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MAXINE: A SPREADSHEET FOR ESTIMATING DOSE FROM CHRONIC ATMOSPHERIC RADIOACTIVE RELEASES

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August 2002

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ABSTRACT

MAXINE is an EXCEL© spreadsheet, which is used to estimate dose to individuals for routine atmospheric releases of radioactive materials. MAXINE does not contain an atmospheric dispersion model, but rather doses are estimated using air and ground concentrations as input. Minimal input is required to run the program and site specific parameters are used when possible. Complete code description, verification of models, and user's manual have been included.

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MAXINE: A SPREADSHEET FOR ESTIMATING MAXIMUM INDIVIDUAL DOSE FROM CHRONIC ATMOSPHERIC RADIOACTIVE RELEASES

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1. INTRODUCTION

MAXINE is an EXCEL© spreadsheet that estimates dose to exposed individuals following routine releases of radioactive materials to the atmosphere. MAXINE employs the methods contained in MAXDOSE-SR (Simpkins 1999). Both MAXINE and MAXDOSE-SR follow U.S. Nuclear Regulatory Commission Regulatory (U.S. NRC) Guide 1.109 (USNRC 1977a) which details how to estimate dose from routine releases. For specified air and ground concentrations, MAXINE will determine the potential dose to exposed individuals. Exposure pathways include 1) inhalation; 2) ground and plume shine; and 3) ingestion of meat, milk, and vegetables.

Verification of MAXINE includes comparisons with the verified code MAXDOSE-SR as well as hand calculations. A complete description of the spreadsheet and user's manual have also been included. The spreadsheet version is useful in the fact that it allows for the determination of dose at distances other than the site boundary. Also, it is convenient for use with uncertainty software such as Crystal Ball©.

2. METHODOLOGY

The methodology basis for the dosimetry portion of MAXDOSE-SR and MAXINE is the GASPAR code (Eckerman et. al. 1980) which was written in 1977 by Oak Ridge National Laboratory for the U. S. NRC. The models in GASPAR calculate atmospheric concentrations, deposition rates, concentrations in foodstuffs, and radiation dose to individuals resulting from chronic releases of radionuclides to the atmosphere.

MAXINE needs the following relative air and ground deposition values for proper execution of the spreadsheet: 1) relative air concentration, χ/Q; 2) relative air concentration decayed by 2.26 days, χ_D/Q; 3) relative air concentration decayed and depleted for 8 days, χ_{DD}/Q; and 4) relative deposition, D/Q. These can all be taken from MAXDOSE-SR output or derived using the methodologies contained within U.S. NRC Regulatory Guide 1.111 (USNRC 1977b). These concentrations are used to calculate concentrations in various media and ultimately dose. Concentrations in various media are determined differently based on the radionuclide of interest. The following discusses how the concentration in each media is estimated.

2.1. Nuclide Concentrations In The Atmosphere

2.1.1. Tritium and Carbon-14

Downwind atmospheric concentrations, χ_i, of tritium and carbon-14 are estimated using

$$\chi_i = \frac{\chi}{Q} \bullet Q_i \bullet 10^6 \frac{\mu Ci}{Ci} \bullet 3.17x10^{-8} \frac{yr}{s} \quad (1)$$

where

χ_i air concentration, μCi/m^3

$\frac{\chi}{Q}$ relative air concentration, s/m^3

Q_i release amount by radionuclide, Ci/yr

Since both tritium and carbon-14 have relatively long half-lives, radiological decay is not taken into account when estimating downwind concentration for these nuclides.

2.1.2. Noble Gases

Air concentrations of noble gases are estimated by,

$$\chi_i = \frac{\chi}{Q} \bullet Q_i \bullet 10^6 \bullet 3.17x10^{-8} \frac{yr}{s} \bullet e^{-\lambda_i t} \quad (2)$$

where the exponential accounts for radioactive decay during transit to the receptor. The parameter t is the average time required for the effluent to reach the receptor and all other terms have been previously defined. The decayed χ /Q is obtained by assuming the effluent is radioactive with a half-life of 2.26 days (USNRC 1977b). The value of t is found by solving the radioactive decay equation used to calculate a 2.26-day decayed relative air concentration,

$$\frac{\chi_D}{Q} = \frac{\chi}{Q} e^{-(112 yr^{-1})t} \quad (3)$$

where the value 112 yr^{-1} is the decay constant for a 2.26 day half-life. The plume travel time (in years) is then,

$$t = \frac{\ln\left(\dfrac{\chi_D / Q}{\chi / Q}\right)}{\left(\dfrac{\ln 2 \bullet 365\,d}{2.26\,d \bullet 1yr}\right)} \qquad (4)$$

2.1.3. Radioiodines

Radioiodine concentrations in the atmosphere are determined using,

$$\chi_i = \left\{\frac{\chi}{Q} \bullet (1 - F_I) + \frac{\chi_{DD}}{Q} \bullet F_I \bullet e^{31.62t}\right\} \bullet Q_i \bullet e^{-\lambda_i t} \qquad (5)$$

where

χ/Q relative air concentration, s/m^3

χ_{DD}/Q decayed and depleted concentration, s/m^3

F_I fraction of iodine that is elemental, unitless

The factor in brackets calculates a weighted relative air concentration accounting for the deposition of the elemental fraction. The positive rate coefficient (31.62) negates decay from the generic 8-day half-life that was already applied to the decayed and depleted χ/Q. An exponential term is also included in this equation to account for the actual radioactive decay during plume transit.

2.1.4. Other Nuclides

Air concentrations of the remaining nuclides (those not considered above) are calculated using

$$\chi_i = \frac{\chi_{DD}}{Q} \bullet Q_i \bullet 10^6 \bullet 3.17x10^{-8}\ \frac{yr}{s} \bullet e^{(31.62 - \lambda_i)t} \qquad (6)$$

where all terms have been defined previously. Again, the positive rate coefficient in the exponential term (31.62 yr^{-1}) negates the decay from the 8-day half-life that was already applied to the decayed and depleted χ/Q.

2.2. Deposition

Deposition rates are estimated from relative deposition values based on the type of radionuclide.

2.2.1. Radioiodine

Deposition rates, d_i, of iodine radioisotopes are estimated using,

$$d_i = \frac{D}{Q} \bullet Q_i \bullet F_I \bullet 10^6 \bullet e^{-(31.62-\lambda_i)t} \qquad (7)$$

where

D/Q	relative deposition value, $1/m^2$
Q_i	radionuclide release rate, Ci/yr
F_I	fraction of iodine assumed to be elemental, unitless
λ_i	nuclide-specific decay constant, yr^{-1}
t	plume travel time from the source to the receptor, yr

2.2.2. Other Nuclides.

Deposition rates for all remaining nuclides are determined using

$$d_i = \frac{D}{Q} \bullet Q_i \bullet 10^6 \bullet e^{(31.62-\lambda_i)t} \qquad (8)$$

where all parameters have been previously defined. Deposition is modeled for all radionuclides, except for tritium, carbon-14 and noble gases.

2.3. Nuclide Concentration In Vegetation

2.3.1. Tritium

A specific activity model describes the uptake of tritium in vegetation. Tritium concentration in vegetation is determined directly from the concentration of tritium in atmospheric moisture. Equilibrium is assumed to be achieved in a short time relative to an annual release. The concentration of tritium in vegetation, C_T^V, is determined by

$$C_T^V = \frac{\chi_T \bullet 0.75 \bullet 0.5}{H} \qquad (9)$$

where

C^V_T	concentration in vegetation, µCi/g
χ_T	atmospheric concentration, µCi/m^3
0.75	fraction of plant mass that is water, unitless
0.5	concentration ratio of plant tritium to atmospheric tritium, unitless
H	annual average absolute humidity (11 g/m^3 for SRS) (Hamby 1990)

Studies (Bauer and Hamby 1993, Hamby 1993) have shown that dose estimates for the vegetation consumption pathway are sensitive to the parameters in this model. Therefore, a site-specific value was determined for the plant-tritium-to-atmospheric-tritium model (Hamby and Bauer 1994).

2.3.2. Carbon 14

The carbon-14 model for vegetation concentration is similar to the tritium model. The following equation is used to estimate the concentration:

$$C_C^V = \frac{\chi_c \bullet F_t \bullet 0.11}{0.00016} \qquad (10)$$

where

χ_c	atmospheric concentration, µCi/m^3
F_t	fraction equilibrium ratio
0.11	fraction of total plant mass that is natural carbon, unitless
0.00016	concentration of natural carbon in the atmosphere, unitless

2.3.3. Other Nuclides

The concentration of other nuclides in vegetation is determined using

$$C_i^V = d_i \bullet \left[\frac{r_i(1-e^{-\lambda_i^w t_e})}{Y_V \lambda_i^w} + \frac{B_i^v(1-e^{-\lambda_i t_b})}{P \bullet \lambda_i} \right] \bullet e^{-\lambda_i t_h} \qquad (11)$$

where

d_i	deposition rate, Ci/m^{2}yr

r_i	fraction of the nuclide deposited that remains on the surface of the plant, unitless
λ_i^w	decay constant representing both weathering and radioactive losses, 1/yr
t_e	crop exposure time, yr
Y_v	crop productivity, kg/m^2
B_i^v	element-specific soil/plant uptake ratio, unitless
λ_i	radioactive decay constant, 1/yr
t_b	time over which the buildup of radionuclides occurs, yr
P	surface soil density, kg/m^2
t_h	hold-up time after harvest (allows for decay before consumption), yr

The first and second expressions in the brackets account for contamination via foliar deposition and root uptake, respectively. All particulate nuclides are assumed to be fully retained on vegetation (r=1) while only 20% of the iodines are retained (r=0.2). The loss constant, λ_i^w accounts for losses through physical weathering (14 day half-life) and radioactive decay. Values of Y_v, t_e, and t_h vary depending on the type of crop and whether the vegetation is for human consumption or is to be used as fodder.

Concentrations in four types of vegetation are calculated in MAXINE. These four types along with their associated default parameter values are given in Table 1. These values are taken from Hamby (1991) and USNRC (1977a). Noble gases are assumed not to concentrate or deposit on vegetation.

Table 1. Default Parameters used for Vegetation Concentration Estimates

Parameter	**Other Vegetables**	**Leafy Vegetables**	**Pasture Grass**	**Stored Feed**
r (iodines)	0.2	same	same	same
r (particulates)	1.0	same	same	same
λ_i (yr^{-1})	18.07+λ_i	same	same	same
t_e (yr)	0.192	0.192	0.0822	0.192
Y_v (kg/m^2)	0.7	0.7	1.8	0.7
B_i	element specific	same	same	same
λ_{ι} (yr^{-1})	nuclide specific	same	same	same
t_b (yr)	scenario specific	same	same	same
P (kg/m^2)	240	same	same	same

t_h (yr)	0.164	0.00274	0	0.247

2.4. Nuclide Concentrations In Meat And Milk

Concentrations of radionuclides in meat and milk are determined from feed concentrations, fodder intake rates, and element-specific feed-to-meat/feed-to-milk transfer factors. The equations for meat and milk concentration estimates are essentially identical with the exception of feed transfer coefficient. Concentrations are estimated using,

$$C_i^{meat} = C_i^{fodder} \bullet F_i^b \bullet Q_F \bullet e^{-\lambda_i t_s} \qquad (12)$$

$$C_i^{milk} = C_i^{fodder} \bullet F_i^m \bullet Q_F \bullet e^{-\lambda_i t_f} \qquad (13)$$

where

C_i^{fodder} nuclide concentration in cattle feed (determined below), Ci/kg

F_i^b and F_i^m feed transfer coefficients for beef cow and milk cow, respectively, d/kg or d/l

Q_F cattle feed rate, kg/d

t_s and t_f transport time for meat and milk, respectively, yr

Values for these parameters are listed in Table 2 as taken from Hamby (1991).

The nuclide concentration in fodder is based on the fraction of time cattle spend on pasture and the fraction of that time that is spent consuming fresh pasture grass. The following equation calculates fodder concentration by weighting the concentration of pasture grass and stored feed.

$$C_i^{fodder} = f_p f_s C_i^p + \left[f_p (1 - f_s) + (1 - f_p) \right] C_i^s \qquad (14)$$

C_i^p concentration in pasture grass, Ci/kg

C_i^s concentration in stored feed, Ci/kg

f_p fraction of time cattle spend on pasture, unitless

f_s fraction of time that cattle eat fresh grass while on pasture, unitless

Concentration of nuclides in goat’s milk are determined in the same manner as cow’s milk and beef except using different values (see Table 2) for feed consumption rate and the fraction of time spent on pasture and eating pasture grass.

Table 2. Default Parameters used for Meat and Milk Concentration Estimates

Parameter	Meat	Milk (cow)	Milk (goat)
Feed consumption rated (kg/d)	44	44	6
Milking/Slaughter to consumption (d)	6	2	2
Fraction of year on pasture	1.00	1.00	0.79
Fraction intake from pasture*	0.75	0.56	0.85

*while on pasture

2.5. Shine Dose

2.5.1. Plume Shine

Dose to individuals from plume shine is estimated in MAXINE only for noble gases. The gamma dose from a particular noble gas in the atmospheric plume is calculated by

$$D_i^p = \chi_i \bullet SF \bullet DF_i^p \bullet 1yr \qquad (15)$$

where

χ_i atmospheric concentration, $\mu Ci/m^3$

SF shielding factor accounting for the fraction of time spent indoors (0.7 for individuals), unitless

DF_i^p nuclide specific plume-shine dose factor, mrem m^3/yr μCi (USDOE 1988a)

2.5.2. Ground-Shine

Ground-shine doses are calculated for all particulate, gamma-emitting nuclides. The dose accounts for buildup over the plant lifetime and is given by,

$$D_i^g = d_i \bullet SF \bullet DF_i^g \bullet \frac{1-e^{-\lambda_i t_b}}{\lambda_i} \bullet 1yr \qquad (16)$$

where

DF_i^g nuclide-specific ground-shine dose factor, mrem m^2/yr μCi (USDOE 1988a)

All other parameters have been previously defined.

2.6. Inhalation Dose

Inhalation dose is determined for individuals assuming a constant breathing rate and a constant concentration throughout the year of exposure. The nuclide-specific dose is estimated by,

$$D_h^{inh} = \chi_i \bullet BR \bullet DF_i^{inh} \bullet 1000\left[\frac{mrem}{rem}\right] \bullet 1yr \qquad (17)$$

where

χ_i atmospheric concentration, µCi/m^2

BR breathing rate, 8000 m^3/yr (USNRC 1977a)

DF_i^{inh} nuclide specific dose conversion factor, rem/µCi (USDOE 1988b)

2.7. Food Ingestion Dose

Dose to an individual is estimated for ingestion of foodstuffs including vegetables, meat, and milk. Two categories of vegetables are available for consumption: "leafy" or "other." The "other" category includes fruits, grains, produce, and below ground vegetables. The dose via vegetable consumption for a one-year period is calculated using,

$$D_i^{veg} = \left[C_i^v U^v f_v + C_i^l U^l f_l\right] \bullet DF_i^{ing} \bullet 1000 \frac{mrem}{rem} \bullet 1yr \qquad (18)$$

where

C_i radionuclide concentrations in leafy (l) or other vegetables (v), µCi/kg

U consumption rates of the two vegetable classifications (see Table 3), kg/yr

f fraction of two vegetable classifications that are home grown, unitless

DF nuclide specific dose conversion factor, rem/µCi (USDOE 1988b)

Individual dose from meat and milk consumption is calculated in the same manner, using the equations

$$D_i^{meat} = C_i^{meat} \bullet U^f \bullet DF_i^{ing} \bullet 1000 \frac{mrem}{rem} \bullet 1yr \quad (19)$$

$$D_i^{milk} = C_i^{milk} \bullet U^m \bullet DF_i^{ing} \bullet 1000 \frac{mrem}{rem} \bullet 1yr \quad (20)$$

Default usage factors for vegetables, meat, and milk are shown in Table 3 for maximum and average individuals.

Table 3. Consumption Parameters (Hamby 1991)

	Consumption Rate	
Parameter	**Maximum**	**Average**
Vegetables	276 kg/yr	163 kg/yr
Meat	81 kg/yr	43 kg/yr
Milk	230 L/yr	120 L/yr

3. VERIFICATION OF MODELS

To verify MAXINE, comparisons were made with MAXDOSE-SR, which has been fully verified (Simpkins 1999). First a detailed comparison was made using all radionuclides available within MAXINE. The input for this detailed test case is shown in Table 4. For each pathway, the doses were compared for each radionuclide. The results of this comparison for total dose are shown in Table 5. The only radionuclide with a difference greater than 1% is I-135. The reason for this difference is two-fold: the short half-life of I-135 (6.6 hrs) and the rounding of conversion factors and constants for time in MAXDOSE-SR and not in MAXINE. All other radionuclides are in good agreement.

Additional verification testing was performed by comparisons with MAXDOSE-SR test cases. All test cases for single release locations were compared and these results are shown in Table 6. Multiple release locations cannot be handled by MAXINE and therefore not all test cases are shown. As shown in Table 6 MAXDOSE-SR and MAXINE are in good agreement.

For quality assurance purposes, a detailed set of test cases was developed specifically for MAXINE. The input for these tests are shown in their entirety in Appendix A. These results should be used as a benchmark any time changes are made to MAXINE.

Hand calculations were performed for Cs-137 doses estimated from test case 1. Results of the hand calculations are shown in Table 7 for all pathways. The actual hand calculations are shown in Appendix B. Hand calculations produced identical results to the MAXINE spreadsheet results.

Table 4. Input Parameters for Expanded Test Case

Input Parameter	Value	Units
Relative Concentration (X/Q):	3.3E-08	sec/m^3
Decayed X/Q:	3.2E-08	sec/m^3
Depleted X/Q:	2.2E-08	sec/m^3
Relative Deposition (D/Q):	1.3E-10	1/m^2
Distance to Receptor:	14014	m
Vegetable Consumption (AVG, MAX, value):	max	276 kg/yr
Leafy Veg Consumption (AVG, MAX, value):	max	43 kg/yr
Milk Consumption (AVG, MAX, value):	max	230 L/yr
Meat Consumption (AVG, MAX, value):	max	81 kg/yr
Origin of Milk (Cow or Goat):	cow	
Deposition Buildup Time(1/2 plant life):	25	yr
Breathing Rate:	8,000	m^3/yr
Elemental Iodine Fraction:	0.50	
Absolute Humidity:	0.01125	kg/m^3
Tritium Plant-to-Air Ratio:	0.50	
Shielding Factor:	0.70	
Fraction of Year C-14 Released:	1.00	
Retained Fraction (iodines):	1.00	
Retained Fraction (particulates):	0.20	
Weathering Rate Constant:	18.1	1/yr
Crop Exposure Time:	0.192	yr
Pasture Grass Exposure Time:	0.0822	yr
Pasture Grass Productivity:	1.8	kg/m^2
Produce Productivity:	0.7	kg/m^2
Surface Soil Density (15 cm):	240	kg/m^2
Pasture Grass Holdup Time:	0.00000	yr
Stored Feed Holdup Time:	0.24700	yr
Leafy Vegetable Holdup Time:	0.00274	yr
Produce Holdup Time:	0.16400	yr
Milk Cattle Feed Consumption (52):	44	kg/d
Beef Cattle Feed Consumption:	44	kg/d
Feed-Milk-Man Transport Time:	0.00548	yr
Fraction of Year on Pasture (beef):	1.00	
Fraction of Year on Pasture (milk):	1.00	
Fraction Intake from Pasture (beef):	0.75	
Fraction Intake from Pasture (milk):	0.56	
Slaughter to Consumption Time:	0.0164	yr
Fraction of Produce from Garden:	0.76	
Fraction of Leafy Vegs from Garden:	1.00	

Table 4 cont. Input for Expanded Test Case (Source Term in Curies)

H-3 (oxide)	1.00E+02
C-14	2.00E+02
Ar-41	3.00E+02
Cr-51	5.00E+02
Co-60	5.00E+02
Zn-65	2.00E+00
Se-75	4.00E+00
Kr-85	6.00E+00
Kr-85m	8.00E+00
Kr-87	1.00E+01
Kr-88	1.00E+00
Sr-90	3.00E+00
Zr-95†	5.00E+00
Nb-95	7.00E+00
Ru-103	9.00E+00
Ru-106†	1.00E+03
Sb-125	5.00E+03
I-129	1.00E+04
I-131	1.00E-04
I-133	2.00E-04
I-135	3.00E-04
Xe-131m	4.00E-04
Xe-133	5.00E-04
Xe-135	6.00E-04
Cs-134	7.00E-04
Cs-137	8.00E-04
Ce-141	9.00E-04
Ce-144	1.00E-03
Pm-147	1.23E-01
Eu-154	4.56E-01
Eu-155	7.89E-01
Os-185	1.10E+00
U-234	2.20E+00
U-235†	3.30E+00
U-238	4.40E+00
Np-237	5.50E+00
Pu-238	6.60E+00
Pu-239	7.70E+00
Am-241	8.80E+00
Am-243	9.90E+00
Cm-242	1.10E+01
Cm-244	2.20E+01
Cf-252	3.30E+01

Table 5. Results of Detailed Test Case

	MAXDOSE-SR Dose (mrem)	MAXINE Dose (mrem)	% Difference
AR 41	5.27E-04	5.27E-04	0.0
AM241	4.69E+01	4.69E+01	0.0
AM243	5.28E+01	5.28E+01	0.0
C 14	1.47E-01	1.46E-01	-0.7
CE141	4.90E-07	4.91E-07	0.2
CE144	1.15E-05	1.15E-05	0.0
CF252	4.00E+01	4.00E+01	0.0
CM242	1.55E+00	1.55E+00	0.0
CM244	6.04E+01	6.04E+01	0.0
CO 60	8.54E+01	8.53E+01	-0.1
CR 51	2.69E-02	2.69E-02	0.0
CS134	6.42E-05	6.43E-05	0.2
CS137	1.11E-04	1.11E-04	0.0
EU154	5.83E-02	5.84E-02	0.2
EU155	4.37E-03	4.36E-03	-0.2
H 3	1.66E-04	1.66E-04	0.0
I 129	4.39E+03	4.39E+03	0.0
I 131	5.68E-07	5.68E-07	0.0
I 133	2.13E-08	2.11E-08	-0.9
I 135	3.59E-09	3.54E-09	-1.4
KR 85	4.91E-08	4.91E-08	0.0
KR 85M	3.15E-06	3.15E-06	0.0
KR 87	7.60E-06	7.60E-06	0.0
KR 88	5.66E-06	5.65E-06	-0.2
NB 95	1.59E-02	1.59E-02	0.0
NP237	2.68E+01	2.68E+01	0.0
OS185	5.79E-03	5.80E-03	0.2
PM147	8.36E-05	8.36E-05	0.0
PU238	3.04E+01	3.04E+01	0.0
PU239	3.97E+01	3.97E+01	0.0
RU103	2.62E-02	2.62E-02	0.0
RU106	4.25E+01	4.25E+01	0.0
SB125	9.05E+01	8.98E+01	-0.8
SE 75	4.18E-02	4.18E-02	0.0
SR 90	2.46E-01	2.46E-01	0.0
U 234	1.95E+00	1.95E+00	0.0
U 235	2.85E+00	2.85E+00	0.0
U 238	3.57E+00	3.57E+00	0.0
XE131M	1.25E-11	1.25E-11	0.0
XE133	6.34E-11	6.34E-11	0.0
XE135	4.47E-10	4.47E-10	0.0
ZN 65	3.95E-02	3.95E-02	0.0
ZR 95	2.46E-02	2.46E-02	0.0

Table 6. Comparison of MAXDOSE-SR Test Cases with MAXINE

Test Case	MAXDOSE-SR Dose (mrem)	MAXINE Dose (mrem)	% Difference
1	3.21E+01	3.22E+01	-0.3
2	3.23E+00	3.23E+00	0.0
3	2.17E+00	2.17E+00	0.0
4	8.00E-01	8.00E-01	0.0
9	5.09E+00	5.11E+00	-0.4

Table 7. Comparison of MAXINE with Hand Calculations

Pathway	MAXINE Dose (mrem)	Hand Calculated Dose (mrem)	% Difference
Shine	2.1E-01	2.1E-01	0.00
Inhalation	2.0E-04	2.0E-04	0.00
Vegetables	4.1E-02	4.1E-02	0.00
Milk	3.8E-02	3.8E-02	0.00
Meat	9.8E-04	9.8E-04	0.00
Total	2.9E-01	2.9E-01	0.00

4. USER'S MANUAL

4.1. First Time User Instructions

The programming for MAXINE is contained in one EXCEL© File entitled 'MAXINE.XLS'. Simply copying this file to your computer installs the program. The spreadsheet has been locked to avoid inadvertent changes to cells performing calculations. Following installation, it is recommended that the user execute at least one test case to ensure the spreadsheet is operating correctly.

4.2. Input Instructions

Table 4 shows the input template in its entirety. In viewing the actual spreadsheet, the user has the ability to change all parameters shown in red. All other cells have been locked to prevent user access. The spreadsheet is set up such that default values are included for each parameter except the source term. Each parameter is discussed in detail below.

Relative Concentration (X/Q):	Enter the relative air concentration in units of s/m^3 for the location of interest. This input is likely estimated using the methods detailed in U.S. NRC Regulatory Guide 1.111 (USNRC 1977b). Valid Range 1E-10 to 1E-05 s/m^3.
Decayed X/Q:	Enter the 2.26 day decayed relative air concentration in units of s/m^3 for the location of interest. Valid Range 1E-10 to 1E-05 s/m^3.
Depleted X/Q:	Enter the 8-day decayed and depleted relative air concentration in units of s/m^3 for the location of interest. Valid Range 1E-10 to 1E-05 s/m^3.
Relative Deposition (D/Q):	Enter the relative deposition of particulates without radioactive decay in units of $1/m^2$. Valid Range: 1E-13 to 1E-08 $1/m^2$
Distance to Receptor:	Enter the distance from the release point to the downwind location of the receptor in meters. Valid Range: 0 to 80,000 m
Vegetable Consumption:	Enter the vegetable consumption rate for the exposed individual as AVG, MAX or a value. The average consumption rate is 163 kg/yr and the max consumption rate is 276 kg/yr. Valid Range: 0 to 900 kg/yr
Leafy Veg Consumption :	Enter the leafy vegetable consumption rate for the exposed individual as AVG, MAX or a value. The average consumption rate is 21 kg/yr and the max consumption rate is 43 kg/yr. Valid Range 0 to 260 kg/yr
Milk Consumption :	Enter the milk consumption rate for the exposed individual as AVG, MAX or a value. The average consumption rate is 120 Lyr and the max consumption rate is 230 L/yr. Valid Range 0 to 500 L/yr
Meat Consumption:	Enter the meat consumption rate for the exposed individual as AVG, MAX or a value. The average consumption rate is 43 kg/yr and the max consumption rate is 81 kg/yr. Valid Range 0 to 470 kg/yr

Origin of Milk:	Enter the type of milk consumed by the exposed individual either as COW or GOAT.
Deposition Buildup Time:	Enter the time (in years) that the radionuclides have been accumulating in the soil. Valid Range: 0-100 yr
Breathing Rate:	Enter the inhalation rate of the individual in m^3/yr. Valid range is 6000 to 10000 m^3/yr
Elemental Iodine Fraction:	Enter the fraction of iodine released that is elemental. The balance is assumed to behave as a gas. Valid Range: 0-1
Absolute Humidity:	Enter the annual average absolute humidity in kg/m^3. Valid Range: 0.003 to 0.020 kg/m^3
Tritium Plant-to-Air Ratio:	Enter the ratio of tritium concentration in the plant moisture to tritium concentration in atmospheric moisture. Valid Range: 0-5
Shielding Factor:	Enter the fraction of time that the individual is exposed to gamma radiation. Valid Rage: 0-1
Fraction of Year C-14 Released:	Enter the ratio of the total annual release time to the total annual time during which photsynthesis occurs (taken to be 4400 hrs). For continual releases a value of one should be entered. Valid Range: 0-1
Retained Fraction (iodines):	Enter the fraction of elemental iodine that is retained on the surface of the vegetation following deposition. Valid Range: 0-1
Retained Fraction (particulates):	Enter the fraction of particulates that are retained on the surface of the vegetation. Valid Range: 0-1
Weathering Rate Constant:	Enter the rate constant describing the removal of particulates from plant surfaces due to weathering. Valid Range: 5 – 250 1/yr
Crop Exposure Time:	Enter the length of time (in yrs) the crops are exposed. This typically equates to the growing season. Valid Range: 0-1 yr
Pasture Grass Exposure Time:	Enter the length of time (in yrs) pasture grass is exposed. Valid Range: 0-1 yr

Pasture Grass Productivity:	Enter the productivity of pasture grass in kg/m^2. Valid Range: 0-3 kg/m^2
Produce Productivity:	Enter the productivity of produce in kg/m^2. Valid Range: 0-3 kg/m^2
Surface Soil Density:	Enter the surface soil density in units of kg/m^2 assuming a contamination depth of 15 cm. Valid Range: 50 –400 kg/m^2.
Pasture Grass Holdup Time:	Enter the length of time (in yrs) between contamination and consumption of pasture grass by grazing cows or goats. Valid Range: 0-1 yr
Stored Feed Holdup Time:	Enter the length of time (in yrs) feed is stored prior to consumption by livestock. Valid Range: 0 – 1 yr
Leafy Vegetable Holdup Time:	Enter the length of time (in yrs) leafy vegetables are stored prior to consumption. Valid Range: 0 – 1 yr
Produce Holdup Time:	Enter the length of time (in yrs) vegetables are stored prior to consumption. Valid Range: 0 – 1 yr
Milk Cattle (Goat) Feed Consumption:	Enter the fodder consumption rate for milk cattle or goats in kg/d. Depending on what is input above under origin of milk, the input statement will change to reflect either milk cattle or goats. The expected value for milk cows is 52 kg/d and the expected value for goats is 6 kg/d. Valid Range: 0-100 kg/d
Beef Cattle Feed Consumption:	Enter the fodder consumption rate for beef cattle in kg/d. Valid Range: 0-100 kg/d
Feed-Milk-Man Transport Time:	Enter the length of time (in yrs) from milking to consumption by exposed individual. Valid Range: 0-0.038 yr
Fraction of Year on Pasture (beef):	Enter the fraction of the year that beef cattle are on the pasture. Valid Range 0-1
Fraction of Year on Pasture (milk):	Enter the fraction of the year that milk cattle or goats are on the pasture. Valid Range 0-1

Fraction Intake from Pasture (beef):	Enter the fraction of a beef cow's diet that is pasture grass while the cow is on pasture. Valid Range: 0-1
Fraction Intake from Pasture (milk):	Enter the fraction of a milk cow's or goat's diet that is pasture grass while on pasture. Valid Range: 0-1
Slaughter to Consumption Time:	Enter the length of time (in yrs) between cattle slaughter and consumption by humans. Valid Range: 0-0.38 yr.
Fraction of Produce from Garden:	Enter the fraction of produce consumed that was grown in local garden. The remaining produce is assumed not to be contaminated. Valid Range: 0-1.
Fraction of Leafy Vegetables from Garden:	Enter the fraction of leafy vegetables consumed that were grown in local garden. The remaining leafy vegetables are assumed not to be contaminated. Valid Range: 0-1

4.3. Output Files Generated

Appendix C shows the MAXINE spreadsheet in its entirety for test case 1. Pages 1 and 2 show user-input. Pages 3 and 4 show radionuclide specific constants used in the dose estimates. The last two pages show the concentration and dose by radionuclide and pathway.

5. CONCLUSIONS

MAXINE is performing as expected and producing correct results for a wide range of test cases. Minimal input is required by the user and output is available in an easily interpreted form. Recommended improvements to MAXINE would be to add atmospheric dispersion estimates to the spreadsheet or link to another spreadsheet that would perform this function.

6. REFERENCES

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APPENDIX A. MAXINE TEST CASES

Table A1. MAXINE Test Case Input

Input Parameter	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Relative Concentration (X/Q):	2.7E-08	3.35E-08	2.7E-08	3.35E-08	2.7E-08	3.35E-08	2.7E-08	3.35E-08
Decayed X/Q:	2.7E-08	3.19E-08	2.7E-08	3.19E-08	2.7E-08	3.19E-08	2.7E-08	3.19E-08
Depleted X/Q:	2.5E-08	2.19E-08	2.5E-08	2.19E-08	2.5E-08	2.19E-08	2.5E-08	2.19E-08
Relative Deposition (D/Q):	2.0E-10	6.78E-11	2.0E-10	6.78E-11	2.0E-10	6.78E-11	2.0E-10	6.78E-11
Distance to Receptor:	7752	7000	8000	9000	8000	7000	6000	2000
Vegetable Consumption (AVG, MAX, value):	Max	Avg	Max	Avg	Max	Avg	Max	Avg
Leafy Veg Consumption (AVG, MAX, value):	Max	Avg	Avg	Max	Max	Avg	Max	Avg
Milk Consumption (AVG, MAX, value):	Max	Avg	Max	Avg	Max	Avg	Avg	Max
Meat Consumption (AVG, MAX, value):	Max	Avg	Avg	Max	Max	Avg	Max	Avg
Origin of Milk (Cow or Goat):	Goat	Cow	Goat	Cow	Goat	Cow	Goat	Cow
Deposition Buildup Time:	38	5	10	15	20	25	30	40
Breathing Rate:	8,000	10000	9000	8000	8000	8000	8000	8000
Elemental Iodine Fraction:	1.00	0	1	1	0	0.5	0.5	0.5
Absolute Humidity:	0.01125	0.01125	0.01125	0.00800	0.00800	0.00800	0.01125	0.01125
Tritium Plant-to-Air Ratio:	0.54	0.54	1.00	0.54	0.54	0.50	0.54	0.54
Shielding Factor:	0.70	1	0.70	0.70	0.70	1.00	0.70	0.70
Fraction of Year C-14 Released:	1.00	0.5	1	0.5	0.5	1	1	1
Retained Fraction (iodines):	1.00	1	1	0.5	0.5	0.5	1	0.8
Retained Fraction (particulates):	0.20	0.4	0.6	0.8	1	0.2	0.2	0.2
Weathering Rate Constant:	18.1	17	18.1	18.1	18.1	18.1	18.1	18.1
Crop Exposure Time:	0.192	0.1	0.192	0.192	0.1	0.192	0.192	0.1
Pasture Grass Exposure Time:	0.0822	0.04	0.0822	0.0822	0.0822	0.0822	0.0822	0.04
Pasture Grass Productivity:	1.8	1.8	1.8	1.8	1.8	2	2	2
Produce Productivity:	0.7	1	0.3	1	0.3	1	0.3	0.3
Surface Soil Density (15 cm):	240	250	240	250	240	240	240	240
Pasture Grass Holdup Time:	0.00000	0.001	0.002	0	0	0	0	0.00247
Stored Feed Holdup Time:	0.24700	0.1	0.24700	0.1	0.24700	0.1	0	0.1
Leafy Vegetable Holdup Time:	0.00274	0.00274	0.00274	0.001	0.00000	0.00274	0.00274	0.001
Produce Holdup Time:	0.16400	0.1	0.164	0	0.1	0.1	0.08	0.164
Goat Feed Consumption (6):	6	1	2	3	4	5	6	7
Beef Cattle Feed Consumption:	36	36	36	36	36	40	5	2
Feed-Milk-Man Transport Time:	0.00822	0.004	0.00822	0.00822	0.004	0.004	0.00822	0.004
Fraction of Year on Pasture (beef):	1.00	1	1	0.5	1	0.2	1	1

Fraction of Year on Pasture (milk):	0.79	1	1	1	1	0.79	0.3	0.2

Table A1. MAXINE Test Case Input cont.

Input Parameter	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
Fraction Intake from Pasture (beef):	0.75	0.2	0.2	0.75	0.75	0.75	0.75	0.75
Fraction Intake from Pasture (milk):	0.85	1	1	1	1	0.7	0.7	0.2
Slaughter to Consumption Time:	0.0164	0.0164	0.0164	0.0164	0.0164	0.0164	0.008	0.008
Fraction of Produce from Garden:	0.76	1	1	1	1	1	0.5	0.3
Fraction of Leafy Vegs from Garden:	1.00	0.25	0.1	0.5	1	1	0.25	1
Source Term	1Ci Each H-3 Cs-137 Pu-239	1Ci Each H-3 Cs-137 Pu-239	1Ci Each H-3 Cs-137 Pu-239	1Ci Each H-3 Cs-137 Pu-239	1Ci Each H-3 Cs-137 Pu-239	1Ci Each H-3 Cs-137 Pu-239	1Ci Each H-3 Cs-137 Pu-239	1Ci Each All Rads

APPENDIX B. HAND CALCULATIONS

The following shows hand calculations for MAXINE Test Case 1 (shown in Table A1) for Cs-137. Appendix C shows the corresponding MAXINE output in its entirety.

Inhalation Dose

$$t = \frac{\ln\left(\frac{\chi_D / Q}{\chi / Q}\right)}{\left(\frac{\ln 2 \bullet 365\,d}{2.26\,d \bullet 1\,yr}\right)}$$

$$t = \frac{\ln\left(\frac{2.7E-08\ \frac{s}{m^3}}{2.7E-08\ \frac{s}{m^3}}\right)}{\left(\frac{\ln 2 \bullet 365\,d}{2.26\,d \bullet 1\,yr}\right)}$$

$$t = 0\,yr$$

$$\chi_i = \frac{\chi_{DD}}{Q} \bullet Q_i \bullet 10^6 \bullet 3.17\,x10^{-8}\ \frac{yr}{s} \bullet e^{(31.62-\lambda_t)t}$$

$$\chi_i = 2.5E-08\ \frac{s}{m^3} \bullet 1\frac{Ci}{yr} \bullet 10^6\ \frac{\mu Ci}{Ci} \bullet 3.17\,x10^{-8}\ \frac{yr}{s} \bullet e^{(31.62-0.023)0}$$

$$\chi_i = 7.925\,E-10\ \frac{\mu Ci}{m^3}$$

$$D_h^{inh} = \chi_i \bullet BR \bullet DF_i^{inh} \bullet 1000\left[\frac{mrem}{rem}\right] \bullet 1yr$$

$$D_h^{inh} = 7.925\,E-10\ \frac{\mu Ci}{m^3} \bullet 8000\ \frac{m^3}{yr} \bullet 3.2E-2\ \frac{rem}{\mu Ci} \bullet 1000\left[\frac{mrem}{rem}\right] \bullet 1yr$$

$$D_h^{inh} = 2.0E-04\,mrem$$

Ground Shine Dose

$$d_i = \frac{D}{Q} \bullet Q_i \bullet 10^6 \bullet e^{(31.62-\lambda_i)t}$$

$$d_i = 2.0E-10\frac{1}{m^2} \bullet 1\frac{Ci}{yr} \bullet 10^6 \bullet e^{(31.62-0.023)0}$$

$$d_i = 2.0E-04\frac{\mu Ci}{m^2 yr}$$

$$D_i^g = d_i \bullet SF \bullet DF_i^g \bullet \frac{1-e^{-\lambda_i t_b}}{\lambda_i} \bullet 1yr$$

$$D_i^g = 2.0E-04\frac{\mu Ci}{m^2 yr} \bullet 0.7 \bullet 57.8\frac{mrem \bullet m^2}{\mu Ci \bullet yr} \bullet \frac{1-e^{-0.023*38}}{0.023yr^{-1}} \bullet 1yr$$

$$D_i^g = 2.1E-01mrem$$

Vegetable Ingestion Dose

$$C_i^V = d_i \bullet \left[\frac{r_i(1-e^{-\lambda_i^w t_e})}{Y_V \lambda_i^w} + \frac{B_i^v(1-e^{-\lambda_i t_b})}{P \bullet \lambda_i}\right] \bullet e^{-\lambda_i t_h}$$

$$C_i^V = 2.0E-04\frac{\mu Ci}{m^2 yr} \bullet \left[\frac{0.2(1-e^{-(18.1+0.023)0.192})}{0.7\frac{kg}{m^2}(18.1+0.023)yr^{-1}} + \frac{1E-2(1-e^{-0.023*38})}{240\frac{kg}{m^2}0.023yr^{-1}}\right] \bullet e^{-0.023*0.164}$$

$$C_i^V = 3.3E-06\frac{\mu Ci}{kg}$$

$$C_i^{LV} = 2.0E-04\frac{\mu Ci}{m^2 yr} \bullet \left[\frac{0.2(1-e^{-(18.1+0.023)0.192})}{0.7\frac{kg}{m^2}(18.1+0.023)yr^{-1}} + \frac{1E-2(1-e^{-0.023*38})}{240\frac{kg}{m^2}0.023yr^{-1}}\right] \bullet e^{-0.023*0.00274}$$

$$C_i^{LV} = 3.3E-06\frac{\mu Ci}{kg}$$

$$D_i^{veg} = \left[C_i^v U^v f_v + C_i^l U^l f_l\right] \bullet DF_i^{ing} \bullet 1000\frac{mrem}{rem} \bullet 1yr$$

$$D_i^{veg} = \left[3.3E-6\frac{\mu Ci}{kg}276\frac{kg}{yr}0.76 + 3.3E-6\frac{\mu Ci}{kg}43\frac{kg}{yr}1.0\right] \bullet 5.0E-02\frac{rem}{\mu Ci} \bullet 1000\frac{mrem}{rem} \bullet 1yr$$

$$D_i^{veg} = 0.041mrem$$

Milk Ingestion Dose

$$C_i^P = d_i \bullet \left[\frac{r_i (1 - e^{-\lambda_i^w t_e})}{Y_V \lambda_i^w} + \frac{B_i^v (1 - e^{-\lambda_i t_b})}{P \bullet \lambda_i} \right] \bullet e^{-\lambda_i t_h}$$

$$C_i^P = 2.0E-04 \frac{\mu Ci}{m^2 yr} \bullet \left[\frac{0.2(1 - e^{-(18.1+0.023)0.0822})}{1.8 \frac{kg}{m^2}(18.1+0.023)yr^{-1}} + \frac{1E-2(1 - e^{-0.023*38})}{240 \frac{kg}{m^2} 0.023yr^{-1}} \right] \bullet e^{-0.023*0}$$

$$C_i^P = 1.16E-06 \frac{\mu Ci}{kg}$$

$$C_i^S = d_i \bullet \left[\frac{r_i (1 - e^{-\lambda_i^w t_e})}{Y_V \lambda_i^w} + \frac{B_i^v (1 - e^{-\lambda_i t_b})}{P \bullet \lambda_i} \right] \bullet e^{-\lambda_i t_h}$$

$$C_i^S = 2.0E-04 \frac{\mu Ci}{m^2 yr} \bullet \left[\frac{0.2(1 - e^{-(18.1+0.023)0.192})}{0.7 \frac{kg}{m^2}(18.1+0.023)yr^{-1}} + \frac{1E-2(1 - e^{-0.023*38})}{240 \frac{kg}{m^2} 0.023yr^{-1}} \right] \bullet e^{-0.023*0.247}$$

$$C_i^S = 3.249E-06 \frac{\mu Ci}{kg}$$

$$C_i^{fodder} = f_p f_s C_i^p + \left[f_p (1 - f_s) + (1 - f_p) \right] C_i^s$$

$$C_i^{fodder} = 0.79 * 0.85 * 1.16E-06 \frac{\mu Ci}{kg} + \left[0.79(1 - 0.85) + (1 - 0.79) \right] 3.249E-06 \frac{\mu Ci}{kg}$$

$$C_i^{fodder} = 1.85E-06 \frac{\mu Ci}{kg}$$

$$C_i^{milk} = C_i^{fodder} \bullet F_i^m \bullet Q_F \bullet e^{-\lambda_i t_f}$$

$$C_i^{milk} = 1.85E-06 \frac{\mu Ci}{kg} \bullet 0.3 \frac{d}{L} \bullet 6 \frac{kg}{d} \bullet e^{-0.023*0.00822}$$

$$C_i^{milk} = 3.32E-06 \frac{\mu Ci}{L}$$

$$D_i^{milk} = C_i^{milk} U^{milk} \bullet DF_i^{ing} \bullet 1000 \frac{mrem}{rem} \bullet 1yr$$

$$D_i^{milk} = 3.32E-06 \frac{\mu Ci}{L} 230 \frac{L}{yr} 5.0E-02 \frac{rem}{\mu Ci} 1000 \frac{mrem}{rem} \bullet 1yr$$

$$D_i^{milk} = 3.8E-02 mrem$$

Meat Ingestion Dose

$$C_i^P = d_i \bullet \left[\frac{r_i(1-e^{-\lambda_i^w t_e})}{Y_V \lambda_i^w} + \frac{B_i^v(1-e^{-\lambda_i t_b})}{P \bullet \lambda_i} \right] \bullet e^{-\lambda_i t_h}$$

$$C_i^P = 2.0E-04 \frac{\mu Ci}{m^2 yr} \bullet \left[\frac{0.2(1-e^{-(18.1+0.023)0.0822})}{1.8 \frac{kg}{m^2}(18.1+0.023)yr^{-1}} + \frac{1E-2(1-e^{-0.023*38})}{240 \frac{kg}{m^2} 0.023yr^{-1}} \right] \bullet e^{-0.023*0}$$

$$C_i^P = 1.16E-06 \frac{\mu Ci}{kg}$$

$$C_i^S = d_i \bullet \left[\frac{r_i(1-e^{-\lambda_i^w t_e})}{Y_V \lambda_i^w} + \frac{B_i^v(1-e^{-\lambda_i t_b})}{P \bullet \lambda_i} \right] \bullet e^{-\lambda_i t_h}$$

$$C_i^S = 2.0E-04 \frac{\mu Ci}{m^2 yr} \bullet \left[\frac{0.2(1-e^{-(18.1+0.023)0.192})}{0.7 \frac{kg}{m^2}(18.1+0.023)yr^{-1}} + \frac{1E-2(1-e^{-0.023*38})}{240 \frac{kg}{m^2} 0.023yr^{-1}} \right] \bullet e^{-0.023*0.247}$$

$$C_i^S = 3.249E-06 \frac{\mu Ci}{kg}$$

$$C_i^{fodder} = f_p f_s C_i^p + [f_p(1-f_s) + (1-f_p)]C_i^s$$

$$C_i^{fodder} = 1.0 * 0.75 * 1.16E-06 \frac{\mu Ci}{kg} + [1.0(1-0.75) + (1-1.0)]3.249E-06 \frac{\mu Ci}{kg}$$

$$C_i^{fodder} = 1.68E-06 \frac{\mu Ci}{kg}$$

$$C_i^{meat} = C_i^{fodder} \bullet F_i^m \bullet Q_F \bullet e^{-\lambda_i t_f}$$

$$C_i^{meat} = 1.68E-06 \frac{\mu Ci}{kg} \bullet 4.0E-03 \frac{d}{kg} \bullet 36 \frac{kg}{d} \bullet e^{-0.023*0.0164}$$

$$C_i^{meat} = 2.42E-07 \frac{\mu Ci}{kg}$$

$$D_i^{meat} = C_i^{meat} U^{meat} \bullet DF_i^{ing} \bullet 1000 \frac{mrem}{rem} \bullet 1yr$$

$$D_i^{meat} = 2.42E-07 \frac{\mu Ci}{kg} 81 \frac{kg}{yr} 5.0E-02 \frac{rem}{\mu Ci} 1000 \frac{mrem}{rem} \bullet 1yr$$

$$D_i^{meat} = 9.8E-04 mrem$$

APPENDIX C. SAMPLE MAXINE OUTPUT

WESTINGHOUSE SAVANNAH RIVER COMPANY

MAXINE: A SPREADSHEET FOR ESTIMATING DOSE FROM CHRONIC ATMOSPHERIC RADIOACTIVE RELEASES

DISTRIBUTION (12)

S. Wood, 773–A

D. B. Moore-Shedrow, 773–A

J.B. Gladden, 773–42A

G.T. Jannik, 773–42A

P.L. Lee, 773–42A

A. A. Simpkins, 773–42A

SRTC Records(4), 773 – 52A
ED Records(3), 773 – 42A