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Unit Curie Dose Evaluation (UCDE)

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Abstract

The development of radiological consequence lookup tables for postulated releases of radionuclides commonly used at Savannah River Site (SRS) and other Department of Energy (DOE) facilities requires the use of the MELCOR Accident Consequence Code System (MACCS)/MACCS2. MACCS2 users input site-specific data: such as stack or ground release, building wake effects, boundary distance from release source, and site-specific meteorological data. MACCS2 also allows the input of more general data such as plume rise and wet and/or dry deposition. The acceptance of such inputs gives the MACCS2 program a broad spectrum of uses at participating DOE facilities. The MACCS2 outputs are converted to an excel spreadsheet to facilitate fast and accurate results for various accident scenarios. Consequence lookup tables can be employed to determine the effects of radiological accident scenarios before they occur. The data is then used by DOE facilities to create regulations and controls to prepare for worst-case scenarios.

Introduction

Consolidated Hazards Analysis Process (CHAP), Accident Analysis, and Documented Safety Analysis (DSA)/Safety Accident Report (SAR) are tools used to implement safety regulations and controls for different DOE radiological waste storage facilities. The regulations and controls are there to prevent or at least mitigate the effects of a radiological release to the environment or the general public. Since the facility has no prior experience with large-scale releases, the safety requirements must be based on dose calculations, computer program runs, and/or consequence lookup tables. The MACCS2 program was developed under the direction of the United States Nuclear Regulatory Commission (USNRC) by Sandia National Laboratories to be used for consequence analysis throughout the country at DOE facilities.[1,2] In creating the most recent lookup tables, MACCS2 version 1.13.1 was used which utilizes Dose Conversion Factors (DCFs) for 825 radionuclides most commonly found at DOE facilities. The most recent DCFs are based on International Commission of Radiological Protection (ICRP) Publications 68 and 72. Updated SRS meteorological data from years 1997 to 2001 was also employed. The use of the most recent input data create more accurate results, which in turn allows for more accurate analyses and assessments.

Analysis Methods and Calculations

The MACCS2 code utilizes four input files to offer a wide variety of release scenarios partly due to the multitude of changeable variables. The ATMOS file specifies the following: plume size and movement, spatial distances to site boundaries, isotopes of interest, wet and/or dry deposition, building wake effects, meteorological conditions, plume buoyancy, release durations, deposition velocity for filtered or unfiltered releases, and the amount of inventory released. UCDE MACCS2 runs utilize a stratified random weather sample for each day of the year. The user can also specify weather category bin sampling, constant meteorological conditions, 120 hours of weather specified in the ATMOS file, or a given start day and hour from the met file. The EARLY file is used to calculate consequences during the first seven days of exposure following the time of release. The EARLY file is used to configure the different outputs created by MACCS2. The user can specify certain boundary distances, affected organs, and location of the DCF files. One major component of the EARLY input file is the option of choosing which organ of the body that MACCS2 includes in the calculations. MACCS2 can input any or all of the following organs for acute effects: skin, red marrow, lungs, pseudo-thyroid for health effects, stomach, and lower large intestine.[1] For lifetime effects, MACCS2 can input the following organs: effective, red marrow, bone surface, breast, lungs, thyroid, lower large intestine, bladder wall, liver, and pseudo-thyroid for health effects.[1] UCDE uses only the effective doses for the Maximally Exposed Offsite Individual (MOI) and the Occupationally Exposed Person (OEP) so no other organs need to be specified. The CHRONC file calculates both environmental and biological long-term effects following the time of the release. Since UCDE is used mainly for Safety Analysis support, where only short-term consequences are sought, the CHRONC module is not used. The DCF file contains the updated values based on ICRP 68 and 72, which are used to calculate the Effective Dose Equivalent (EDE) for a unit release of commonly used radionuclides at SRS facilities. The values from ICRP 68 and 72 can also be utilized for other facilities dealing with radioactive isotopes. Based on ICRP 68, a 5-µm activity mean aerodynamic diameter (AMAD) particle size is used to determine the DCF values for an OEP. The 5-µm particle size is used to represent a general workplace aerosol found at SRS. ICRP 71 recommends that a 1-µm AMAD particle size be used to determine the DCF values for the MOI. The DCF also includes the various lung clearance classes of each radionuclide, which are divided based on the absorption rate: fast (F), moderate (M), and slow (S). Many radionuclides have multiple classes and DCF values. The DCF value and class for each radionuclide was chosen based on conservatism, which means selecting the value that will yield the highest EDE at the given receptors. The conservative approach is used so the appropriate safety controls and requirements apply to all release scenarios not just worst case. The complete systematic execution of MACCS2 is shown in Figure 1. SRS consequence lookup tables specify a ground level release with release durations of three minutes, twenty minutes, one hour, and eight hours. The most recent 5 years of meteorological data (1997-2001) was used in order to determine the maximum dose for each radionuclide at the various receptors. Both filtered and unfiltered releases were considered. Filtered releases are defined by a 0.1 cm/s deposition velocity while the unfiltered releases specify 1.0 cm/s deposition velocity. Filtered and unfiltered releases correspond to most isotopes at SRS other then noble gases and tritium oxide. Noble gases have no deposition velocity and a tritium oxide release uses a 0.5 cm/s deposition velocity.

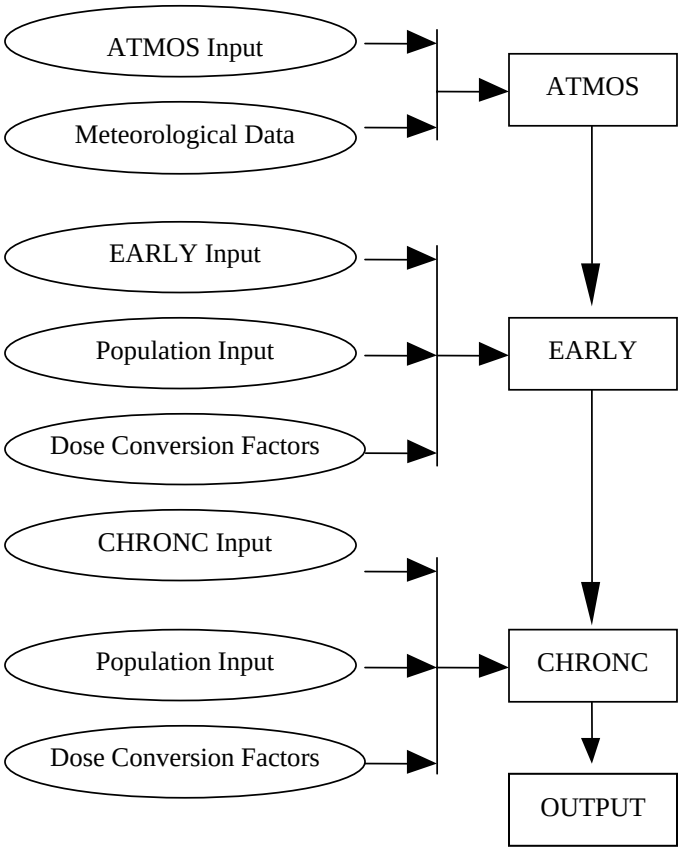

Figure 1: Flow chart of MACCS2 execution.

Receptor Distance

The TEDE analysis will use a 100 m receptor distance to calculate the doses for the OEP and TABLE 1 below shows the distances used for the MOI.

Table 1: SRS MOI Receptor Distance.

Area	Analysis Distance (km)
A	0.67
B	5.2
C	9.3
D	1.66
E	10.5
F	9.4
H	11.5
K	8.9
L	9.2
M	1.30
N	10.9
P	9.2
R	7.9
S	10.9
TNX	0.60
Z	10.0

Results

For consequence lookup tables used at SRS, MACCS2 results are based on a unit curie release and can be scaled to determine the EDE for a wide variety of accident scenarios. Pu-238 examples of MACCS2 outputs for the MOI and OEP are listed below in TABLE 2 through TABLE 5. The tables include five years of meteorological data and the maximum dose from those five years. The doses are measured in rem/Ci. Table 2 contains the doses for a filtered release with a 3 cm surface roughness length. Table 3 contains the doses for an unfiltered release with a 3 cm surface roughness length. Table 4 contains the doses for a filtered release with a 100 cm surface roughness length. Table 5 contains the doses for an unfiltered release with a 100 cm surface roughness length.

TABLE 2: Sample Filtered Releases with 3 cm Surface Roughness Length.[3]

Radiological Nuclide	Release Duration	Deposition Velocity (cm/s)	Distance (km)	1997	1998	1999	2000	2001	Max.
Pu-238	3.0 min	0.1	0.1	1.44E+02	1.46E+02	1.53E+02	1.50E+02	1.63E+02	1.63E+02
	3.0 min	0.1	1.7	8.11E+00	8.01E+00	7.93E+00	8.25E+00	7.95E+00	8.25E+00
	3.0 min	0.1	10.5	4.79E-01	4.71E-01	4.66E-01	4.88E-01	4.80E-01	4.88E-01
	20 min	0.1	0.1	9.47E+01	9.65E+01	9.91E+01	9.78E+01	1.06E+02	1.06E+02
	20 min	0.1	1.7	5.57E+00	5.47E+00	5.34E+00	5.66E+00	5.36E+00	5.66E+00
	20 min	0.1	10.5	3.32E-01	3.28E-01	3.24E-01	3.35E-01	3.32E-01	3.35E-01
	1.0 hr	0.1	0.1	7.66E+01	7.86E+01	8.15E+01	8.02E+01	8.78E+01	8.78E+01
	1.0 hr	0.1	1.7	4.51E+00	4.38E+00	4.33E+00	4.52E+00	4.34E+00	4.52E+00
	1.0 hr	0.1	10.5	2.61E-01	2.55E-01	2.52E-01	2.62E-01	2.62E-01	2.62E-01
	8.0 hr	0.1	0.1	3.98E+01	4.05E+01	4.20E+01	4.11E+01	4.50E+01	4.50E+01
	8.0 hr	0.1	1.7	2.25E+00	2.21E+00	2.15E+00	2.29E+00	2.17E+00	2.29E+00
	8.0 hr	0.1	10.5	1.36E-01	1.31E-01	1.30E-01	1.34E-01	1.35E-01	1.36E-01

TABLE 3: Sample Unfiltered Releases with 3 cm Surface Roughness Length.[4]

Radiological Nuclide	Release Duration	Deposition Velocity (cm/s)	Distance (km)	1997	1998	1999	2000	2001	Max.
Pu-238	3.0 min	1.0	0.1	4.34E+01	4.42E+01	4.53E+01	4.45E+01	4.83E+01	4.83E+01
	3.0 min	1.0	1.7	2.42E+00	2.37E+00	2.36E+00	2.44E+00	2.37E+00	2.44E+00
	3.0 min	1.0	10.5	1.03E-01	1.03E-01	1.04E-01	1.04E-01	1.06E-01	1.06E-01
	20 min	1.0	0.1	2.89E+01	2.94E+01	3.00E+01	2.97E+01	3.27E+01	3.27E+01
	20 min	1.0	1.7	1.62E+00	1.57E+00	1.57E+00	1.63E+00	1.58E+00	1.63E+00
	20 min	1.0	10.5	7.15E-02	7.17E-02	7.18E-02	7.23E-02	7.35E-02	7.35E-02
	1.0 hr	1.0	0.1	2.34E+01	2.39E+01	2.48E+01	2.43E+01	2.66E+01	2.66E+01
	1.0 hr	1.0	1.7	1.45E+00	1.42E+00	1.42E+00	1.49E+00	1.44E+00	1.49E+00
	1.0 hr	1.0	10.5	5.76E-02	5.73E-02	5.79E-02	5.84E-02	5.90E-02	5.90E-02
	8.0 hr	1.0	0.1	1.19E+01	1.23E+01	1.26E+01	1.25E+01	1.37E+01	1.37E+01
	8.0 hr	1.0	1.7	6.24E-01	6.17E-01	6.14E-01	6.25E-01	6.17E-01	6.25E-01
	8.0 hr	1.0	10.5	2.82E-02	2.83E-02	2.84E-02	2.91E-02	2.92E-02	2.92E-02

TABLE 4: Sample Filtered Releases with 100 cm Surface Roughness Length.[5]

Radiological Nuclide	Release Duration	Deposition Velocity (cm/s)	Distance (km)	1997	1998	1999	2000	2001	Max.
Pu-238	3.0 min	0.1	0.1	6.95E+01	7.14E+01	7.36E+01	7.24E+01	8.07E+01	8.07E+01
	3.0 min	0.1	1.7	4.23E+00	4.15E+00	4.07E+00	4.25E+00	4.10E+00	4.25E+00
	3.0 min	0.1	10.5	2.47E-01	2.42E-01	2.40E-01	2.48E-01	2.48E-01	2.48E-01
	20 min	0.1	0.1	4.80E+01	4.89E+01	4.99E+01	4.93E+01	5.50E+01	5.50E+01
	20 min	0.1	1.7	2.80E+00	2.73E+00	2.70E+00	2.79E+00	2.69E+00	2.80E+00
	20 min	0.1	10.5	1.65E-01	1.60E-01	1.60E-01	1.67E-01	1.65E-01	1.67E-01
	1.0 hr	0.1	0.1	3.94E+01	4.02E+01	4.16E+01	4.09E+01	4.48E+01	4.48E+01
	1.0 hr	0.1	1.7	2.25E+00	2.21E+00	2.15E+00	2.29E+00	2.17E+00	2.29E+00
	1.0 hr	0.1	10.5	1.37E-01	1.31E-01	1.30E-01	1.35E-01	1.36E-01	1.37E-01
	8.0 hr	0.1	0.1	1.97E+01	2.01E+01	2.07E+01	2.03E+01	2.26E+01	2.26E+01
	8.0 hr	0.1	1.7	1.23E+00	1.22E+00	1.21E+00	1.29E+00	1.22E+00	1.29E+00
	8.0 hr	0.1	10.5	6.86E-02	6.80E-02	6.70E-02	7.08E-02	6.93E-02	7.08E-02

TABLE 5: Sample Unfiltered Releases with 100 cm Surface Roughness Length.[6]

Radiological Nuclide	Release Duration	Deposition Velocity (cm/s)	Distance (km)	1997	1998	1999	2000	2001	Max.
Pu-238	3.0 min	1.0	0.1	2.21E+01	2.27E+01	2.36E+01	2.32E+01	2.55E+01	2.55E+01
	3.0 min	1.0	1.7	1.58E+00	1.54E+00	1.54E+00	1.57E+00	1.54E+00	1.58E+00
	3.0 min	1.0	10.5	7.62E-02	7.64E-02	7.60E-02	7.74E-02	7.79E-02	7.79E-02
	20 min	1.0	0.1	1.58E+01	1.59E+01	1.66E+01	1.63E+01	1.76E+01	1.76E+01
	20 min	1.0	1.7	9.79E-01	9.57E-01	9.53E-01	9.83E-01	9.46E-01	9.83E-01
	20 min	1.0	10.5	5.28E-02	5.26E-02	5.24E-02	5.37E-02	5.34E-02	5.37E-02
	1.0 hr	1.0	0.1	1.21E+01	1.25E+01	1.28E+01	1.27E+01	1.39E+01	1.39E+01
	1.0 hr	1.0	1.7	7.98E-01	7.85E-01	7.83E-01	8.08E-01	7.85E-01	8.08E-01
	1.0 hr	1.0	10.5	4.11E-02	4.09E-02	4.07E-02	4.17E-02	4.20E-02	4.20E-02
	8.0 hr	1.0	0.1	6.09E+00	6.22E+00	6.38E+00	6.27E+00	6.88E+00	6.88E+00
	8.0 hr	1.0	1.7	4.15E-01	4.10E-01	4.08E-01	4.17E-01	4.11E-01	4.17E-01
	8.0 hr	1.0	10.5	2.13E-02	2.12E-02	2.12E-02	2.17E-02	2.17E-02	2.17E-02

Conclusions

The consequence lookup tables offer a platform for standardization of consequence analysis. Consequence lookup tables can be tailored to any geographical region or a multitude of different release scenarios. SRS employees can use the UCDE consequence lookup tables to forecast the consequences of a radiological release without the use of extensive calculations. The results are then used to support the revisions of the safety documentation that bound the contracts for safe operation of the facilities. The UCDE lookup tables are based on a unit curie release that may be scaled to estimate the consequences of a wide array of radiological release scenarios. Although the UCDE table can be used as a supporting reference to certain safety analyses, users are cautioned when assessing criticality releases with fast decaying isotopes and chains of radioactive daughter products that require extensive additional analysis to obtain accurate results.

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