COMPARISONS OF CAP88PC VERSION 2.0 DEFAULT PARAMETERS TO SITE SPECIFIC INPUTS

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ABSTRACT

The effects of varying the input for the CAP88PC Version 2.0 program on the total effective dose equivalents (TEDEs) were determined for hypothetical releases from the Hot Fuel Examination Facility (HFEF) located at the Argonne National Laboratory site on the Idaho National Engineering and Environmental Laboratory (INEEL). Values for site specific meteorological conditions and agricultural production parameters were determined for the 80 km radius surrounding the HFEF. Four nuclides, ^{3}H, ^{85}Kr, ^{129}I, and ^{137}Cs (with its short lived progeny, ^{137m}Ba) were selected for this study; these are the radioactive materials most likely to be released from HFEF under normal or abnormal operating conditions. Use of site specific meteorological parameters of annual precipitation, average temperature, and the height of the inversion layer decreased the TEDE from ^{137}Cs-^{137m}Ba up to 36%; reductions for other nuclides were less than 3%. Use of the site specific agricultural parameters reduced TEDE values between 7% and 49%, depending on the nuclide. Reductions are associated with decreased committed effective dose equivalents (CEDEs) from the ingestion pathway. This is not surprising since the HFEF is located well within the INEEL exclusion area, and the surrounding area closest to the release point is a high desert with limited agricultural diversity. Livestock and milk production are important in some counties at distances greater than 30 km from the HFEF.

INTRODUCTION

The CAP88PC Version 1.0 program described in Reference 1 was developed by the US Environmental Protection Agency (EPA) to be used to demonstrate compliance with the National Emission Standards for Hazardous Air Pollutants (NESHAPS) promulgated in Reference 2. Version 2.0 of this program, described in Reference 3, was approved recently by Reference 4 to demonstrate compliance. The later version incorporates several improvements, notably in treating the radionuclides in serial decay chains. Since it was issued in 1997, Version 2.0 has been distributed to more than 1,200 users in governmental and academic institutions as well as in the private sector. Predictions by Versions 1.0 and 2.0 are essentially the same for identical input parameters.

Both versions calculate radiation exposures to selected individuals or to populations located within an 80 km distance from as many as six release points or areas within a close proximity. Exposures include contributions from materials that remain outside the body and from materials taken into the body. Cancer risks for adults are estimated for individual exposures and for collective population doses assuming the linear no threshold model is applicable to low values of individual and collective dose equivalents.

A modified Gaussian plume model for dispersion in the atmosphere is used to calculate airborne concentrations and ground deposition of radionuclides released from a given facility. Releases are specified in units of Curies per year. Exposure pathways include submersion in a cloud of airborne gases or particles, irradiation from a large ground plane contaminated with radioactive particles, and internally deposited radionuclides. Three meteorological parameters: annual precipitation, average temperature, and elevation of the inversion layer or “lid” must be supplied to estimate airborne concentrations and deposition rates of released materials. In addition to effective dose equivalents from external sources, uptakes from both inhalation and ingestion are considered. National or state average agricultural production and consumption rates are provided within the program, but users are encouraged to use site specific data where available.

In either version of CAP88PC, the Gaussian model for atmospheric dispersion is appropriate for flat terrain devoid of significant changes in elevation and heat sources. For the Argonne facilities at the INEEL, these limitations are appropriate for vectors to the North, South, and West; there are marked rises in elevation to the East of potential release points. Long-term averages of meteorological parameters such as precipitation, temperature, and wind speed and direction as a function of elevation are determined for the Argonne site by the National Oceanographic and Atmospheric Administration (NOAA). If site specific data are not available, default values are provided by the program.

Concentrations and depositions of radionuclides are determined for distances corresponding to each of the specified receptors. From these values, the TEDE values in units of mrem per year are found for each receptor. Collective TEDE values in person-rem per year are calculated based on the population distribution as a function of distance from the release point. In each of the sixteen compass sectors, the assessment area is divided into concentric rings. Linear interpolation between the inner and outer sector radii is applied to determine average concentrations and deposition of radioactive materials in each interval. Calculated parameters are assumed to be uniform within each of the annular areas defined by the concentric rings. Likewise, production and consumption rates of agricultural products are the same for all members of the population included in that interval. Therefore, everyone within a given set of boundaries receives the same dose equivalents from each exposure pathway. Multiplication of the average dose equivalents by the number of people in the interval yields the collective dose in units of person-rem per year.

Each CAP88PC calculation can be done for individual receptors or for a population distribution within the 80 km radius of the release points. Population data are based on official data from the last census or on estimated figures for later census dates. All of the comparisons in this paper are based on population distributions projected for the year 2010 or for individual receptors. Table I shows the four receptors selected for this study and their distances and bearings from the HFEF.

Table I

Location Of Specific Receptors With Respect To The Release Point

Receptor Location	Distance (km)	Bearing From HFEF
Nearest Site Boundary	5.0	SSE
Maximally Exposed Individual	8.7	SSE
Mud Lake, ID	32.5	NNE
Idaho Falls, ID	48.0	E

SOURCE TERMS

Of all of the facilities operated by Argonne at the INEEL, the HFEF was selected for this comparison study because of the number and variety of its programs and the inventory of radionuclides within its hot cells. All releases were assumed to exit from a 1.44 m diameter stack 28.6 m above the ground. Volumetric flow through the stack imparted an exit velocity of 13.4 m/s which increased the effective height of release because of the momentum of the effluent. Increases depend on the average wind velocities in each of the sixteen directions considered. At the distances of interest, over 5 km, the height of release should have little effect on airborne concentrations in any direction. All calculations in this study are performed with data collected for NOAA at the 10 m elevation; this data set gave larger TEDE values than the data appropriate for winds at the 80 m elevation.

Four nuclides, ^{3}H, ^{85}Kr, ^{129}I, and ^{137}Cs (with its short lived progeny, ^{137m}Ba) were selected for this study; these are the radioactive materials most likely to be released from HFEF under normal or abnormal operating conditions. Treatment of their behavior in the environment by CAP88PC differs because of differences in atmospheric transport, deposition, and uptake by crops, animals, and humans. Both ^{3}H and ^{85}Kr are gases; ^{129}I and ^{137}Cs are treated as particles. Most of the very small TEDEs calculated by CAP88PC for estimated emissions from HFEF is dominated by submersion in ^{85}Kr and uptake of ^{3}H. Even though the particulates are more effective in imparting dose equivalents from all pathways, emissions are far below minimum detectable levels. Inventories of ^{129}I in HFEF are very small, and this element tends to adhere to surfaces because of its high chemical activity. Effluent control systems, notably the filtration trains that incorporate high efficiency particulate-air (HEPA) filters minimize the activity of ^{137}Cs even though thousands of Curies are present within the hot cells in the HFEF. All of the calculations in this paper are based on emission rates of one Curie per year of each of the four materials. Except for ^{85}Kr, actual emissions have been far below this value.

METEOROLOGICAL PARAMETERS

In addition to the wind velocity data, the program requires the input of the annual precipitation, the average annual temperature, and the average height of the inversion layer. Site specific values have been supplied by NOAA and are tabulated in Reference 5, one of the annual NESHAPS reports issued for facilities at the INEEL. Table II compares the CAP88PC default values with those from NOAA for the Argonne site.

Table II

Comparisons Of Meteorological Parameters Used In CAP88PC

Meteorological Parameter	CAP88PC Default	Site Specific Value
Annual Precipitation (cm/yr)	100	30
Average Air Temperature (°C)	10	5.8
Inversion Layer Height (m)	1,000	800

FOOD PRODUCTION AND CONSUMPTION PARAMETERS

In CAP88PC, users must specify the number of beef cattle and milk cows per hectare of the assessment area. Currently, the input screen for this section of the program shows these densities per square kilometer, but this is erroneous according to Reference 6. Since the results of this study are comparisons, rather than absolute values of the TEDEs, the impact of this problem is minimized. Another parameter supplied to the program is the fraction of the land in the assessment area that is cultivated for vegetable crops. Default values are given for each state, but since facilities at the INEEL are located on a government reservation where activities are severely restricted, it is important to find more appropriate parameters for these variables.

A review of References 7, 8, 9, and 10 provided the most current information used to develop food production parameters for the area within 80 km of the HFEF. A digitized map of Idaho with the INEEL superimposed on it reveals that parts of fourteen counties lie within the radius of the assessment area. Of the portions within the 80 km radius, significant fractions of those counties closest to the release point lie within the boundaries of the INEEL. Table III shows the fraction of the county within the assessment area and the weighted numbers of livestock per unit area and the annual weight of vegetables grown assuming uniform crop production and animal population for each county.

Table III
Weighted Agricultural Production Data For Counties In The Assessment Area

Idaho County Name	Percent In Assessment Area	Annual Vegetable Production (kg)	Number Of Beef Cattle	Number Of Milk Cows
Bannock	20	11,000,000	2,600	211
Bingham	88	830,000,000	23,000	7,400
Blaine	14	1,700,00	1,700	31
Bonneville	37	148,000,000	5,600	240
Butte	93	24,000,000	9,200	360
Caribou	0.1	29,000	6	1
Clark	45	202,500,000	3,050	58
Custer	2	170,000	185	7
Fremont	8	36,000,000	900	74
Jefferson	100	450,000,000	17,000	5,100
Lemhi	1	2,400,000	340	11
Madison	42	220,000,000	3,000	640
Minidoka	1	4,500,000	51	85
Power	14	67,000,000	1,400	99

Comparing the data for the three parameters in Table III with the defaults for the entire state, we developed site specific values that are compared in Table IV. Note the significant reduction in the fraction of land cultivated for vegetable crops. This is not surprising because of the large exclusion area of the INEEL and the cold dry climate of Southeast Idaho.

Table IV
Comparison Of Agricultural Parameters For Counties In The Assessment Area

Production Parameter	CAP88PC Default	Site Specific	Reduction
Beef Cattle Density	0.0719	0.0338	53.0%
Milk Cow Density	0.00856	0.00712	16.8%
Cultivated Land Fraction	0.0715	0.0000172	99.9%

Six options for food sources consumed by individuals or populations in the assessment area are available. The user may select default values for the fraction of vegetables, milk, and meat obtained from urban, rural, regional, or local sources. Another option is to specify that none of these items are produced in the assessment area; all of the food is imported. Alternately, the fraction that is appropriate for the area may be entered. Determination of these fractions was beyond the scope of this paper; this would require a detailed marketing survey that included identification of the origins of foodstuffs consumed in all fourteen counties.

Clearly, the urban option is not appropriate for the relatively low population density surrounding the INEEL. If the regional option is selected, the ingestion CEDEs are grossly overestimated because CAP88PC assumes that food is produced uniformly throughout the entire assessment area. Since concentrations of radionuclides are much higher closer to the release point, foodstuffs are much more contaminated. Because of the exclusion area, there is no food production in areas close to the release point. The local option assumes that all of the vegetables, milk, and meat consumed come from the area immediately around the receptor or in the population interval if a collective annual dose is calculated. If the local option is selected, the ingestion CEDE would be overestimated because it is likely that at least some of the food consumed would come from outside of the assessment area. But radionuclide concentrations are appropriate for the receptor locations, rather than for regions closer to the emission source.

The rural option assumes that 70% of the vegetables, 39.9% of the milk, and 44.2% of the meat come from the area around the receptor; the rest is produced regionally. So this option gives higher CEDE values than the local option, but lower values than are given by the regional option. The lowest ingestion CEDE values are from the imported option which specifies that none of the food is contaminated by the radionuclide emissions. In the absence of detailed marketing surveys, we believe that the most accurate values of the ingestion CEDE are less than those predicted by the local option, but more than those predicted by the imported option.

RESULTS

In the first phase of the study, the effect of varying the meteorological parameters in Table II were determined for the three nuclides with four of the food source options using a population distribution estimated for the year 2010. Since ^{85}Kr does not contribute to ingestion doses; it is omitted. For this nuclide, the precipitation, temperature, and height of the inversion layer did not influence the TEDE values. There were no differences for ^{129}I either. Table V presents the comparisons for ^{3}H and the ^{137}Cs-^{137m}Ba isobaric pair.

Table V
Collective TEDEs For ^{3}H and ^{137}Cs In Person-Rem Per Year For Meteorological Parameters

Nuclide	Food Source	Default Values	Site Specific	Change
^{3}H	Rural	0.000451	0.000458	1.55 %
^{3}H	Regional	0.000626	0.000632	0.96 %
^{3}H	Local	0.000313	0.000320	2.24 %
^{3}H	Imported	0.0000449	0.0000459	2.23 %
^{137}Cs + ^{137m}Ba	Rural	2.39	1.65	- 30.96 %
^{137}Cs + ^{137m}Ba	Regional	2.79	1.80	- 35.48 %
^{137}Cs + ^{137m}Ba	Local	2.01	1.44	- 28.36 %
^{137}Cs + ^{137m}Ba	Imported	1.55	1.21	- 21.96 %

All of the calculated collective annual doses are based on one Curie per year releases from the HFEF stack of each nuclide; actual releases have been far less.

Collective TEDEs were found for the four food source options for ^{3}H, ^{129}I, and ^{137}Cs for the default and site specific food production parameters using the site specific meteorological parameters. As expected, there is no effect on the TEDE from ^{85}Kr because it does not enter the food chain; Table VI presents the comparisons for the three nuclides.

Table VI
Collective TEDEs For ^{3}H, ^{129}I, and ^{137}Cs In Person-Rem Per Year For Agricultural Parameters

Nuclide	Food Source	Default	Site Specific	Change
^{3}H	Rural	0.000458	0.000267	- 41.70 %
^{3}H	Regional	0.000632	0.000329	- 47.94 %
^{3}H	Local	0.000320	0.000178	- 44.38 %
^{3}H	Imported	0.0000459	0.0000459	0 %
^{129}I	Rural	7.07	4.90	- 30.69 %
^{129}I	Regional	13.8	7.89	- 42.83 %
^{129}I	Local	1.15	0.678	- 41.04 %
^{129}I	Imported	0.0439	0.0439	0 %
^{137}Cs + ^{137m}Ba	Rural	1.84	1.66	- 9.78 %
^{137}Cs + ^{137m}Ba	Regional	2.13	1.82	- 14.55 %
^{137}Cs + ^{137m}Ba	Local	1.57	1.45	- 7.64 %
^{137}Cs + ^{137m}Ba	Imported	1.21	1.21	0 %

Differences in the ^{3}H and ^{129}I values reflect their importance in the ingestion pathway. Inhalation and exposures from external sources are more important for the ^{137}Cs + ^{137m}Ba isobars than for ^{3}H and ^{129}I.

The population file used in the above parameter study distributed individuals in five intervals in the assessment area. These intervals were centered at 8.05 km, 24.14 km, 40.23 km, 56.33 km, and 72.42 km from the HFEF. The same population was then distributed in a finer grid with 16 annular intervals out to 80 km. Distance between the centers varied from 0.6 to 8 km. Since this grid placed more intervals closer to the point of emission, the TEDE values increased somewhat. For ^{85}Kr, the increase was 1%. Results are given in Table VII for the other three nuclides using site specific values for food production and meteorological parameters. The only increases over 2% are observed for ^{129}I. Of all the nuclides considered, it gives the highest percentage contribution to the TEDE from the ingestion pathway.

Table VII
Effects Of A Finer Distribution Of Population On The TEDE

Nuclide	Food Source	Increase
^{3}H	Rural	0.37 %
^{3}H	Regional	0.30 %
^{3}H	Local	1.12 %
^{3}H	Imported	1.09 %
^{129}I	Rural	3.67 %
^{129}I	Regional	2.79 %
^{129}I	Local	15.93 %
^{129}I	Imported	15.95 %
$^{137}Cs + ^{137m}Ba$	Rural	0.60 %
$^{137}Cs + ^{137m}Ba$	Regional	0.55 %
$^{137}Cs + ^{137m}Ba$	Local	0.69 %
$^{137}Cs + ^{137m}Ba$	Imported	1.65 %

For the four individual receptors described in Table I, changes in the meteorological and food production parameters had no effect on the TEDE values for any of the four nuclides. However, the food source option selected influenced the TEDE delivered by the three nuclides that enter the food chain to a receptor located 5 km from the HFEF as shown in Table VIII. Many of the previous CAP88PC calculations performed for Argonne facilities selected the rural option, so it is used as the base for comparisons in Table VIII. Projected TEDE values in Table VIII are appropriate for one Curie per year releases of each nuclide.

Table VIII
Effect Of The Food Source Option On The Annual TEDE At The Nearest Site Boundary

Nuclide	Food Source	TEDE (mrem/year)	Percent Of Rural Value
^{3}H	Rural	0.0000180	100 %
^{3}H	Regional	0.0000220	122 %
^{3}H	Local	0.0000130	72.2 %
^{3}H	Imported	0.0000032	17.8 %
^{129}I	Rural	1.4	100 %
^{129}I	Regional	1.9	135.7 %
^{129}I	Local	0.87	62.1 %
^{129}I	Imported	0.073	5.21 %
^{137}Cs + ^{137m}Ba	Rural	0.18	100 %
^{137}Cs + ^{137m}Ba	Regional	0.19	105.6 %
^{137}Cs + ^{137m}Ba	Local	0.17	94.4 %
^{137}Cs + ^{137m}Ba	Imported	0.15	83.3 %

For either the site specific or default values for meteorological or food production inputs, the annual TEDE decreases at the same rate as a function of receptor distance from the HFEF. Because of its high deposition velocity, the contributions from ^{129}I are reduced the fastest. Contributions from the two gases, ^{3}H and ^{85}Kr, vary slowly with distance because of the dilution effect rather than by deposition. Particles of ^{137}Cs - ^{137m}Ba are removed more slowly than ^{129}I particles by gravity or precipitation from the cloud of effluent.

CONCLUSIONS

Substitution of site specific meteorological and food production parameters for default values in CAP88PC Version 2.0 have the most effect on collective TEDEs; there are only minor effects for individual receptors. The most likely nuclide to be released, ^{85}Kr, is essentially independent of these parameters. As the number of intervals in the population distribution increases, there is a slight increase in the projected TEDEs for releases from the HFEF. Changes in the three meteorological parameters had the most effect on contributions from the ^{137}Cs - ^{137m}Ba isobaric pair. Use of the local food option is suggested to obtain conservative estimates of the contribution of the ingestion pathway. Ingestion is more important for ^{129}I and ^{3}H than for the ^{137}Cs - ^{137m}Ba isobars. In spite of significant changes in the food production parameters, especially in the fraction of land in the assessment area cultivated for crops, changes in the TEDE were less than a factor of two for the nuclides considered. These results emphasize the importance of considering all of the exposure pathways in projecting collective and receptor TEDEs using CAP88PC Version 2.0.

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