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Population Files for use with CAP88 at Los Alamos

Michael W McNaughton and Burgandy R Brock

Introduction

CAP88 (Clean Air Act Assessment Package 1988) is a computer model developed for the US Environmental Protection Agency to assess the potential dose from radionuclide emissions to air and to demonstrate compliance with the Clean Air Act. It has options to calculate either individual doses, in units of mrem, or a collective dose, also called population dose, in units of person·rem. To calculate the collective dose, CAP88 uses a population file such as LANL.pop, that lists the number of people in each sector (N, NNE, NE, etc.) as a function of distance (1 to 2 km, etc.) out to a maximum radius of 80 km.

Early population files are described in the Los Alamos National Laboratory (LANL) Environmental Reports for 1985 (page 14) and subsequent years. LA-13469-MS describes a population file based on the 1990 census. These files have been updated several times, most recently in 2006 for CAP88 version 3. The 2006 version used the US census for 2000. The present paper describes the 2012 updates, using the 2010 census.

Regulatory Requirements

The collective dose is included in the annual report for compliance with the National Emission Standards for Hazardous Air Pollutants (Rad-NESHAP) and in the annual Environmental Report. This is not an EPA requirement. A calculation of the collective dose is required by DOE Order 458.1, Section 4.e.(2), which states "Dose evaluations ... must include ... the collective dose (population dose) that is a realistic-as-practicable estimate of the sum of the doses to all members of the actual exposed population." The method used here strives to be as realistic as practicable.

DOE Order 458.1 Section 4.e.(1)(d) states "Collective dose for members of the public must be representative of the total dose and of adequate quality for supported comparisons, trending or decisions. Consistent with the graded approach, collective dose estimates may be truncated by distance (e.g., 50 miles) or individual dose level (e.g., 10 microrem) when integration of doses beyond such thresholds does not significantly affect data quality objectives." The individual dose rate decreases with distance, R , and is approximately proportional to $1/R^{1.5}$ (Appendix A) so if the individual dose is 1 mrem at a distance of 0.8 km it will be approximately 1 microrem at 80 km, so truncation at 50 miles is reasonable. Furthermore, truncation at 50 miles has been standard since 1985, so for trending purposes we continue with the same method.

Census Data

We used the 2010 census data to update the 2006 data, which used the 2000 census. The census data are listed by county. Within each county there are also data for a limited number of "Census Designated Places" (CDPs). However, these represent only a fraction of the population. For example, Los Alamos County has two CDPs, Los Alamos and White Rock, as follows.

The county population is listed as 17950 <http://quickfacts.census.gov/qfd/states/35/35028.html> .

The Los Alamos CDP population is 12019 <http://quickfacts.census.gov/qfd/states/35/3542320.html> .

And the White Rock CDP population is 5725 <http://quickfacts.census.gov/qfd/states/35/3584740.html> .

According to the census, 206 people live in some other part of Los Alamos County. As another example,

Espanola CDP is listed with a population of 10224, which does not include people who live nearby. Smaller communities are not CDPs, so the CDPs omit many people. In summary, the county data are the most reliable and the CDPs are of limited value.

Details

Most of the people within 80 km of LANL reside in 4 counties: Los Alamos, Rio Arriba, Sandoval, and Santa Fe. The 80-km radius touches Taos County but does not reach Taos city; it also touches San Miguel County but does not reach Las Vegas; it also touches a rural area of Mora County but does not reach Mora city. According to the census, the populations of these areas have not changed significantly since 2000 so we left the estimates for these areas unchanged. These are represented primarily by the areas between 60 and 80 km in the directions toward ESE, E, ENE, and NE.

For simplicity, we divide the sectors of the population file as follows.

- Los Alamos town site: E, ENE, NE, NNE, N, NNW, NW, WNW, and W from 0 to 10 km.
- White Rock: SSE, SE, and ESE from 5 to 10 km.
- Bandelier National Monument: WSW, SW, SSW, and S, from 5 to 10 km.
- Rio Arriba County: NE, NNE, N, NNW, NW, and WNW from 10 to 80 km.
- Sandoval County: W, WSW, SW, SSW, and S from 10 to 80 km.
- Santa Fe County: SSE, SE, ESE, E, and ENE from 10 to 60 km.

Table 1 shows the “long range” (>10 km) population information. It is the same for all population files, regardless of source.

Table 1 Population by direction and distance from LANL (km). The distance at the head of each column is the outer radius. Three counties are color coded as shown.						
Sector↓	Outer radius (km)					
	20	30	40	50	60	80
N	16	103	1077	0	945	641
NNW	7	22	291	0	0	528
NW	2	27	56	821	0	1153
WNW	0	35	41	0	0	3305
W	14	119	575	0	135	257
WSW	14	70	696	0	4673	0
SW	5	0	0	0	3965	0
SSW	6	1766	2392	5674	4591	100236
S	9	31	274	0	0	6060
SSE	51	406	6811	3328	0	0
SE	1	1318	88346	9870	218	6
ESE	14	868	10461	0	803	2430
E	1915	5002	511	588	1	598
ENE	2600	5419	4317	194	1128	1752
NE	1314	17067	2878	1604	1597	3527
NNE	15	2739	479	3483	0	58
Totals by County:						
	Rio Arriba	40246	Sandoval	131561	Santa Fe	144170

For simplicity, we assumed the entire populations of Rio Arriba, Sandoval, and Santa Fe counties are within 80 km of LANL, and we adjusted the populations within each designated area to make the totals equal to the 2010-census totals:

- Rio Arriba County: 40246
- Sandoval County: 131561
- Santa Fe County: 144170.

Within each county, we used the same relative distribution as in previous population files and scaled all cells by the same factor to get the total for the county. Some cells of the pop10.xlsx file include a comment indicating the name of the town or city. For example, the outskirts of Albuquerque are in the SSW sector between 60 and 80 km, and Santa Fe is SE between 30 and 40 km.

The relatively small numbers that represent the western edges of San Miguel County, Mora County, and Taos County were left unchanged from previous files.

Also, the White Rock and Bandelier sectors are unchanged from the 2006 version, as shown in Table 2 below. Table 2 is used for all population files for the sectors indicated.

Table 2 Population distribution for White Rock and Bandelier National Monument.							
	Outer radius (km)						
Sector↓	0.5	1	2	3	4	5	10
WSW	0	0	0	0	0	0	2
SW	0	0	0	0	0	0	5
SSW	0	0	0	0	0	0	36
S	0	0	0	0	0	0	20
SSE	0	0	0	0	0	0	765
SE	0	0	0	0	0	0	5764
ESE	0	0	0	0	0	0	36

When the Los Alamos town site is included, the total population within 80 km is approximately 343,000.

Los Alamos Town Site

In the past, the sectors and distances were defined with LANSCE (TA-53) as the center. This assumption does not significantly affect the more distant locations. However, it does affect the Los Alamos town site because it is close to some of the sources, especially technical areas TA-1 and TA-21.

The town site extends approximately 6.5 km from the Quemazon area in the west to Los Pueblos street in the east, and approximately 3.5 km from Royal Crest in the south to Guaje Pines in the north. We consider several models of the source relative to the town site: a point source with radial geometry, a line source along the southern boundary of a rectangular town, and a rectangular source south of a rectangular town.

We begin by assuming 9,600 people are uniformly distributed in a semi-circle with a radius of 3 km, with another 2,400 living farther, mostly toward the NW quadrant. The areas of the sectors depend on the radius (Appendix A2). If the distribution is uniform, there would be 267 people within a radius if 0.5 km,

800 people between 0.5 and 1 km, 3200 people between 1 and 2 km, and 5333 people between 2 and 3 km. The remaining 2400 people are between 3 and 5 km in the "North Community" toward the NW of the town site.

This model underestimates the number of people close to TA-21. For example, the Eastern Area (next to the airport) has 75 houses, Verde Ridge (N of DP Road) has 13 buildings each with 4 apartments, El Sombrillo has 64 beds, and Aspen Ridge has 60 residents, so there are about 600 people within 0.5 km of material disposal area MDA B at TA-21.

As further guidance, consider the Los Alamos county precincts. The county is divided into 17 precincts. Precincts #1 through #6 are in White Rock and #7 through #17 are in the town site; each precinct contains about 1,000 people. The semicircle with radius 1 km includes most of Precinct #9, and the semicircle between 1 and 2 km includes most of Precincts #7, #8, and #15, so there are about 4000 people within a radius of 2 km.

In addition to residences, there are also businesses in these precincts. However, according to DOE Order 458.1, the population estimate should be "as realistic as practicable" so we assume these businesses are occupied one quarter of the time, and the occupants of these businesses are approximately equal to the number of residents who are away from home, working at LANL during this time. So the selected numbers reasonably represent the number of residents.

The uniform-distribution model overestimates the number of people in more distant sectors, especially toward the E, ENE, and NE, so we have decreased the numbers in these distant sectors and increased the numbers close to the source. With these adjustments, there are 600 people within 0.5 km, corresponding to the Eastern Area, El Sombrillo, Aspen Ridge, and Verde Ridge; also there are 1300 people within 1 km corresponding to Precinct #9 and part of Precinct #8; and there are 4100 people within 2 km, corresponding to Precincts #7, #8, #9, and #15. The results are shown in Table 3 below.

Table 3 Population distribution in the Los Alamos town site, assuming the source is TA21.							
	Outer radius (km)						
	0.5	1	2	3	4	5	10
E	0	0	0	333	0	0	0
ENE	0	0	0	0	0	0	0
NE	100	0	400	666	0	0	0
NNE	100	0	400	666	0	0	0
N	100	0	400	666	0	0	0
NNW	100	200	400	666	400	0	0
NW	100	200	400	666	800	400	0
WNW	100	200	400	666	800	457	0
W	0	100	400	333	400	0	0

There are many LANL sources, so we also modeled the town site as a rectangle: 6.5 km from east to west and 3.5 km from north to south; and we assumed the LANL sources are uniformly distributed within a rectangle, 6 km east to west and 5 km north to south, that is adjacent to and immediately south of the town site. An Excel spreadsheet (pop10.xlsx) was used to populate the sectors, and the total was

normalized to the total population of the Los Alamos "Census Designated Place", 12019. The results are shown below in Table 4.

Table 4							
Population distribution in the Los Alamos town site, assuming LANL is an area adjacent to the southern boundary of the town site.							
	Outer Radius (km)						
	0.5	1	2	3	4	5	10
E	0	7	22	26	25	30	18
ENE	4	19	34	65	115	142	281
NE	8	4	58	146	218	266	1030
NNE	4	17	102	173	375	282	1299
N	4	13	89	231	274	514	1350
NNW	4	17	102	173	375	282	1299
NW	8	4	58	146	218	266	1030
WNW	4	19	34	65	115	142	281
W	0	7	22	26	25	30	18

We also modeled the LANL sources as a line of sources along the southern boundary of the town site, corresponding primarily to the historical areas of TA-1 and TA21. This population distribution is in Table 5 below.

Table 5							
Population distribution in the Los Alamos town site, assuming the primary sources are in a line close to the southern boundary of the town site.							
	Outer radius (km)						
	0.5	1	2	3	4	5	10
E	0	0	134	156	150	181	106
ENE	24	117	205	321	359	348	407
NE	51	24	260	372	447	343	106
NNE	26	99	284	423	442	0	0
N	26	79	313	506	326	0	0
NNW	26	99	284	423	442	0	0
NW	51	24	260	372	447	343	106
WNW	24	117	205	321	359	348	407
W	0	0	134	156	150	181	106

Finally, for use when the source is at TA-53, we retained the town-site population distribution of the 2006 file, except we added 50 people north of TA-53 to represent the new hotel and the new Co-op. The file pop10.xlsx includes comments that identify the approximate locations in the town site.

Summary

In summary, the population files are as follows.

LANLta53.pop should be used if the source is at TA-53.

LANLta21.pop should be used if the source is at TA-21.

LANLarea.pop should be used if the source consists of multiple stacks and diffuse sources.

LANLline.pop should be used if the source is the historical areas, TA-1, TA-21, and Los Alamos Canyon.

Printouts of these files are in Appendix B.

The calculation spreadsheet pop10.xlsx is in the RAD-NESHAPS\CAP88 v3 work\Population files folder.

References

CAP88 version 3. <http://www.epa.gov/radiation/assessment/CAP88/> (2007).

LA-13469-MS. Jacobson, Keith W, Duffy, Susan, and Kowalewsky, Karen. "Population Array and Agricultural Data Arrays for the Los Alamos National Lab." (1998).

US Census. <http://2010.census.gov/2010census/data/> (2010)

Appendix A: Mathematical Models

Section A.1: Dose as a function of distance (radius)

Generally, dose decreases with distance, R . This is easily visualized by the log-log plots produced by the Lawrence-Livermore-Lab program: "Hotspot". For simplicity, choose an effective release height of zero to avoid the lofting that occurs from a stack and display the "TEDE Graph". Near to the source, the dose decreases by a factor of 100 for every factor-of-ten increase in distance, so the dose is proportional to $1/R^2$. This is because the plume spreads horizontally and vertically. In some cases, especially at larger distances, the dose decreases by a factor of 1000 for every factor-of-100 increase in distance, so the dose is proportional to $1/R^{1.5}$. This is because the vertical extent of the plume is limited by the ground below and possibly a "Mixing Layer", "Inversion", or "Mixing Height". Experience with Hotspot shows that from 0.8 km to 80 km, the dose decreases by at least a factor of 1000.

Section A.2: Geometry

The CAP88 population files use polar coordinates: 16 directions each subtending 22.5° , and 13 radii: $R = 0.5$ km, 1 km, 2 km, 3 km, etc. The tables use the CAP88 convention and list the outer radius. In each case, CAP88 assigns the population to the average radius: 0.25 km, 1.5 km, 2.5 km, etc. For polar geometry, the area in one of the 16 sectors between R_1 and R_2 is $\pi(R_2^2 - R_1^2)/16$.

The population distributions for the line and area sources are calculated in pop10.xlsx. The worksheet "calcs" begins with an array from 0 to 6.25 km from west to east and 3.25 km from south to north, and for each cell, we use the Pythagorean theorem to calculate the distance. This array is repeated with east-west offsets to represent a line of sources along the southern border. Below these arrays there are similar arrays containing the angle, and to the right we use the COUNTIFS function to count the number that satisfy the criteria for each range of distances and directions.

A more even distribution is obtained by using a smaller step size. So we generate more cases by making a small change to cell A2, copying the results into worksheets calc2 and calc3, and averaging the results. The results are normalized to 100% and then multiplied by a factor so the total is equal to the population of the town site, assumed to be 12019.

For an area source, we introduce a series of offsets in the north-south direction, average the results, normalize to 100%, and multiply by a factor so the total is 12019.

Appendix B: Population files

Introduction

The actual population files are difficult to read and difficult to edit. For editing, we recommend using the CAP88 "Population File Editor" and then checking the file with the "Scan Population Files" option of CAP88. For a printout that is easier to read, we recommend the CAP88 Synopsis file.

The population files and the population file editor both use the outer radius of each cell, as in the tables of this paper. However, the synopsis file uses the midpoint distance. For each pop file, the output of the synopsis file is listed below.

POPULATION DATA

Distance (m)							
Direction	250	750	1500	2500	3500	4500	7500
N	0	50	0	157	184	183	0
NNW	0	0	0	566	276	397	50
NW	0	0	0	312	647	786	1336
WNW	0	0	0	38	959	1047	5063
W	0	0	0	0	161	169	15
WSW	0	0	0	0	0	0	2
SW	0	0	0	0	0	0	5
SSW	0	0	0	0	0	0	36
S	0	0	0	0	0	0	20
SSE	0	0	0	0	0	0	765
SE	0	0	0	0	0	0	5764
ESE	0	0	0	0	0	0	36
E	0	0	0	0	0	0	3
ENE	0	0	0	0	0	0	0
NE	0	0	11	0	0	0	0
NNE	0	1	22	0	0	0	0

Distance (m)						
Direction	15000	25000	35000	45000	55000	70000
N	16	103	1077	0	945	641
NNW	7	22	291	0	0	528
NW	2	27	56	821	0	1153
WNW	0	35	41	0	0	3305
W	14	119	575	0	135	257
WSW	14	1	696	0	4673	0
SW	5	0	0	0	3965	0
SSW	6	1766	2392	5674	4591	100236
S	9	31	274	0	0	6060
SSE	51	406	6811	3328	0	0
SE	1	1318	88346	9870	218	6
ESE	14	868	10461	0	803	2430
E	1915	5002	511	588	1	598
ENE	2600	5419	4317	194	1128	1752
NE	1314	17067	2878	1604	1597	3527
NNE	15	2739	479	3483	0	58

POPULATION DATA

Distance (m)							
Direction	250	750	1500	2500	3500	4500	7500
N	100	0	400	666	0	0	0
NNW	100	200	400	666	400	0	0
NW	100	200	400	666	800	400	0
WNW	100	200	400	666	800	457	0
W	0	100	400	333	400	0	0
WSW	0	0	0	0	0	0	2
SW	0	0	0	0	0	0	5
SSW	0	0	0	0	0	0	36
S	0	0	0	0	0	0	20
SSE	0	0	0	0	0	0	765
SE	0	0	0	0	0	0	5764
ESE	0	0	0	0	0	0	36
E	0	0	0	333	0	0	0
ENE	0	0	0	0	0	0	0
NE	100	0	400	666	0	0	0
NNE	100	0	400	666	0	0	0

Distance (m)						
Direction	15000	25000	35000	45000	55000	70000
N	16	103	1077	0	945	641
NNW	7	22	291	0	0	528
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NE	1314	17067	2878	1604	1597	3527
NNE	15	2739	479	3483	0	58

LANline.pop

POPULATION DATA

Direction	Distance (m)						
	250	750	1500	2500	3500	4500	7500
N	26	79	313	506	326	0	0
NNW	26	99	284	423	442	0	0
NW	51	24	260	372	447	343	106
WNW	24	117	205	321	359	348	407
W	0	0	134	156	150	181	106
WSW	0	0	0	0	0	0	2
SW	0	0	0	0	0	0	5
SSW	0	0	0	0	0	0	36
S	0	0	0	0	0	0	20
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POPULATION DATA

Distance (m)							
Direction	250	750	1500	2500	3500	4500	7500
N	4	13	89	231	274	514	1350
NNW	4	17	102	173	375	282	1299
NW	8	4	58	146	218	266	1030
WNW	4	19	34	65	115	142	281
W	0	0	22	26	25	30	18
WSW	0	0	0	0	0	0	2
SW	0	0	0	0	0	0	5
SSW	0	0	0	0	0	0	36
S	0	0	0	0	0	0	20
SSE	0	0	0	0	0	0	765
SE	0	0	0	0	0	0	5764
ESE	0	0	0	0	0	0	36
E	0	0	22	26	25	30	18
ENE	4	19	34	65	115	142	281
NE	8	4	58	146	218	266	1030
NNE	4	17	102	173	375	282	1299

Distance (m)						
Direction	15000	25000	35000	45000	55000	70000
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