E+06 4.3780E+10 4.7700E+11 1.5020E+11 7.1490E+11 2.0800E+12
6.0260E+12 3.5180E+11 7.1910E+12 7.4050E+11 6.7710E+12 5.5330E+12
U-234 1.2000E-02
2.3404E+02 2.4500E+05 1.8720E+01 1.3000E+08 2.6000E+05
1 0.0000E+00
1.0080E-03 7.3590E-03 5.6960E-02 1.9610E-01 2.7860E+01 1.1900E+02
7.1810E+03 1.8800E+04 1.1260E+04 2.2180E+04 5.0880E+03 4.3000E+04
5.5800E+03 3.4150E+04 2.8990E+04 1.4010E+06 3.6520E+06 1.9500E+08
U-235 9.4000E-01
2.3504E+02 7.0400E+08 1.8810E+01 1.2000E+08 2.5000E+05
1 0.0000E+00
6.5730E-06 3.1880E-05 1.6930E-04 4.4090E-04 1.3730E-03 1.5940E-03
2.8460E-03 4.8810E-03 3.4470E-05 2.8620E+00 6.9110E+01 3.9320E+01
3.2890E+02 3.0370E+03 7.2240E+04 1.3180E+06 3.0440E+05 5.3010E+05
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5.1000E-02 9.0780E-02 1.3480E-02 2.0650E-01 6.1820E-02 4.7550E-01
4.8430E-02 1.7730E-02 7.0870E-01 6.4570E+03 5.1820E-02 6.6140E-02
U-238 4.3200E-02
2.3805E+02 4.4600E+09 1.9050E+01 1.2000E+08 2.3000E+05
1 0.0000E+00
1.9290E-04 9.0870E-04 4.6320E-03 1.1540E-02 3.4200E-02 3.8060E-02
4.0750E-01 1.6000E+02 1.6160E+02 9.7430E+02 1.7720E+03 2.3600E+03
3.2400E+03 4.7560E+03 6.6560E+03 2.0090E+04 5.2910E+04 9.7420E+04

20 N U                      3
2.8964E+01 8.9000E-03 1.2000E+03 1.0000E-02
U-234 5.6000E-05
2.3404E+02 2.4500E+05 1.8720E+01 1.3000E+08 2.6000E+05
1 0.0000E+00
1.0080E-03 7.3590E-03 5.6960E-02 1.9610E-01 2.7860E+01 1.1900E+02
7.1810E+03 1.8800E+04 1.1260E+04 2.2180E+04 5.0880E+03 4.3000E+04
5.5800E+03 3.4150E+04 2.8990E+04 1.4010E+06 3.6520E+06 1.9500E+08
U-235 7.0500E-03
2.3504E+02 7.0400E+08 1.8810E+01 1.2000E+08 2.5000E+05
1 0.0000E+00
6.5730E-06 3.1880E-05 1.6930E-04 4.4090E-04 1.3730E-03 1.5940E-03
2.8460E-03 4.8810E-03 3.4470E-05 2.8620E+00 6.9110E+01 3.9320E+01
3.2890E+02 3.0370E+03 7.2240E+04 1.3180E+06 3.0440E+05 5.3010E+05
U-238 9.9289E-01
2.3805E+02 4.4600E+09 1.9050E+01 1.2000E+08 2.3000E+05
1 0.0000E+00
1.9290E-04 9.0870E-04 4.6320E-03 1.1540E-02 3.4200E-02 3.8060E-02
4.0750E-01 1.6000E+02 1.6160E+02 9.7430E+02 1.7720E+03 2.3600E+03
3.2400E+03 4.7560E+03 6.6560E+03 2.0090E+04 5.2910E+04 9.7420E+04

21 D U                      2
2.8964E+01 8.9000E-03 1.2000E+03 1.0000E-02
U-235 1.9500E-03
2.3504E+02 7.0400E+08 1.8810E+01 1.2000E+08 2.5000E+05
1 0.0000E+00
6.5730E-06 3.1880E-05 1.6930E-04 4.4090E-04 1.3730E-03 1.5940E-03

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2.8460E-03	4.8810E-03	3.4470E-05	2.8620E+00	6.9110E+01	3.9320E+01
3.2890E+02	3.0370E+03	7.2240E+04	1.3180E+06	3.0440E+05	5.3010E+05
U-238	9.9805E-01				
2.3805E+02	4.4600E+09	1.9050E+01	1.2000E+08	2.3000E+05	
1	0.0000E+00				
1.9290E-04	9.0870E-04	4.6320E-03	1.1540E-02	3.4200E-02	3.8060E-02
4.0750E-01	1.6000E+02	1.6160E+02	9.7430E+02	1.7720E+03	2.3600E+03
3.2400E+03	4.7560E+03	6.6560E+03	2.0090E+04	5.2910E+04	9.7420E+04

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[1.0000E+01 kg]

DIRECT RADIATION EXPOSURE:

DISTANCE FROM SOURCE = 152.40 m
DOSE RATES:
CONTRIBUTION DUE TO U-232 = 3.2048E-07 rem/hr
CONTRIBUTION DUE TO U-234 = 4.0427E-07 rem/hr
CONTRIBUTION DUE TO U-235 = 1.9360E-07 rem/hr
CONTRIBUTION DUE TO U-236 = 2.1572E-12 rem/hr
CONTRIBUTION DUE TO U-238 = 1.0484E-09 rem/hr
TOTAL = 9.1941E-07 rem/hr
EXPOSURE TIME = 3.00 hours
DOSE DUE TO DIRECT RADIATION = 2.7582E-06 rem

ATMOSPHERIC DISPERSION CALCULATIONS:

AMBIENT PROPERTIES: AMBIENT TEMPERATURE = 298.0 K
MOLECULAR WEIGHT OF AMBIENT AIR = 28.96
DENSITY OF AMBIENT AIR = 1.1614E+00 kg/m3
WIND VELOCITY AT 2 m = 1.00 m/s

PLUME PROPERTIES: MOLECULAR WEIGHT OF PLUME = 28.96
FLAME TEMPERATURE = 1200.0 K
INITIAL PLUME RADIUS = 0.50 m
BURN RATE = 8.9000E-04 kg/s
INITIAL VERTICAL PLUME VELOCITY = 1.00 m/s
EQUILIBRIUM PLUME RISE = 3.6867E+01 m

RECEPTOR INFORMATION: CROSSWIND DISTANCE = 0.0000E+00 m
ELEVATION OF RECEPTOR = 0.0000E+00 m
EXPOSURE TIME = 0.0000E+00 hr
BREATHING RATE = 1.20 m3/hr

Downwind Distance (m)	Stability Class	Concentration (mg/m3)	Concentration *Exposure Time (mg-hr/m3)	Inhalation Dose (rem)	Uptake (mg)
100.0	A	1.0325E-01	3.2224E-01	4.1055E+00	3.8669E-01
200.0	A	5.2527E-02	1.6394E-01	2.0887E+00	1.9673E-01
300.0	B	4.2874E-02	1.3382E-01	1.7049E+00	1.6058E-01
400.0	B	4.0805E-02	1.2736E-01	1.6226E+00	1.5283E-01
500.0	E	4.1906E-02	1.3079E-01	1.6664E+00	1.5695E-01
600.0	E	5.4997E-02	1.7165E-01	2.1869E+00	2.0598E-01
700.0	E	6.0561E-02	1.8902E-01	2.4082E+00	2.2682E-01
800.0	E	6.1264E-02	1.9121E-01	2.4361E+00	2.2945E-01
900.0	F	6.0137E-02	1.8769E-01	2.3913E+00	2.2523E-01
1000.0	F	6.4247E-02	2.0052E-01	2.5547E+00	2.4062E-01
1100.0	F	6.5887E-02	2.0564E-01	2.6199E+00	2.4677E-01
1200.0	F	6.5847E-02	2.0552E-01	2.6184E+00	2.4662E-01
1300.0	F	6.4727E-02	2.0202E-01	2.5738E+00	2.4242E-01
1400.0	F	6.2949E-02	1.9647E-01	2.5031E+00	2.3576E-01
1500.0	F	6.0798E-02	1.8976E-01	2.4176E+00	2.2771E-01
1600.0	F	5.8464E-02	1.8247E-01	2.3248E+00	2.1897E-01
1700.0	F	5.6071E-02	1.7500E-01	2.2296E+00	2.1000E-01
1800.0	F	5.3695E-02	1.6759E-01	2.1351E+00	2.0110E-01
1900.0	F	5.1384E-02	1.6037E-01	2.0433E+00	1.9245E-01
2000.0	F	4.9167E-02	1.5345E-01	1.9551E+00	1.8414E-01

WORST CASE VALUES:

100.0 A 1.0325E-01 3.2224E-01 4.1055E+00 3.8669E-01

MAXIMUM RADIOLOGICAL CONSEQUENCES OF INHALATION:

RADIOLOGICAL DOSES:

CONTRIBUTION DUE TO U-232 = 5.9979E+02 rem/g
CONTRIBUTION DUE TO U-234 = 9.7344E+03 rem/g
CONTRIBUTION DUE TO U-235 = 2.4391E+02 rem/g
CONTRIBUTION DUE TO U-236 = 3.7312E+01 rem/g
CONTRIBUTION DUE TO U-238 = 1.7470E+00 rem/g
TOTAL = 1.0617E+04 rem/g

DOSE DUE TO INHALATION = 4.1055E+00 rem

MAXIMUM CHEMICAL CONSEQUENCES OF INHALATION:

UPTAKE DUE TO INHALATION = 3.8669E-01 mg

WATER TRANSPORT CALCULATIONS:

FRACTION REACHING PUBLIC DRINKING SUPPLY = 1.0000E-02
TANK VOLUME = 4.7317E+02 m³
DAILY WATER UPTAKE = 2.0000E-03 m³
MASS AVAILABLE FOR UPTAKE = 4.2268E-07 kg

RADIOLOGICAL CONSEQUENCES OF INGESTION:

RADIOLOGICAL DOSES:

CONTRIBUTION DUE TO U-232 = 1.1638E+00 rem/g
CONTRIBUTION DUE TO U-234 = 1.9469E+01 rem/g
CONTRIBUTION DUE TO U-235 = 5.0814E-01 rem/g
CONTRIBUTION DUE TO U-236 = 7.7734E-02 rem/g
CONTRIBUTION DUE TO U-238 = 3.3485E-03 rem/g
TOTAL = 2.1222E+01 rem/g

DOSE DUE TO INGESTION = 8.9699E-03 rem

CHEMICAL CONSEQUENCES OF INGESTION:

INTAKE DUE TO INGESTION = 4.2268E-01 mg

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[1.0000E+01 kg]

DIRECT RADIATION EXPOSURE:

DISTANCE FROM SOURCE = 152.40 m
DOSE RATES:
CONTRIBUTION DUE TO U-234 = 1.8866E-09 rem/hr
CONTRIBUTION DUE TO U-235 = 1.4520E-09 rem/hr
CONTRIBUTION DUE TO U-238 = 2.4097E-08 rem/hr
TOTAL = 2.7435E-08 rem/hr
EXPOSURE TIME = 3.00 hours
DOSE DUE TO DIRECT RADIATION = 8.2306E-08 rem

ATMOSPHERIC DISPERSION CALCULATIONS:

AMBIENT PROPERTIES: AMBIENT TEMPERATURE = 298.0 K
MOLECULAR WEIGHT OF AMBIENT AIR = 28.96
DENSITY OF AMBIENT AIR = 1.1614E+00 kg/m3
WIND VELOCITY AT 2 m = 1.00 m/s

PLUME PROPERTIES: MOLECULAR WEIGHT OF PLUME = 28.96
FLAME TEMPERATURE = 1200.0 K
INITIAL PLUME RADIUS = 0.50 m
BURN RATE = 8.9000E-04 kg/s
INITIAL VERTICAL PLUME VELOCITY = 1.00 m/s
EQUILIBRIUM PLUME RISE = 3.6867E+01 m

RECEPTOR INFORMATION: CROSSWIND DISTANCE = 0.0000E+00 m
ELEVATION OF RECEPTOR = 0.0000E+00 m
EXPOSURE TIME = 3.1211E+00 hr
BREATHING RATE = 1.20 m3/hr

Downwind Distance (m)	Stability Class	Concentration (mg/m3)	Concentration *Exposure Time (mg-hr/m3)	Inhalation Dose (rem)	Uptake (mg)
100.0	A	1.0325E-01	3.2224E-01	3.3800E-02	3.8669E-01
200.0	A	5.2527E-02	1.6394E-01	1.7196E-02	1.9673E-01
300.0	B	4.2874E-02	1.3382E-01	1.4036E-02	1.6058E-01
400.0	B	4.0805E-02	1.2736E-01	1.3358E-02	1.5283E-01
500.0	E	4.1906E-02	1.3079E-01	1.3719E-02	1.5695E-01
600.0	E	5.4997E-02	1.7165E-01	1.8005E-02	2.0598E-01
700.0	E	6.0561E-02	1.8902E-01	1.9826E-02	2.2682E-01
800.0	E	6.1264E-02	1.9121E-01	2.0056E-02	2.2945E-01
900.0	F	6.0137E-02	1.8769E-01	1.9687E-02	2.2523E-01
1000.0	F	6.4247E-02	2.0052E-01	2.1033E-02	2.4062E-01
1100.0	F	6.5887E-02	2.0564E-01	2.1570E-02	2.4677E-01
1200.0	F	6.5847E-02	2.0552E-01	2.1557E-02	2.4662E-01
1300.0	F	6.4727E-02	2.0202E-01	2.1190E-02	2.4242E-01
1400.0	F	6.2949E-02	1.9647E-01	2.0608E-02	2.3576E-01
1500.0	F	6.0798E-02	1.8976E-01	1.9904E-02	2.2771E-01
1600.0	F	5.8464E-02	1.8247E-01	1.9140E-02	2.1897E-01
1700.0	F	5.6071E-02	1.7500E-01	1.8356E-02	2.1000E-01
1800.0	F	5.3695E-02	1.6759E-01	1.7578E-02	2.0110E-01
1900.0	F	5.1384E-02	1.6037E-01	1.6822E-02	1.9245E-01
2000.0	F	4.9167E-02	1.5345E-01	1.6096E-02	1.8414E-01

WORST CASE VALUES:

100.0 A 1.0325E-01 3.2224E-01 3.3800E-02 3.8669E-01

MAXIMUM RADIOLOGICAL CONSEQUENCES OF INHALATION:

RADIOLOGICAL DOSES:

CONTRIBUTION DUE TO U-234 = 4.5427E+01 rem/g
CONTRIBUTION DUE TO U-235 = 1.8293E+00 rem/g
CONTRIBUTION DUE TO U-238 = 4.0153E+01 rem/g
TOTAL = 8.7409E+01 rem/g

DOSE DUE TO INHALATION = 3.3800E-02 rem

MAXIMUM CHEMICAL CONSEQUENCES OF INHALATION:

UPTAKE DUE TO INHALATION = 3.8669E-01 mg

WATER TRANSPORT CALCULATIONS:

FRACTION REACHING PUBLIC DRINKING SUPPLY = 1.0000E-02
TANK VOLUME = 4.7317E+02 m³
DAILY WATER UPTAKE = 2.0000E-03 m³
MASS AVAILABLE FOR UPTAKE = 4.2268E-07 kg

RADIOLOGICAL CONSEQUENCES OF INGESTION:

RADIOLOGICAL DOSES:

CONTRIBUTION DUE TO U-234 = 9.0854E-02 rem/g
CONTRIBUTION DUE TO U-235 = 3.8111E-03 rem/g
CONTRIBUTION DUE TO U-238 = 7.6960E-02 rem/g
TOTAL = 1.7163E-01 rem/g

DOSE DUE TO INGESTION = 7.2542E-05 rem

CHEMICAL CONSEQUENCES OF INGESTION:

INTAKE DUE TO INGESTION = 4.2268E-01 mg

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[1.0000E+01 kg]

DIRECT RADIATION EXPOSURE:

DISTANCE FROM SOURCE = 152.40 m
DOSE RATES:
CONTRIBUTION DUE TO U-235 = 4.0162E-10 rem/hr
CONTRIBUTION DUE TO U-238 = 2.4222E-08 rem/hr
TOTAL = 2.4624E-08 rem/hr
EXPOSURE TIME = 3.00 hours
DOSE DUE TO DIRECT RADIATION = 7.3871E-08 rem

ATMOSPHERIC DISPERSION CALCULATIONS:

AMBIENT PROPERTIES: AMBIENT TEMPERATURE = 298.0 K
MOLECULAR WEIGHT OF AMBIENT AIR = 28.96
DENSITY OF AMBIENT AIR = 1.1614E+00 kg/m3
WIND VELOCITY AT 2 m = 1.00 m/s

PLUME PROPERTIES: MOLECULAR WEIGHT OF PLUME = 28.96
FLAME TEMPERATURE = 1200.0 K
INITIAL PLUME RADIUS = 0.50 m
BURN RATE = 8.9000E-04 kg/s
INITIAL VERTICAL PLUME VELOCITY = 1.00 m/s
EQUILIBRIUM PLUME RISE = 3.6867E+01 m

RECEPTOR INFORMATION: CROSSWIND DISTANCE = 0.0000E+00 m
ELEVATION OF RECEPTOR = 0.0000E+00 m
EXPOSURE TIME = 3.1211E+00 hr
BREATHING RATE = 1.20 m3/hr

Downwind Distance (m)	Stability Class	Concentration (mg/m3)	Concentration *Exposure Time (mg-hr/m3)	Inhalation Dose (rem)	Uptake (mg)
100.0	A	1.0325E-01	3.2224E-01	1.5803E-02	3.8669E-01
200.0	A	5.2527E-02	1.6394E-01	8.0400E-03	1.9673E-01
300.0	B	4.2874E-02	1.3382E-01	6.5625E-03	1.6058E-01
400.0	B	4.0805E-02	1.2736E-01	6.2457E-03	1.5283E-01
500.0	E	4.1906E-02	1.3079E-01	6.4143E-03	1.5695E-01
600.0	E	5.4997E-02	1.7165E-01	8.4179E-03	2.0598E-01
700.0	E	6.0561E-02	1.8902E-01	9.2696E-03	2.2682E-01
800.0	E	6.1264E-02	1.9121E-01	9.3772E-03	2.2945E-01
900.0	F	6.0137E-02	1.8769E-01	9.2047E-03	2.2523E-01
1000.0	F	6.4247E-02	2.0052E-01	9.8338E-03	2.4062E-01
1100.0	F	6.5887E-02	2.0564E-01	1.0085E-02	2.4677E-01
1200.0	F	6.5847E-02	2.0552E-01	1.0079E-02	2.4662E-01
1300.0	F	6.4727E-02	2.0202E-01	9.9073E-03	2.4242E-01
1400.0	F	6.2949E-02	1.9647E-01	9.6351E-03	2.3576E-01
1500.0	F	6.0798E-02	1.8976E-01	9.3059E-03	2.2771E-01
1600.0	F	5.8464E-02	1.8247E-01	8.9487E-03	2.1897E-01
1700.0	F	5.6071E-02	1.7500E-01	8.5823E-03	2.1000E-01
1800.0	F	5.3695E-02	1.6759E-01	8.2186E-03	2.0110E-01
1900.0	F	5.1384E-02	1.6037E-01	7.8650E-03	1.9245E-01
2000.0	F	4.9167E-02	1.5345E-01	7.5256E-03	1.8414E-01

WORST CASE VALUES:

100.0 A 1.0325E-01 3.2224E-01 1.5803E-02 3.8669E-01

MAXIMUM RADIOLOGICAL CONSEQUENCES OF INHALATION:

RADIOLOGICAL DOSES:

CONTRIBUTION DUE TO U-235 = 5.0598E-01 rem/g
CONTRIBUTION DUE TO U-238 = 4.0362E+01 rem/g
TOTAL = 4.0868E+01 rem/g
DOSE DUE TO INHALATION = 1.5803E-02 rem

MAXIMUM CHEMICAL CONSEQUENCES OF INHALATION:

UPTAKE DUE TO INHALATION = 3.8669E-01 mg

WATER TRANSPORT CALCULATIONS:

FRACTION REACHING PUBLIC DRINKING SUPPLY = 1.0000E-02
TANK VOLUME = 4.7317E+02 m3
DAILY WATER UPTAKE = 2.0000E-03 m3
MASS AVAILABLE FOR UPTAKE = 4.2268E-07 kg

RADIOLOGICAL CONSEQUENCES OF INGESTION:

RADIOLOGICAL DOSES:
CONTRIBUTION DUE TO U-235 = 1.0541E-03 rem/g
CONTRIBUTION DUE TO U-238 = 7.7360E-02 rem/g
TOTAL = 7.8414E-02 rem/g
DOSE DUE TO INGESTION = 3.3144E-05 rem

CHEMICAL CONSEQUENCES OF INGESTION:

INTAKE DUE TO INGESTION = 4.2268E-01 mg

TOTAL RADIOLOGICAL DOSES FOR SHIPMENT:

TOTAL RADIOLOGICAL DOSE DUE TO DIRECT RADIATION = $2.9144\text{E}-06$ rem

TOTAL RADIOLOGICAL DOSE DUE TO INHALATION = $4.1551\text{E}+00$ rem

TOTAL RADIOLOGICAL DOSE DUE TO INGESTION = $9.0756\text{E}-03$ rem

APPENDIX C

Letters from Local Water Treatment Plants

SEP 18 '97 13:22 KUB WATER PLANT OPS.

P. 1/1

KNOXVILLE UTILITIES BOARD

2000 RIVERSIDE DRIVE
KNOXVILLE, TN 37915
423-594-1234
Fax: 423-594-1234

September 18, 1997

Mr. Jim Anderson, Engr. Assoc.
Lockheed-Martin Energy Systems
Central Engineering Services
Bldg. 1000
Mail Stop 6332
Oak Ridge, Tenn. 37831

Dear Mr. Smith:

In response to your request for information on pass-through rates of certain particulate sizes in our filter at the MBW Water Plant, we have found an average of some 5,000 particles per ml in our raw water from the Tennessee River in the 2-15 micron size range. After treatment and filtration, this number will average about 30 particles per ml in this same size range, with very few, if any, particles larger than this passing through.

Please don't hesitate to contact me if you need further information.

Sincerely,

JOE SNYDER
TREATMENT PLANTS SUPERVISOR
KNOXVILLE UTILITIES BOARD

THU, SEP-18-97 1:48PM

J I WATER PLANT

241 2911

P.01

ETMC/Johnson Controls
Post Office Box 4247
Oak Ridge, Tennessee 37831
Ph. (423) 574-3050
Fax (423) 241-2911

September 18, 1997

Mr. Jim Anderson
Engineering Analyst
Lockheed Martin Energy Systems
FAX #576-4722

Mr. Anderson,

The particle counting system was installed at the D.O.E./Oak Ridge Water Treatment Plant in 1995. We have fourteen filters with particle counters on the effluent side. Also, the clearwell which collects all the water from the filters before it goes to the customers has a particle counter. The raw water particle counters are located at four locations prior to the water entering on top of the filters. We normally have very low turbidity water entering the top of the filters and an average particle range would be 1100 per 100 ml sample in 2-5u range, 800 5-10u, 100 10-15u <100 15-25u.

The filtered water going to the customer normally has 15 to 20 per 100 ml sample in the 2-5u range, <8 in the 5-10u range, and 0 in 10-25u.

We have taken readings at the river intake station on the raw water in the river and the particle counts are in the 9,000 to 10,000 range. The readings at the plant on raw water particles are after chemicals have been added in the flocculation process and most of the particles have dropped to the bottom of the settling basin.

Sincerely,

A handwritten signature in black ink, appearing to read "Winthrop C. Wilson". The signature is fluid and cursive, with the first name "Winthrop" and last name "Wilson" clearly distinguishable.

Winthrop C. Wilson
WTP Superintendent