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INTERNATIONAL
TECHNOLOGY
CORPORATION

BASELINE RADIOLOGICAL RISK ASSESSMENT FOR THE HUDSON'S BRANCH WATERSHED

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TABLE OF CONTENTS

DEFINITIONS 4

INTRODUCTION 5

APPROACH 7

IDENTIFICATION OF RADIONUCLIDES 8
Contaminant Concentrations 8
Evaluation of Background 9

DOSE ASSESSMENT 10
Characterization of Exposure Settings 10
Identification of Exposure Pathways 10
Radiation Dose Assessment 11

RISK ASSESSMENT 14

UNCERTAINTY ANALYSIS 15
Uncertainties in the Assessment of Dose 15
Uncertainties in the Assessment of Risk 15

SUMMARY AND CONCLUSIONS 16

REFERENCES 17

TABLE 1: RADIONUCLIDE CONCENTRATIONS IN SOIL 19

TABLE 2: CONTAMINANT CONCENTRATIONS 20

TABLE 3: BACKGROUND RADIONUCLIDE CONCENTRATIONS 21

TABLE 4: CONTAMINANT CONCENTRATIONS USED FOR THE RISK ASSESSMENT 22

TABLE 5: FRACTION OF TOTAL DOSE IN YEAR ONE AFTER DEPOSITION . . 23

TABLE 6: UNCERTAINTIES IN THE DOSE ASSESSMENT 24

FIGURE 1: Location of the Newfield Plant 26

FIGURE 2: Grid Locations in the Hudson's Branch 27

FIGURE 3: Frequency Distribution of Soil Concentrations 28

FIGURE 4: Total Dose from Radioactive Materials in the Hudson's Branch 29

APPENDIX A: PARAMETER VALUES USED FOR THE DOSE ASSESSMENT . . 30

APPENDIX B: RESRAD PATHWAY SELECTIONS 35

DEFINITIONS

Baseline Risk Assessment - An assessment of potential risks to human health and the environment from current site conditions in the absence of remediation.

Committed Effective Dose Equivalent (CEDE) - The weighted sum of the dose equivalents to individual organs received over a 70-year lifetime. The magnitude of the weighting factor for each organ is determined by the risk of cancer induction in the individual organ (ICRP 1977).

Committed Dose Equivalent - The total dose equivalent averaged throughout a tissue in a specified time period after intake of a radionuclide into the body. For this assessment, a 50-year time period after intake is specified.

Dose Equivalent - A measure of the radiation effect obtained by multiplying the absorbed dose by the quality factor and other modifying factors. The common unit for dose equivalent is the "rem".

Dose Limits - Maximum dose rates permitted by regulations. Dose limits do not define a boundary between safe and hazardous conditions but rather they are conservatively established for regulatory purposes at levels that are not known to induce observable health effects in humans.

Exposure Pathway - A transport route and mechanism for human exposure to materials that have migrated from a source. An exposure pathway consists of a point of exposure in the environment, a receptor, a migration pathway, and a mechanism of entering the body (e.g., inhalation).

Migration Pathway - Mechanism for the transport of hazardous materials through environmental media.

Receptor - A person in the environment who may be exposed to hazardous materials.

INTRODUCTION

Shieldalloy Metallurgical Corporation (Shieldalloy) operates a manufacturing facility in Newfield, New Jersey (see Figure 1). This facility manufactures or has manufactured specialty steel and super alloy additives, primary aluminum master alloys, refractory and metal carbides, powdered metals, and optical surfacing products. Raw materials currently used at the facility include oxides of columbium (niobium), aluminum metal, titanium metal, strontium metal, zirconium metal, and fluoride (titanium and boron) salts. During the manufacturing processes, the facility generates slag, dross, bag house dust, and waste waters, among other waste streams.

Some of the materials received, used or stored by Shieldalloy at Newfield contain radioactive material which is classified as "source material" pursuant to Title 10, Code of Federal Regulations, Part 40. The U. S. Nuclear Regulatory Commission (USNRC) has issued a license to Shieldalloy to possess, use, and store source material at its Newfield site.

An evaluation of environmental radiological conditions at the Newfield site was completed in 1992 (IT 1992). For this evaluation, the following two specific tasks were performed:

1. Determine the whole body exposure rate at the boundary fence of the site; and

2. Obtain additional information on the potential for soil and sediment contamination at on-site locations, off-site portions of the Hudson's Branch watershed, and on South Haul Road.

The summary report, entitled "Assessment of Environmental Radiological Conditions at the Newfield Facility", indicated that elevated surface count rates were identified during walkover surveys due south of the Department 111 bag house.[1] Also, thorium and uranium concentrations in soil/sediment that are slightly in excess of background were noted outside of the Shieldalloy property boundaries in an area known as the Hudson's Branch Watershed. The most likely mechanism for transport of these radioactive materials outside of the property boundaries was through physical migration by way of storm water runoff, rather than movement through the groundwater. The Department 111 bag house (during silo-

[1] The Department 111 bag house contains low-concentration radioactive materials. The bag house silo is emptied periodically, and its contents are transported by open vehicle to the "lime pile", which is located in the southwestern corner of the storage yard. Fugitive emissions from this transfer operation may be the source of the elevated surface soil count rates identified in this area.

emptying operations) and the lime pile in the storage yard are considered to be the likely sources of physical migration of radioactive materials into the Hudson's Branch.

Shieldalloy intends to perform a feasibility study for remediation of the Hudson's Branch. As part of that effort, a baseline assessment of the radiological risk to members of the general population from the materials which currently exist in the Hudson's Branch was performed. This document contains a description of the approach and results of the risk assessment, and will form the basis for evaluating corrective measures for the Hudson's Branch.

APPROACH

The basic approach to completion of the baseline radiological risk assessment for the Hudson's Branch was to first identify the radioactive constituents of potential concern. The second step was to characterize the exposure setting and identify exposure pathways. The concentrations of contaminants at potential exposure points were assessed for both present and future time intervals. For the present time, direct measurements of radionuclide concentrations in soil, as reflected in the site characterization report, were used to determine exposure point concentrations. Environmental transport models were used to predict future concentrations.

After the pathways were identified and the radionuclide fate and transport were determined, a radiation dose assessment was performed. For this effort, the methodologies contained in "A Manual for Implementing Residual Radioactive Material Guidelines" (ANL 1989) were used to provide radiation dose estimates from radionuclides contained in soil and groundwater. To estimate the potential risks to humans from the calculated doses, the methods promulgated by the National Council on Radiological Protection and Measurement (NCRP) were used (NCRP 1987). For this report, risk is defined as the annual or lifetime probability of the development of fatal cancer from exposure to ionizing radiation, and is estimated by:

$$Risk = (D)\ (CF)$$

where D = the dose received by the maximally-exposed individual, and CF = a conversion factor based upon the linear, no-threshold hypothesis. The conversion factor that was used for this assessment is 1.25×10^{-4} fatal cancers per rem of radiation dose equivalent (NCRP 1987).

The final step in this risk assessment process was the development of conclusions for the no-action alternative for the radioactive materials in the Hudson's Branch. The remainder of this document contains the results of the risk assessment, including a description of the radionuclides of potential concern and their concentrations, a description and results of the dose assessment, an evaluation of risks, and a discussion of the uncertainties which are associated with the dose and risk assessment.

IDENTIFICATION OF RADIONUCLIDES

The assessment of potential human health risks associated with any site first requires identification of the contaminants of potential concern. The radionuclides identified in the Newfield site characterization report (IT 1992) are considered to be contaminants of potential concern under current and future land-use conditions for the Hudson's Branch Watershed. These contaminants are Thorium-232, Uranium-238, and Radium-226. However, the types and concentrations of contaminants used for this assessment are based on conditions as they existed during the 1991 sampling effort, with the effect of future releases not considered.

Contaminant Concentrations

The concentrations of thorium, uranium and radium in soil in and around the Hudson's Branch were measured and reported in the site characterization report (IT 1992), and are summarized in Table 1.[2] These data were used to develop a "mean concentration" for input into the dose and risk assessment.

Figure 3 depicts the frequency distribution of these data, which shows that the measured results cannot be adequately represented by a symmetric normal distribution. The data are actually skewed (asymmetrical) such that a log-normal distribution appears to be more a reasonable approximation of the true distribution.[3] Therefore, the mean concentration is estimated by:

$$Mean = \exp\left(\bar{y} + \frac{s^2}{2}\right)$$

where y = the arithmetic mean of transformed values where $y_i = \ln x_i$, and s = the variance.[4] Table 2 shows the mean concentrations for each contaminant of potential concern in the Hudson's Branch.

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[2] Figure 2 contains a map showing the grid locations referenced in Table 1. See (IT 1992) for specific information on radionuclide locations at each sampling location.

[3] Log-normal distributions of data are not untypical for environmental media (Horton 1980, Pinder 1975, McLendon 1975).

[4] Since runoff is a likely mechanism by which the radionuclides migrate, the range of their concentrations at various locations within the Hudson's Branch and at various times of the year is also assumed to be log-normally distributed about some mean value.

Evaluation of Background

The term "background" refers to the average level of radioactivity that would be present in the Hudson's Branch if the Shieldalloy operation had never existed. The site characterization report (IT 1992) contains soil concentrations for background locations that were similar to and representative of the Hudson's Branch. Table 3 shows a summary of those results.[5] Unlike the soil concentrations measured in the Hudson's Branch, the background concentrations do not follow an obvious geometric distribution. Therefore, for the purposes of this assessment, it is assumed that the range of background values at various locations and at various times of the year are normally distributed about some mean value.

The concentrations of radioactive materials in the Hudson's Branch that were used as input to the dose assessment were determined by subtracting the mean background concentration for each of the radionuclides of interest (Table 3) from the mean measured concentration in the Hudson's Branch (Table 2). The results are shown in Table 4.

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[5] See (IT 1992) for an explanation of the grid locations shown in Table 3.

DOSE ASSESSMENT

The general procedure for conducting the radiation dose assessment from radionuclides present in the Hudson's Branch Watershed consisted of the following:

- Characterization of the exposure settings;
- Identification of the exposure pathways; and
- Estimation of potential human intake of radionuclides and assessment of radiation dose equivalent.

Characterization of Exposure Settings

The majority of the Shieldalloy site is in active industrial use. Access to the industrial portion is controlled by a chain-link fence topped with barbed wire, a gate entrance, and a guard. The remainder of the property is undeveloped and has unrestricted access. However, there are currently no residents within approximately 50 yards of the property boundary.

The Hudson's Branch Watershed is located southwest of the Shieldalloy plant, and crosses the property boundary in an area that has unrestricted access. During the 1991 walk-over survey of the area, elevated surface count rates were noted only in the immediate vicinity of the Hudson's Branch. Outside of this small area, surface count rates and soil concentrations did not differ from background. Therefore, for this assessment, it was assumed that the soil area of interest is represented by a 135 m^2 land area, which was the area of interest for the site characterization report (IT 1992).

The city of Vineland has designated certain areas of the city as aquifer exclusion zones, requiring mandatory connection with public water systems and sealing of domestic and supply wells. However, residents located outside of this well restriction, primarily to the south of the Shieldalloy site, may use private wells as a potable drinking water source (TRC 1992). Therefore, both soil and groundwater are considered to be possible sources of human exposure to ionizing radiation from contaminants in the Hudson's Branch.

Identification of Exposure Pathways

Dose estimates for this assessment were based on a "farm family" scenario. In this scenario, a family is assumed to move onto 135 m^2 of property in the Hudson's Branch. Even though it is physically impossible for such a small land area to support a dwelling, livestock, and crops, it is assumed that the family builds a home, and raises crops and livestock for family

consumption. Consequently, these family members may incur a radiation dose by the following pathways:

- Direct radiation from radionuclides in the soil;
- Inhalation of re-suspended dust;
- Ingestion of food from crops grown in the contaminated soil;
- Ingestion of milk from livestock raised in the contaminated area;
- Ingestion of meat from livestock raised in the contaminated area;
- Ingestion of fish from a nearby (hypothetical) pond contaminated by water percolating through the contaminated zone; and
- Ingestion of water from a (hypothetical) well contaminated by water percolating through the contaminated zone.

The basis for selection of a resident farm family as the critical population for this dose assessment is that exposure of permanent residents is long-term in nature, generally involves a greater number of exposure pathways than for non-residents,[6] and results in a higher estimate of radiation dose.

Radiation Dose Assessment
To assess radiation dose to members of the hypothetical farm family, it was assumed that the entire area of the Hudson's Branch (135 m^2) is evenly contaminated with radioactive materials at the concentrations shown in Table 4. The computer code entitled RESRAD (ANL 1989) was used to model radionuclide fate and transport, and to assess the committed dose equivalent from these contaminants.

In the code, the concentrations in soil are assumed to decrease with time due to radioactive decay and leaching of the radionuclides into the subsurface soils and subsequently into the

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[6] The non-resident group most likely to receive exposure from radioactive materials contained in the Hudson's Branch consists of "scavengers". While scavenging can occur, this is not considered to be a likely scenario considering the lack of economic value of the contaminated materials in the Hudson's Branch. Furthermore, the exposure of scavengers is much smaller than that of a hypothetical permanent resident since the scavenger will spend less time at the Hudson's Branch than the resident.

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regional aquifer. Dose calculations were performed for a period of time starting at initial placement of the material (t=0 years) and ending 1000 years later.[7]

Concentrations of radionuclides in food crops and forage were calculated by multiplying a single soil-to-vegetable transfer factor for each stable element by the calculated concentration in soil over time. Radionuclide concentrations in beef and milk were calculated by multiplying elemental transfer factors for forage-to-milk and forage-to-beef by the concentration in forage and the daily consumption rate of forage by cows.

External radiation doses from soil were calculated by assuming continuous occupancy. In addition, the receptor (farm family member) is assumed to be located at the center of a cylindrical waste area of 135 m^2, and that no shielding exists between the contaminated soil and the receptor.

In general, the input parameters to the RESRAD code, including Dose Conversion Factors, were selected from the RESRAD default values. Appendix A contains a listing of those parameters, and Appendix B contains a listing of the RESRAD pathways considered for this analysis.

Figure 4 shows the total dose to a member of the farm family for all radionuclides in the Hudson's Branch and all exposure pathways. The maximum dose of 14.18 millirem per year occurs within the first year after initial deposition of the radioactive materials in the Hudson's Branch.[8]

Table 5 shows the relative contribution of the various exposure pathways to the total dose. The majority of the dose (89%) received in the first year is attributed to external radiation exposure. However, it is important to note that the <u>maximum measured</u> exposure rate above background in the Hudson's Branch was 9 millirem per year (IT 1992).[9] The <u>average</u>

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7 Even though active surveillance measures by Shieldalloy to prevent residency on the Hudson's Branch are likely to remain in effect for at least 50 years, and that it is not likely a family will build a house in a flood plain, it is nonetheless assumed that the farm family occupies the site at t=0, and that each member lives on or adjacent to the contaminated soil for 50 years.

8 For comparison, the environmental radiological dose standard promulgated by the U. S. Nuclear Regulatory Commission is 100 millirem per year (NRC 1991). The standard promulgated by the U. S. Environmental Protection Agency (EPA 1991) is 25 millirem per year.

9 Walkover survey measurements at a height of one meter above the ground surface revealed a maximum of 67 mR per year, and the average background for the Newfield area was 58 mR per year, for a net value of 9 mR per year.

measured dose rate did not differ significantly from background.[10] Therefore, the dose estimate produced by the RESRAD code is clearly conservative.

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[10] Walkover survey measurements at a height of one meter above the ground surface revealed an average of 41.5 mR per year, which does not differ significantly from the average background for the Newfield area of 58 mR per year.

RISK ASSESSMENT

The principal adverse biological effects associated with ionizing radiation exposure from radioactive substances in the environment are carcinogenicity, mutagenicity, and teratogenicity.[11] Radiation may induce other deleterious effects at acute doses in excess of 100 rem (100,000 millirem), but doses of this magnitude are seldom associated with environmental radioactivity. Therefore, the basis for assessing the radiation-related human health risks for the hypothetical farm family in the Hudson's Branch is a risk factor for fatal cancers of 1.25×10^{-4} per rem (CEDE) of ionizing radiation (NCRP 1987).

For this assessment, the cancer risk attributed to exposure to radionuclides in the Hudson's Branch is estimated by multiplying the maximum total dose for all radionuclides in a particular pathway by the risk factor for fatal cancer of 1.25×10^{-4} per rem. The total risk from all pathways, based upon the maximum total risk value of 14.18 millirem per year at year t=0 is:

$$Risk = 14.18 \frac{mrem}{year} \times \frac{1\ rem}{1000\ mrem} \times 1.25x10^{-4} \frac{fatal\ cancers}{rem} = 1.77x10^{-6} \frac{fatal\ cancers}{year}$$

It is important to note that this rate only occurs at the time of initial placement of radioactive materials in the Hudson's Branch. The dose rate, and thus the risk rate, decreases with time. For comparison, the following is the risk estimate to an average member of the United States population from annual background radiation exposure:

$$Risk = 380 \frac{mrem}{year} \times \frac{1\ rem}{1000\ mrem} \times 1.25x10^{-4} \frac{fatal\ cancers}{rem} = 4.75x10^{-5} \frac{fatal\ cancers}{year}$$

Thus the hypothetical farm family's risk of fatal cancer associated with normal background radiation exposure is approximately 27 times greater than the risk associated with the radioactive materials in the Hudson's Branch.

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[11] Carcinogenicity is the ability to produce cancer. Mutagenicity is the property of being able to induce genetic mutation which may be in the nucleus of either body cells or reproductive cells. Teratogenicity refers to the ability of an agent to induce or increase the incidence of congenital malformations as a result of the permanent structure or functional deviations produced during the growth and development of the embryo.

UNCERTAINTY ANALYSIS

Uncertainties in the Assessment of Dose

Uncertainties associated with the dose assessment portion of this effort include those related to fate and transport modeling, the characterization of radiological constituents in the Hudson's Branch, and exposure parameters. A summary of the sources of uncertainty is contained in Table 6.

Uncertainties in the Assessment of Risk

Numerous references provide numeric estimates of the risk of fatal cancer induction from ionizing radiation. These are generally a function of CEDE, dose to a single organ, whole body dose, duration of exposure, or quantity of radioactive material ingested or inhaled. For this assessment, however, a single factor for lifetime risk of fatal cancer as a function of CEDE was selected. It was felt that the greater accuracy attributed to the use of multiple factors for specific exposure routes would be masked by the magnitude of the other uncertainties in estimating human intake of radionuclides.

The risk factor used for this assessment assumes full expression of cancer risk (which is unlikely to occur from exposure received late in life) and that the farm family "population" is normally distributed over age and sex. In other words, the risk factor used is an average for both sexes and for a normal population distribution between 18 and 60 years of age (NCRP 1987).

SUMMARY AND CONCLUSIONS

A recent site characterization effort at Shieldalloy Metallurgical Corporation's Newfield facility revealed the presence of radioactive materials outside of the Shieldalloy controlled area, in the Hudson's Branch Watershed. In order to guide remedial action decisions, a baseline assessment of the radiological risk from the materials which currently exist in the Hudson's Branch was performed. In general, the risk assessment was based on the methodologies contained in Gilbert, T. L., et al, "A Manual for Implementing Residual Radioactive Material Guidelines" (ANL 1989) and on cancer risk coefficients based on the recommendations of the NCRP (NCRP 1987).

The maximum radiation dose rate to a resident farm family as a result of the thorium, radium, and uranium which currently exists in the Hudson's Branch is 14.18 millirem per year, which occurs at the time of initial placement of the materials. The dose rate drops steadily thereafter, to a rate of less than 5 millirem per year after year 70. The risk of fatal cancer is 1.77×10^{-6} at the time of initial placement. This can be compared to a risk of 4.75×10^{-5} incurred by an average member of the United States population from annual background radiation exposure. The risk of fatal cancers to individuals who may frequent areas of the Hudson's Branch <u>outside</u> of the 135 m^2 area of interest is virtually zero.

There are a number of uncertainties associated with this assessment. In particular, the assumptions used in this baseline radiological risk assessment were clearly conservative. The following are examples of those assumptions which are likely to lead to over-estimations of the dose:

- Assuming a "farm family" scenario, even though it is not likely that a family would build a house directly within this flood plain.
- Assuming the soil area of interest was 135 m^2, even though it is not possible to support a farm family on this small plot of land.
- Assuming the contaminant level was assumed to be homogeneous, even though this is not supported by the walk-over survey data or the soil sampling results.

The true risk to a farm family member is likely to be significantly less than the exaggerated risk of 1.77×10^{-6} based upon these conservative assumptions. Consequently, if no remedial actions are taken, the human health risks associated with the radioactive materials which exist in the Hudson's Branch are acceptable.

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TABLE 1: RADIONUCLIDE CONCENTRATIONS IN SOIL

Grid Location	U-238 (pCi/g)	Th-232 (pCi/g)	Ra-226 (pCi/g)
0+10,10L	5.65	5.1	21
-0+10,10L	5.65	--	21
-0+20	1.75	3.17	0.8
-0+30	4.20	--	3.1
-0+50	1.36	1.94	1.6
-0+50(QC)	1.63	9.56	14
-0+60	3.14	3.41	19
-0+90	2.10	2.61	17
-3+50(QC)	1.63	--	14
0+20	2.57	1.38	2.4
0+30,10L	0.96	1.11	0.7
0+100 10L	5.71	8.86	34
1+10,10R	1.92	2.34	4.7
1+20	--	2.63	7.0
1+50,10R	1.27	1.56	2.1
1+80,10R	0.89	1.62	1.9
1+80L,10L	1.18	1.97	0.6
1+100,10L	2.55	--	12
2+20,10R	2.67	2.93	<1.4
2+30,10R	2.37	4.11	12
2+60,10L	1.10	1.31	0.5
2+70	2.25	3.73	11
2+80,10L	1.03	1.11	0.4
2+90,10L	0.77	1.68	0.6
3+80,10R (QC)	1.38	1.51	8.1

TABLE 2: CONTAMINANT CONCENTRATIONS

Radionuclide	**Mean Concentration in the Hudson's Branch (pCi/g)**
Thorium-232 Concentration in Soil	2.47
Uranium-238 Concentration in Soil	1.95
Radium-226 Concentration in Soil	4.17

TABLE 3: BACKGROUND RADIONUCLIDE CONCENTRATIONS

Grid Location:	Radionuclide Concentration in Soil		
	Th-232 (pCi/gram)	Ra-226 (pCi/gram)	U-238 (pCi/gram)
ORAU 1	0.3	0.5	1.3
ORAU 2	0.5	0.4	<0.4
ORAU 3	0.1	0.3	0.3
ORAU 4	0.1	0.2	<0.3
ORAU 5	0.4	0.7	<0.4
ORAU 6	0.5	0.9	0.4
ORAU 7	0.6	0.5	0.8
ENSR 1	1.48	0.6	0.83
ENSR 2	0.28	1.0	1.38
ENSR 3	1.91	0.82	1.37
ENSR 4	1.68	< 0.5	0.92
ENSR 5	1.19	0.85	1.04
ENSR 6	1.35	0.81	0.42
Mean $\pm$ σ	0.8 $\pm$ 0.6	0.6 $\pm$ 0.3	0.8 $\pm$ 0.4

TABLE 4: CONTAMINANT CONCENTRATIONS USED FOR THE RISK ASSESSMENT

Radionuclide	*Net Concentration in Soil (pCi/g)*
Thorium-232	*1.67*
Uranium-238	*1.14*
Radium-226	*3.57*

TABLE 5: FRACTION OF TOTAL DOSE IN YEAR ONE AFTER DEPOSITION

Pathway	**Fraction**
Ground	0.8926
Inhalation of Dust	0.0788
Radon	0.0044
Plant	0.0219
Meat	0.0001
Milk	0.0000
Soil	0.0021
Water	0.0000
Fish (Water-dependent pathway)	0.0000
Radon (Water-dependent pathway)	0.0000
Plant (Water-dependent pathway)	0.0000
Meat (Water-dependent pathway)	0.0000
Milk (Water-dependent pathway)	0.0000

TABLE 6: UNCERTAINTIES IN THE DOSE ASSESSMENT

Uncertainty	Effect on the Estimate of Risk (Low, Moderate, High)*
SITE CHARACTERIZATION:	
Sufficient numbers of samples were not taken to fully characterize the media being evaluated	High potential for over- or under-estimation of exposure
Surface soil samples used in the characterization of the Hudson's Branch were biased in that sample locations were selected based on high count rates on survey equipment	Low potential for over-estimation of exposure
EXPOSURE PARAMETER ESTIMATION:	
The contaminated ground surface was greater than 135 m^2 in area	High potential for over-estimation of exposure.
The standard assumptions regarding body weight, periods exposed, rates of intake, life span, etc. may not be representative of any actual exposure population	Low potential for over- or under-estimation of exposure
Use of conservative dose conversion factors to model radionuclide dose	Low potential for over-estimation of exposure
FATE AND TRANSPORT MODELING:	
All of the soil contained in the Hudson's Branch is assumed to be from a single, evenly-contaminated source	Moderate potential for over-estimation of exposure
Child is assumed to ingest soil for 274 days per year	High potential for over-estimation of exposure

Concentrations selected for soil assumed a normal distribution of sample concentrations about a mean value. The distribution of sample concentrations were not symmetrical around the mean, but highly skewed	Moderate potential for over-estimation of exposure
Assumption that the regional aquifer is homogeneous in composition	Low potential for over- or under-estimation of exposure
Selection of seepage velocities for the movement through the unsaturated soil into the aquifer	Low potential for over- or under-estimation of exposure
Assumption of a constant infiltration rate into the aquifer	Low potential for over- or under-estimation of exposure
Estimates of leachate concentration for groundwater transport	High potential for over- or under-estimation of exposure
Assumptions on the chemical and physical forms of contaminants and their effect on movement via groundwater	Moderate potential for over- or under-estimation of the arrival time at the receptor

- Low = could effect estimation of intake by less than one order of magnitude; Moderate = Could effect estimate of intake from one to two orders of magnitude; and High = Could effect estimation of intake by greater than two orders of magnitude.

FIGURE 1: Location of the Newfield Plant

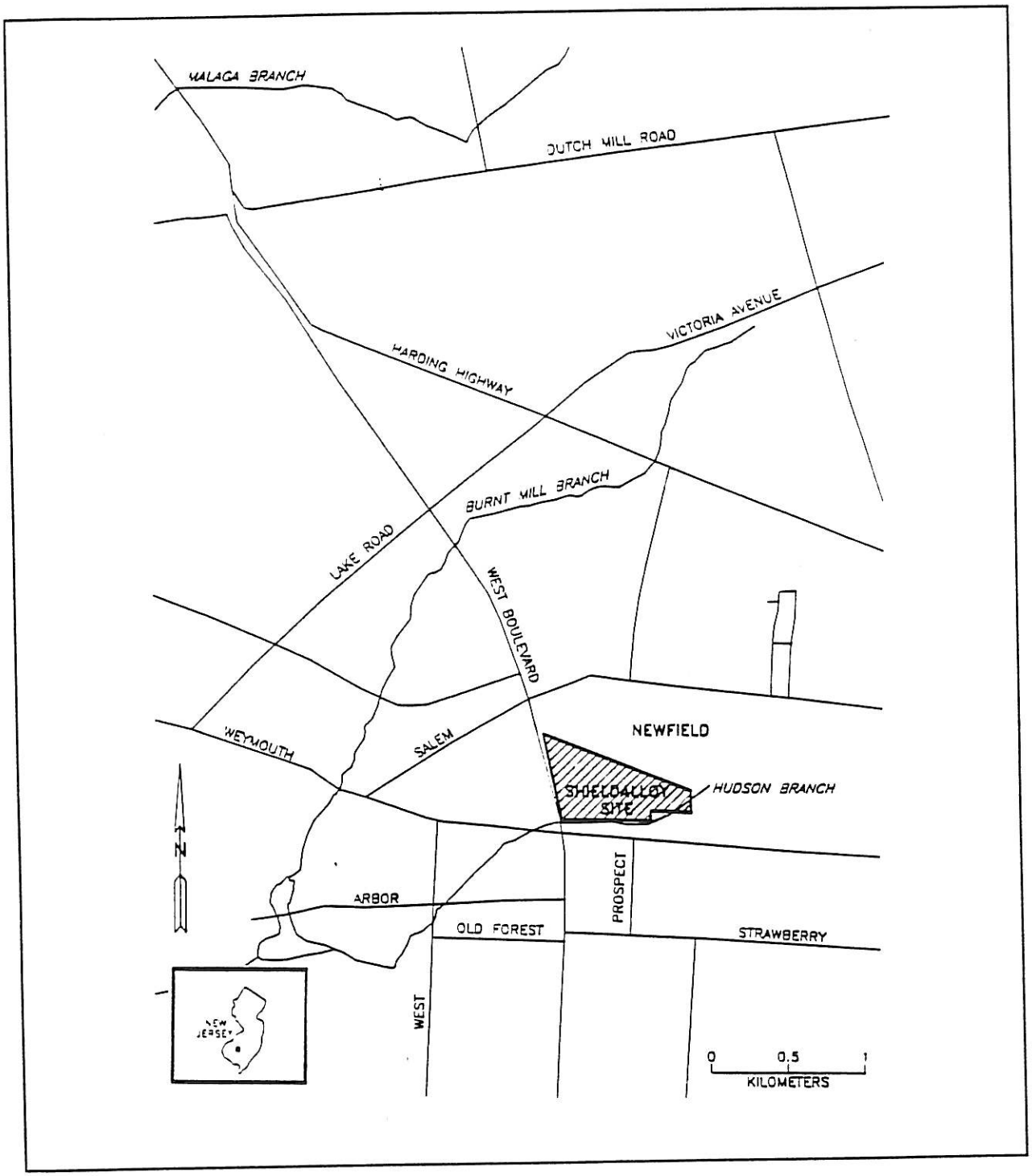


FIGURE 2: Grid Locations in the Hudson's Branch

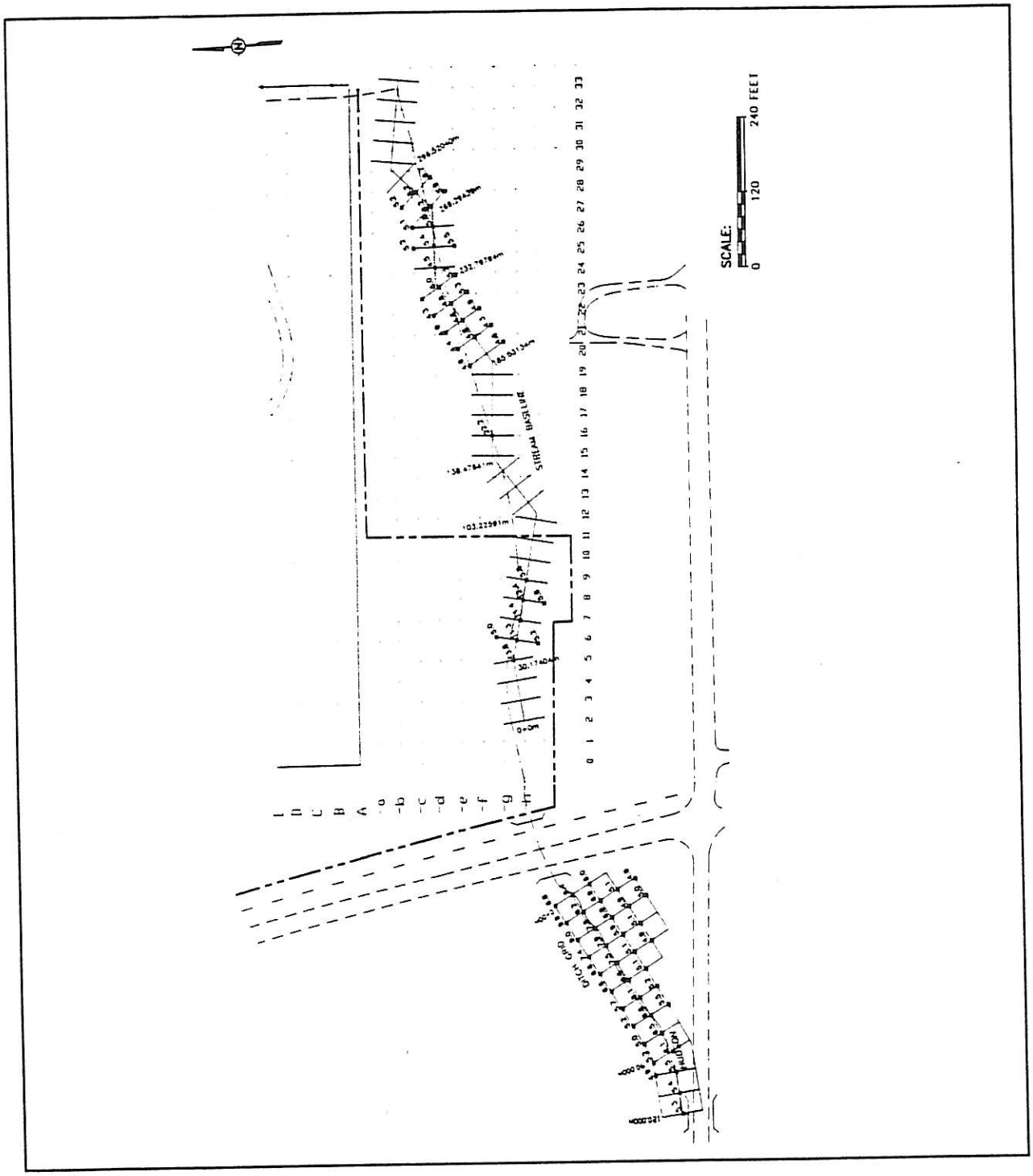


FIGURE 3: Frequency Distribution of Soil Concentrations

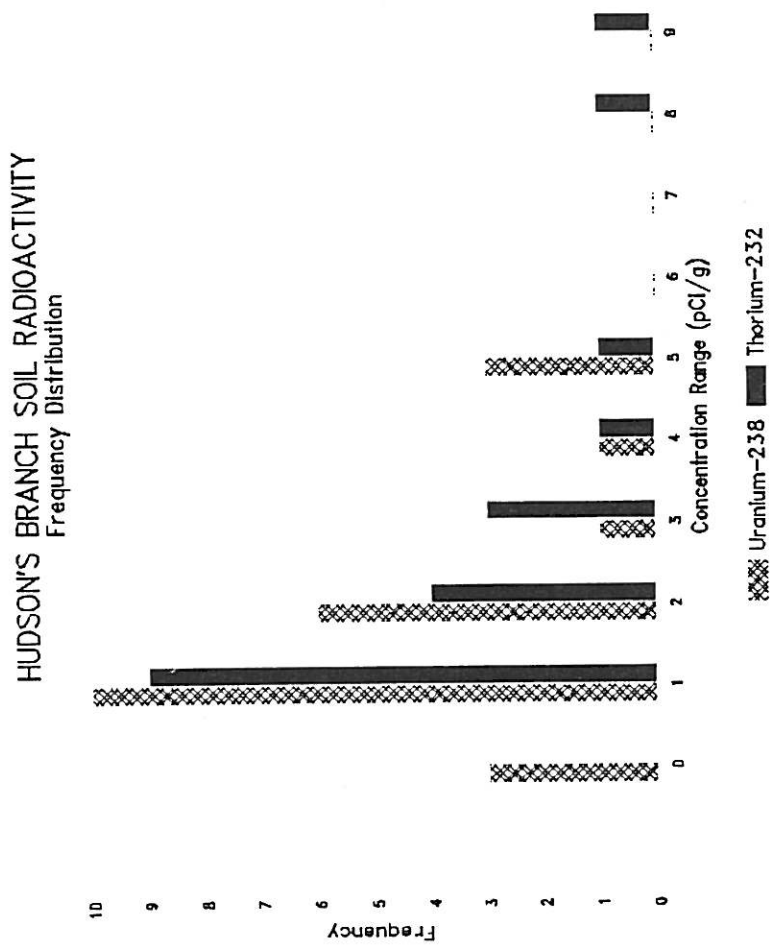
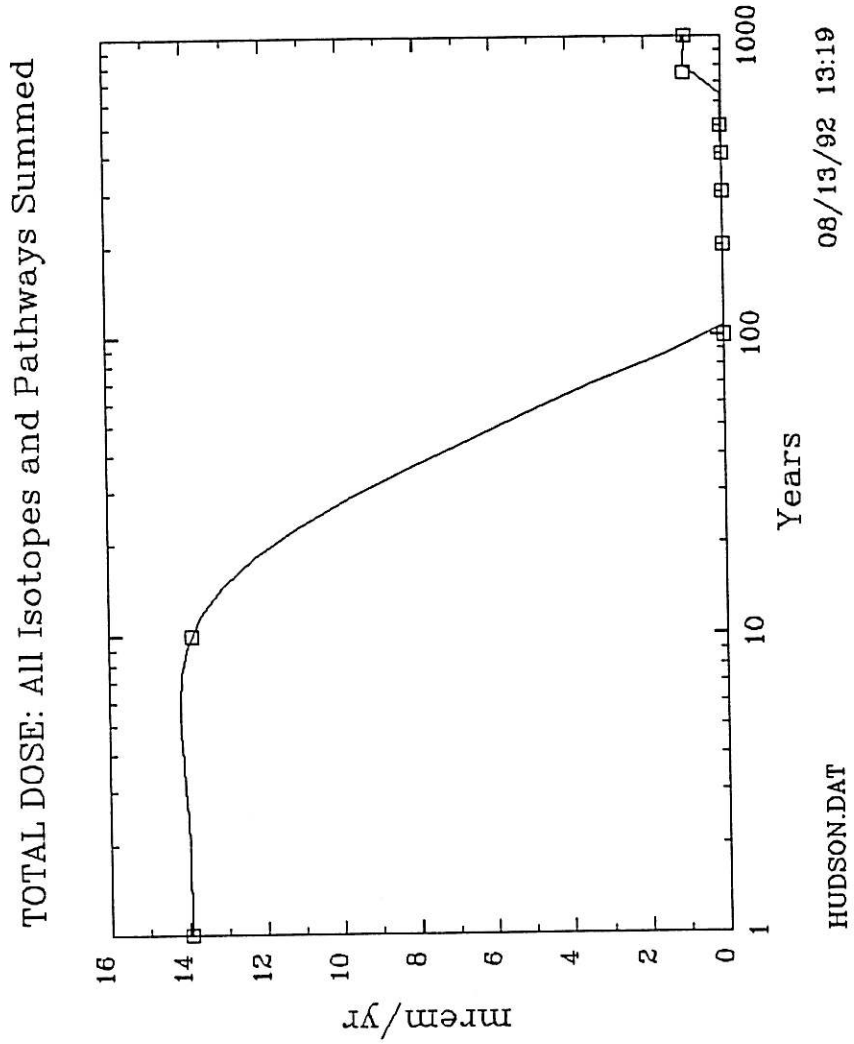


FIGURE 4: Total Dose from Radioactive Materials in the Hudson's Branch



APPENDIX A: PARAMETER VALUES USED FOR THE DOSE ASSESSMENT

Parameter	Input Value
Area of contaminated zone (m^2)	1.350E+02
Thickness of contaminated zone (m)	1.000E-01
Length parallel to aquifer flow (m)	1.000E+02
Basic radiation dose limit (mrem/yr)	1.000E+02
Time since placement of material (yr)	0.000E+00
Initial principal radionuclide (pCi/g ^{226}Ra)	3.570E+00
Initial principal radionuclide (pCi/g^{232}Th)	1.670E+00
Initial principal radionuclide (pCi/g ^{238}U)	2.320E+00
Cover depth (m)	0.000E+00
Density of contaminated zone (g/cm^3)	1.600E+00
Contaminated zone erosion rate (m/yr)	1.000E-03
Contaminated zone total porosity	4.000E-01
Contaminated zone effective porosity	1.000E-01
Contaminated zone hydraulic conductivity (m/yr)	1.000E+01
Contaminated zone b parameter	5.300E+00
Evapotranspiration coefficient	6.000E-01
Precipitation (m/yr)	1.000E+00
Irrigation (m/yr)	1.000E-01
Irrigation mode	Overhead
Runoff coefficient	2.000E-01
Watershed area for nearby stream or pond (m^2)	1.000E+06
Density of saturated zone (g/cm^3)	1.600E+00
Saturated zone total porosity	4.000E-01
Saturated zone effective porosity	2.000E-01
Saturated zone hydraulic conductivity (m/yr)	1.000E+02
Saturated zone hydraulic gradient	2.000E-02

Saturated zone b parameter	5.300E+00
Water table drop rate (m/yr)	1.000E-03
Well pump intake depth (m below water table)	1.000E+01
Model: Nondispersion (ND) or Mass Balance (MB)	ND
Individual's use of groundwater (m^3/yr)	1.500E+02
Number of unsaturated zone strata	1
Unsaturated zone 1, thickness (m)	4.000E+00
Unsaturated zone 1, soil density (g/cm^3)	1.600E+00
Unsaturated zone 1, total porosity	4.000E-01
Unsaturated zone 1, effective porosity	2.000E-01
Unsaturated zone 1, soil-specific b parameter	5.300E+00
Unsaturated zone 1, hydraulic conductivity (m/yr)	1.000E+02
Distribution coefficients for Ra-226:	
Contaminated zone (cm^3/g)	7.000E+01
Unsaturated zone 1 (cm^3/g)	7.000E+01
Saturated zone (cm^3/g)	7.000E+01
Leach rate (per year)	0.000E+00
Distribution coefficients for Th-232:	
Contaminated zone (cm^3/g)	6.000E+04
Unsaturated zone 1 (cm^3/g)	6.000E+04
Saturated zone (cm^3/g)	6.000E+04
Leach rate (per year)	0.000E+00
Distribution coefficients for U-238:	
Contaminated zone (cm^3/g)	5.000E+01
Unsaturated zone 1 (cm^3/g)	5.000E+01
Saturated zone (cm^3/g)	5.000E+01
Leach rate (per year)	0.000E+00
Distribution coefficients for daughter Pb-210:	
Contaminated zone (cm^3/g)	1.000E+02

Unsaturated zone 1 (cm^3/g)	1.000E+02
Saturated zone (cm^3/g)	1.000E+02
Leach rate (per year)	0.000E+00
Distribution coefficients for daughter Ra-228:	
Contaminated zone (cm^3/g)	7.000E+01
Unsaturated zone 1 (cm^3/g)	7.000E+01
Saturated zone (cm^3/g)	7.000E+01
Leach rate (per year)	0.000E+00
Distribution coefficients for daughter Th-228:	
Contaminated zone (cm^3/g)	6.000E+04
Unsaturated zone 1 (cm^3/g)	6.000E+04
Saturated zone (cm^3/g)	6.000E+04
Leach rate (per year)	0.000E+00
Distribution coefficients for daughter Th-230:	
Contaminated zone (cm^3/g)	6.000E+04
Unsaturated zone 1 (cm^3/g)	6.000E+04
Saturated zone (cm^3/g)	6.000E+04
Leach rate (per year)	0.000E+00
Distribution coefficients for daughter U-234:	
Contaminated zone (cm^3/g)	5.000E+01
Unsaturated zone 1 (cm^3/g)	5.000E+01
Saturated zone (cm^3/g)	5.000E+01
Leach rate (per year)	0.000E+00

Inhalation rate (m^3/yr)	8.400E+03
Mass loading for inhalation (g/m^3)	2.000E-04
Dilution length for airborne dust, inhalation (m)	3.000E+00
Occupancy factor, inhalation	4.500E-01
Occupancy and shielding factor, external gamma	6.000E-01
Shape factor, external gamma	1.000E+00

Fruits, vegetables and grain consumption (kg/yr)	1.600E+02
Leafy vegetable consumption (kg/yr)	1.400E+01
Milk consumption (l/yr)	9.200E+01
Meat and poultry consumption (kg/yr)	6.300E+01
Fish consumption (kg/yr)	5.400E+00
Other seafood consumption (kg/yr)	9.000E-01
Soil ingestion rate (g/yr)	3.650E+01
Drinking water intake (l/yr)	4.100E+02
Fraction of drinking water from site	1.000E+00
Fraction of aquatic food from site	5.000E-01
Livestock fodder intake for meat (kg/day)	6.800E+01
Livestock fodder intake for milk (kg/day)	5.500E+01
Livestock water intake for meat (l/day)	5.000E+01
Livestock water intake for milk (l/day)	1.600E+02
Mass loading for foliar deposition (g/m^3)	1.000E-04
Depth of soil mixing layer (m)	1.500E-01
Depth of roots (m)	9.000E-01
Drinking water fraction from ground water	1.000E+00
Livestock water fraction from ground water	1.000E+00
Irrigation fraction from ground water	1.000E+01
Total porosity of the building foundation	1.000E-01
Volumetric water content of the foundation	1.000E-02
Diffusion coefficient for radon gas (m/sec):	
In foundation material	2.000E-08
In contaminated zone soil	2.000E-06
Radon vertical dimension of mixing (m)	2.000E+00
Average annual wind speed (m/sec)	2.000E+00
Average building air exchange rate (l/hr)	1.000E+00
Height of the building (room) (m)	2.500E+00

Building interior area factor	1.000E+00
Bulk density of building foundation (g/cm^3)	2.400E+00
Thickness of building foundation (m)	1.500E-01
Building depth below ground surface (m)	1.000E+00
Fraction of time spent indoors	5.000E-01
Fraction of time spent outdoors (on site)	2.000E-01
Emanating power of Rn-222 gas	2.000E-01
Emanating power of Rn-220 gas	1.000E-01

APPENDIX B: RESRAD PATHWAY SELECTIONS

RESRAD Pathway	Selection Status
External gamma	Active
Inhalation	Active
Plant ingestion	Active
Meat Ingestion	Active
Milk Ingestion	Active
Aquatic foods	Active
Drinking water	Active
Radon	Active
Soil ingestion	Active