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ABSTRACT

Recovery of oil from shale by use of nuclear explosives has been proposed. The principal radiological impact of this application of nuclear explosives would be expected to result from introduction of tritium into hydrocarbon products, including gasoline. We estimated the potential radiation dose that could result from tritiated gasoline by assuming that all gasoline used in the metropolitan Denver area in 1971 contained 5 microcuries of tritium per gallon. The tritium would be converted to HTO and released from automobile exhausts at ground level. Traffic counts at various locations in the area together with a national average value for gasoline consumption was used to estimate tritium release rates in each of 400 four-km^2 areas into which the metropolitan area was divided. This information, together with annual average meterological data from the Denver area, provided input to the AIRDOT computer code which calculates doses from dispersed atmospheric radioactivity releases. The estimated highest potential dose to a continuously exposed individual is 0.006 millirem/year and the potential population dose to 1.06 million people living in the area is 2.3 man-rem/year. These figures can be compared with the estimated background radiation dose from natural sources in Colorado of 164.6 millirem/year which results in a population dose to 1.06 million people of 175,000 man-rem/year.

INTRODUCTION

One of the many peaceful uses of nuclear explosives that have been suggested is the recovery of oil from oil shale.[1] No oil has been produced by this means and it is not clear at this time when, if ever, the technology of this particular nuclear application will progress to the production stage. Furthermore, even if commercial production of gasoline should result from use of nuclear explosives, it seems highly unlikely that all gasoline in a particular metropolitan area would be produced by this means. Nevertheless, the simplest method to estimate potential radiation doses to individuals and to population groups is to assume, as we have done in this study, that the entire gasoline supply is contaminated with tritium which is converted to HTO and released from automobile or truck exhausts at ground level. We selected the metropolitan Denver area for this study because of the availability of meteorological data and population distribution information collected in an earlier investigation of potential radiation doses due to hypothetical use of natural gas from nuclearly stimulated wells to fuel the Cherokee Steam Electric Station in this area.[2]

METHOD OF CALCULATION

In order to estimate radiation dose from a radionuclide released over a wide area, we used a computer code called AIRDOT which is an unpublished adaptation by F. H. Clark of this Laboratory of the AIRDOS code[3] which deals with point sources. The AIRDOS code is a refinement of the STACKDOSE code used in the Cherokee study[2] mentioned above. The model on which the AIRDOT code is based considers an area to be covered by a 20 x 20 square grid and the code calculates the contribution of each of the 400 squares to the pollution level in the other 399 squares, sums the individual pollution concentrations, and calculates the corresponding dose. Release rates for each square and annual average meteorological data are required input information. Also, if population dose is desired, population distribution data must be supplied.

LOCATION OF GRID USED IN THE AIRDOT CODE

For the purposes of this calculation the 20 x 20 grid was superimposed on a map of metropolitan Denver. The entire grid forms a large square 40 kilometers on a side. The grid thus contains 400 small squares each 2 kilometers on a side. The grid is bounded on the north by latitude 39.91711°N, on the east by longitude 104.750°W, on the south by latitude 39.5544°N, and on the west by longitude 105.21624°W. Figure 1 shows how the grid fits the Denver area, and indicates the location of major roads and many of the surburban communities.

ESTIMATION OF HYPOTHETICAL TRITIUM RELEASE IN EACH SQUARE OF GRID

Traffic density maps[4] of metropolitan Denver for 1971 were used to estimate the daily car-miles of traffic in each square. These maps give the average daily weekday traffic density for the various streets. For each square the product of the length of each street and its daily traffic density were summed to obtain the total daily car-miles.

We used a conversion factor of 12.16 miles per gallon to convert from car-miles to volume of gasoline consumed; this is an average figure that has been reported for the whole United States for 1971.[5] For the

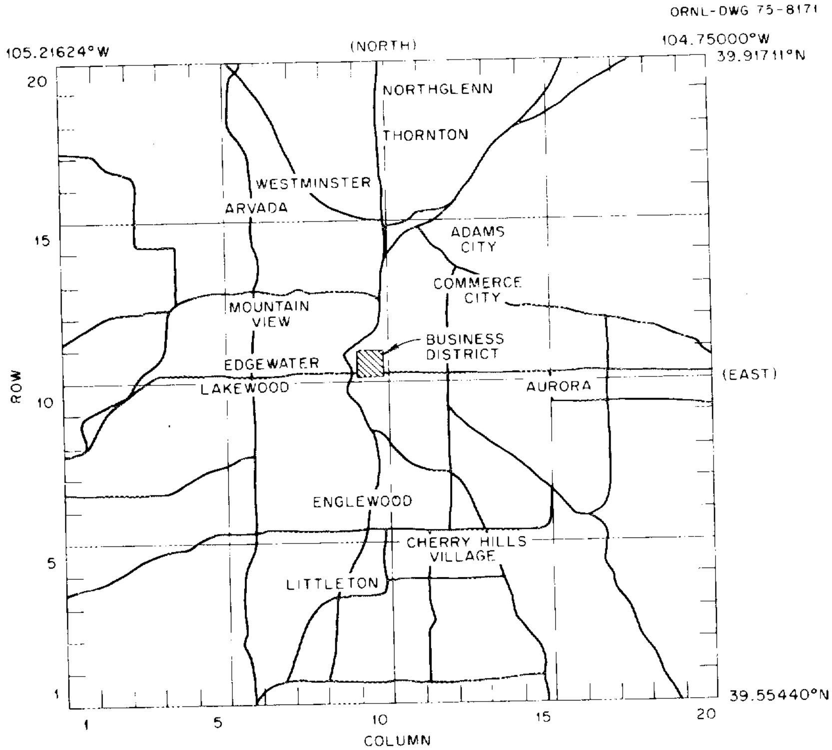

Figure 1. Location of 20 x 20 Grid on Map of Metropolitan Denver.

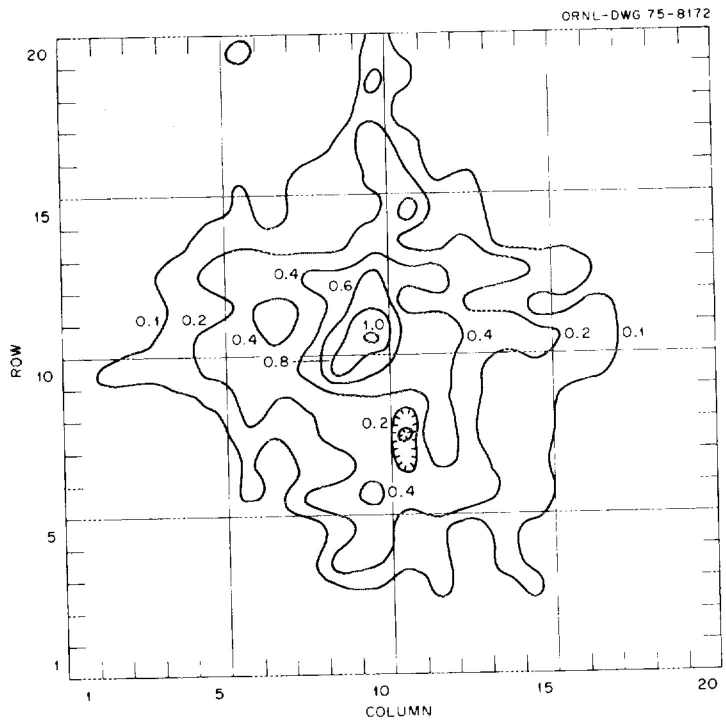

Figure 2. Release Rate Contours for Tritium Relative to the Maximum Calculated Rate (1.49 μCi sec^{-1} per square).

purposes of this calculation we have assumed that the weekend traffic density is the same as that for weekdays. The total 1971 gasoline consumption over the whole grid calculated from these data comes to 57% of the 1973 reported sales[6] of gasoline in the metropolitan Denver area. We believe this shows good agreement with our calculated gasoline consumption when we consider that different years are involved and that the areas may be somewhat different.

To convert from gallons of gasoline to the equivalent tritium that would be released if the gasoline were produced using nuclear explosives, we used a factor of 5 microcuries of tritium per gallon. This concentration is an estimate of Schwartz, Levy and Taylor;[7] they reported that this figure has an uncertainty of a factor of 2. The resulting estimated tritium release rate for each of the squares is given in Table 1. Figure 2 shows how the release rates vary over the grid.

Population in Each Grid Square

Census data for 1970 were used to determine the population in each square of the grid. The data for each census district included the total residents of the district and the location of its centerpoint in longitude and latitude. A computer was used to assign each census district of this area to a particular grid square according to the location of its centerpoint. All of the residents of the district were assumed to live in that square. The resulting data for all the squares of the grid are shown in Table 2; these data were used in constructing Figure 3.

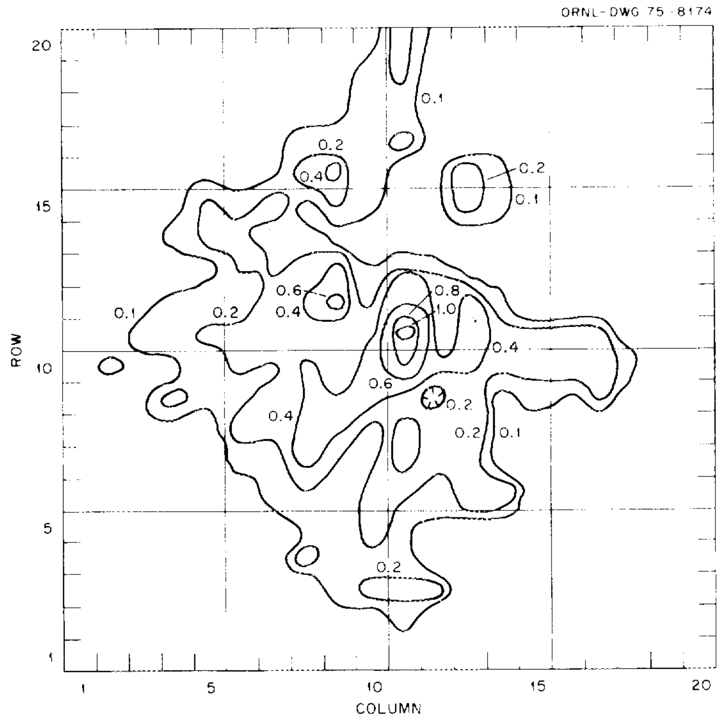

Figure 3. Relative Population Density in Metropolitan Denver in 1970.

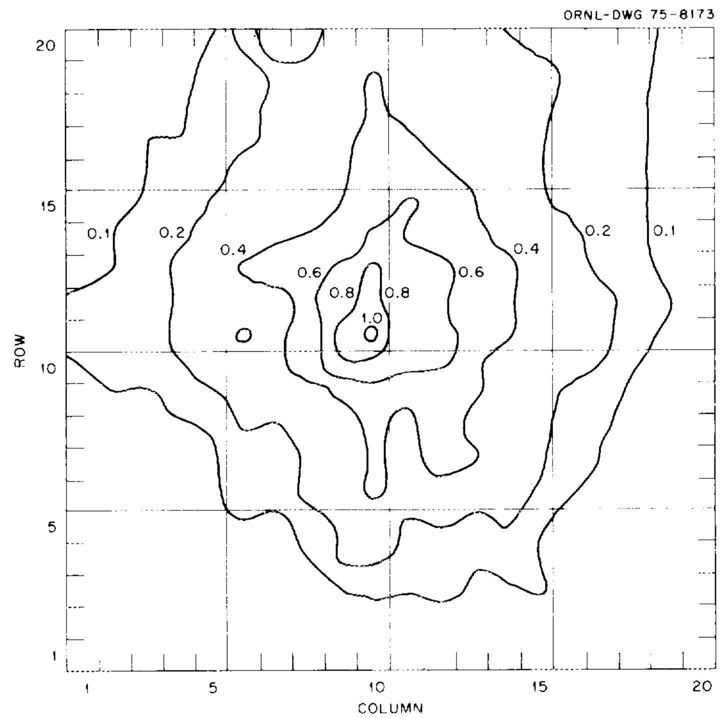

Figure 4. Estimated Relative Annual Doses Hypothetically Received by Residents of Metropolitan Denver from Burning Gasoline Containing 5 μCi Tritium per Gallon.

Table 1. Estimated Average Rate of Tritium Release in Metropolitan Denver as Result of Burning Gasoline Produced from Nuclearly-Stimulated Shale Oil

Release Rate (mμCi-sec^{-1}-square^{-1})

Row	Column 1(W)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20(E)
										(North)										
20	6	10	20	12	12	266	67	66	62	183	80	15	2	6	18	85	55	30	2	2
19	0	0	18	1	0	73	129	22	73	357	180	47	29	17	131	56	6	1	1	0
18	13	0	19	2	1	71	143	19	65	282	89	12	5	138	62	24	2	2	1	0
17	5	18	37	2	2	70	26	79	169	457	252	77	113	77	29	0	0	0	3	1
16	0	2	27	25	29	149	45	251	184	357	330	144	167	98	0	0	0	0	0	0
15	5	6	60	74	87	192	77	216	247	170	685	236	236	58	0	0	0	0	0	0
14	0	52	26	89	269	261	238	176	150	513	252	228	300	81	13	53	4	4	1	0
13	0	51	74	265	336	537	511	651	699	962	685	810	367	471	287	371	0	6	0	0
12	130	67	84	188	195	347	219	321	637	1160	382	528	257	261	0	148	214	70	49	21
11	131	16	106	240	357	461	288	451	1170	1490	834	834	566	490	428	252	200	119	36	40
10	103	197	221	224	334	594	428	661	1390	962	784	742	362	142	277	283	190	54	29	7
9	80	60	0	120	155	335	169	321	397	580	504	661	366	115	210	83	119	3	0	0
8	124	18	14	47	41	293	163	269	366	542	60	881	300	75	216	101	72	2	0	0
7	0	49	5	0	42	157	38	209	266	461	249	623	576	150	186	34	64	2	0	0
6	25	76	20	27	73	157	135	305	409	751	404	480	447	276	242	65	46	9	4	3
5	0	48	38	36	20	76	13	92	228	388	78	180	28	233	85	0	19	3	2	2
4	52	18	2	4	15	59	24	93	394	390	175	185	72	233	40	3	12	10	1	1
3	0	0	0	0	5	45	12	67	103	135	78	178	60	109	158	31	34	32	2	2
2	0	0	0	0	2	48	7	25	4	36	9	36	11	0	106	0	0	17	16	0
1	0	0	0	0	5	48	60	64	34	26	11	9	2	1	103	0	0	1	31	0
										(South)										

Table 2. Population[a] in Squares of the 40 km x 40 km Grid[b] Superimposed over Metropolitan Denver

Row	Column									
	1(W)	2	3	4	5	6	7	8	9	10
						(North)				
20	0	0	0	0	0	219	0	20	0	297
19	0	0	561	0	0	0	0	20	43	5183
18	0	0	0	0	0	0	526	0	2156	4790
17	0	0	0	0	0	0	2011	4599	5218	4923
16	313	0	0	633	1440	1692	2114	7825	12309	5590
15	0	0	0	843	8416	4666	8759	2234	6297	2854
14	262	338	1204	4268	7039	6790	3688	3489	2682	499
13	0	0	341	833	1687	5799	5517	9688	14281	2999
12	0	0	1907	3528	4859	3055	10014	11733	17679	2563
11	2440	1178	4381	3683	7028	7408	9564	9448	7907	9561
10	1000	3251	1958	2351	3386	7241	5599	12553	4454	16218
9	0	266	1444	6929	2985	4589	7967	11721	11644	13575
8	0	0	0	3545	0	8514	7152	13369	11480	3401
7	0	23	0	0	153	3268	4006	15673	4631	5570
6	922	205	0	785	1015	484	4089	5122	2868	7943
5	0	0	164	0	912	0	223	3241	3876	10389
4	0	0	0	319	0	0	945	5898	4020	5040
3	0	0	0	501	0	0	1948	807	4735	6422
2	0	551	0	0	0	0	1437	602	1067	1621
1	0	0	0	0	0	0	1448	0	0	0
						(South)				

Row	Column									
	11	12	13	14	15	16	17	18	19	20(E)
					(North)					
20	9474	60	0	0	2130	0	0	0	0	0
19	10589	244	6	25	0	0	0	0	0	0
18	4535	1719	82	275	0	0	0	0	0	0
17	10041	1276	0	664	0	0	0	0	0	0
16	2190	132	7119	3610	0	0	115	0	0	0
15	831	331	7326	4927	0	0	0	0	0	0
14	868	462	1938	2039	0	0	0	0	0	0
13	5151	3765	2	72	0	0	4976	0	66	0
12	16180	10483	13288	5355	0	0	8505	0	0	0
11	28085	9117	14121	10166	11141	10679	6842	817	762	270
10	22955	12513	13253	8036	7508	8186	9731	3268	118	0
9	11118	3960	7593	2238	4311	2240	6423	115	0	0
8	11475	7713	13757	2292	1032	2325	248	30	0	0
7	13572	7394	5939	1250	49	1194	0	0	0	76
6	6013	4187	9713	8948	2795	0	0	0	0	0
5	3921	579	1763	7	973	0	0	0	0	0
4	4511	0	788	33	270	268	215	0	0	0
3	7050	8821	436	1224	13	212	0	0	407	0
2	4001	492	922	888	0	0	26	0	0	0
1	0	0	0	0	0	0	0	0	0	0
					(South)					

[a]Data from 1970 census.

[b]Grid bounded by 104.7500°W to 105.2164°W latitude and 39.5544°N to 39.91711°N latitude. Each square is 2 km x 2 km.

Meteorology of the Denver Area

The meteorological data used in this calculation are in general the same as those used in an earlier analysis of hypothetical tritium doses to be expected if the Denver Cherokee Electric Power Station were to burn nuclearly-stimulated natural gas.[2] The data used are averages of readings taken at the Stapleton International Airport in Denver in the period 1951 - 1960.

The fraction of time the wind blows at different speeds and in different directions is shown in Table 3. For use in this calculation we averaged the wind speeds on a reciprocal basis as well as in the normal way.

Because the dispersion of gas depends on the relative stability of the air column, it was also necessary to know the fraction of time various stability categories occurred. We used the same values as Moore and Barton[2] after shifting Pasquill stability categories B to G one step toward the less stable condition in order to compensate (as recommended by Gifford[8]) for the instability arising both from the presence of heat sources and from the air turbulence caused by buildings. The final values are shown in Table 4.

Dose and Meteorological Assumptions

Several additional data and assumptions were necessary in order to calculate doses. The ICRP standard man breathing rate[9] of 833,000 cm^3/hr was used in dose calculations. A value of 1512 meters was taken as the annual average "lid" height, the point above which the air column is stable; this is the value used by Moore and Barton.[2] We took 13°C

Table 3. Meteorological Data Taken at Stapleton International Airport, Denver, Colorado[a]

Wind Direction		Percent of Year at Each Wind Speed and Direction					Average Wind Speed (m/sec)	
		Wind Speed (m/sec)				Total		
From	Toward	0-1.56	1.56-5.59	5.59-10.98	>10.98		Normal	Reciprocal
N	S	0.7	4.0	2.0	0.2	6.9	4.90	3.06
NNW	SSE	0.5	2.7	1.0	0	4.2	4.36	2.80
NW	SE	0.6	3.4	1.8	0.2	6.0	4.99	3.10
WNW	ESE	0.4	2.0	1.6	0.4	4.4	5.80	3.42
W	E	0.3	1.9	1.0	0.2	3.4	5.21	3.25
WSW	ENE	0.4	2.0	0.5	0.1	3.0	4.27	2.66
SW	NE	0.6	3.6	1.0	0.0	5.2	4.16	2.77
SSW	NNE	1.7	9.6	5.2	0.1	16.6	4.81	3.05
S	N	1.8	10.5	5.1	0.2	17.6	4.74	3.02
SSE	NNW	0.5	3.1	1.1	0.1	4.8	4.54	2.94
SE	NW	0.5	3.0	0.9	0.0	4.4	4.21	2.79
ESE	WNW	0.4	2.4	0.8	0.0	3.6	4.31	2.84
E	W	0.5	2.8	1.1	0.1	4.5	4.60	2.90
ENE	WSW	0.5	2.6	1.1	0.2	4.4	4.82	2.93
NE	SW	0.5	3.1	1.1	0.1	4.8	4.54	2.94
NNE	SSW	0.6	3.6	1.7	0.1	6.0	4.77	3.04

[a]Averages for period 1951-1960.

Table 4. Annual Average Frequency of Occurrence of Atmospheric Stability Categories in Denver (fraction of time)[a]

Wind Direction		Stability Categories						
From	Toward	A	B	C	D	E	F	G
N	S	0.1546	0.1930	0.5630	0.0481	0.0303	0.0103	0.0000
S	N	0.0445	0.0727	0.5035	0.2070	0.1248	0.0464	0.0000

[a]After shifting categories B-G one category to left to compensate for extra turbulence arising from thermal sources and from roughness of buildings in a city such as Denver.

(55°F) as an average temperature. We assumed that the ^3H existed as gaseous HTO without being absorbed to suspended dust and that it was not taken up by the ground, or absorbed in rain. This latter assumption is justified because Denver is located in a semi-arid region with an average annual rainfall of 14.8 in.

Our meteorological model does not take into consideration the street-canyon effect in the downtown area where the highest calculated tritium concentrations occur. Hanna[10] has pointed out that measured carbon monoxide values in this situation exceed values predicted by a simple meteorological model by a factor of two. However, our dose calculations assume continuous (168 hr/week) exposure and it is unlikely that many people would be exposed in the business area for more than 40 hr/week. The continuous exposure assumption more than compensates for the street-canyon effect.

For a dose conversion factor we used 1.1×10^{-4} rem/μCi, a value calculated by Killough, Rohwer and Turner.[11] Part of this value, 0.6×10^{-4}, corresponds to inhalation and absorption through the lungs; the rest, 0.5×10^{-4}, accounts for absorption through the skin.

Results of the Calculation

The estimated annual doses of tritium in the various squares of the grid are shown in Table 5. The maximum estimated dose, which is 5.7 μrem/yr, is in the square that covers the Denver central business district (column 10, row 11). The annual doses in the other squares have been divided by this maximum dose, and resulting numbers have been

Table 5. Estimated Tritium Dose from Hypothetical Use of Gasoline from Shale Oil Produced with Nuclear Explosives

Row	Dose (μrem/yr) Column 1(W)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20(E)
										(North)										
20	0.30	0.35	0.44	0.50	0.62	1.25	1.06	1.13	1.32	1.85	1.69	1.45	1.27	1.15	1.13	1.10	0.86	0.68	0.51	0.43
19	0.31	0.36	0.47	0.52	0.65	0.95	1.26	1.16	1.47	2.29	1.97	1.63	1.44	1.34	1.38	1.05	0.77	0.62	0.50	0.41
18	0.35	0.39	0.52	0.56	0.69	1.00	1.29	1.27	1.64	2.40	2.05	1.74	1.58	1.63	1.27	0.98	0.75	0.62	0.50	0.41
17	0.34	0.43	0.58	0.62	0.77	1.12	1.18	1.59	1.99	2.82	2.55	2.07	1.94	1.63	1.22	0.95	0.77	0.63	0.49	0.40
16	0.35	0.43	0.61	0.75	0.94	1.39	1.34	2.00	2.15	2.64	3.03	2.44	2.20	1.72	1.20	0.97	0.77	0.63	0.49	0.39
15	0.36	0.48	0.69	0.89	1.24	1.64	1.62	2.03	2.29	2.59	3.64	2.70	2.45	1.74	1.25	1.03	0.79	0.63	0.48	0.37
14	0.36	0.58	0.68	1.06	1.69	2.01	2.18	2.35	2.59	3.68	3.27	3.12	2.75	2.06	1.51	1.38	0.86	0.64	0.48	0.36
13	0.44	0.61	0.79	1.36	1.74	2.40	2.53	3.08	3.67	4.78	4.02	4.06	2.83	2.68	1.86	1.83	0.98	0.70	0.50	0.36
12	0.69	0.63	0.82	1.24	1.55	2.09	1.99	2.53	3.90	5.45	3.75	3.71	2.78	2.45	1.55	1.49	1.36	0.86	0.58	0.39
11	0.66	0.61	0.91	1.29	1.76	2.29	2.10	2.78	4.93	5.68	4.33	4.07	3.10	2.55	2.14	1.62	1.27	0.85	0.50	0.37
10	0.57	0.82	0.93	1.09	1.49	2.24	2.05	2.78	4.50	4.05	3.74	3.62	2.53	1.72	1.69	1.45	1.10	0.61	0.41	0.27
9	0.51	0.48	0.42	0.73	0.93	1.55	1.35	1.85	2.29	2.90	2.64	3.29	2.33	1.46	1.42	0.97	0.83	0.43	0.30	0.22
8	0.48	0.36	0.37	0.48	0.59	1.24	1.09	1.51	1.94	2.53	1.66	3.37	2.20	1.32	1.33	0.87	0.65	0.36	0.26	0.20
7	0.23	0.39	0.33	0.35	0.53	0.90	0.79	1.33	1.70	2.41	1.94	2.64	2.43	1.39	1.22	0.69	0.56	0.32	0.24	0.19
6	0.24	0.40	0.33	0.37	0.50	0.76	0.78	1.26	1.71	2.58	1.83	1.93	1.70	1.38	1.12	0.61	0.45	0.28	0.22	0.18
5	0.20	0.31	0.30	0.32	0.34	0.52	0.46	0.75	1.32	1.75	1.05	1.15	0.73	1.14	0.69	0.40	0.35	0.24	0.20	0.17
4	0.25	0.21	0.19	0.22	0.27	0.42	0.39	0.62	1.31	1.39	0.95	0.97	0.65	0.95	0.56	0.37	0.31	0.25	0.18	0.15
3	0.13	0.15	0.16	0.18	0.22	0.36	0.32	0.47	0.59	0.68	0.57	0.74	0.48	0.55	0.66	0.35	0.29	0.26	0.18	0.15
2	0.12	0.13	0.14	0.16	0.19	0.33	0.30	0.36	0.32	0.38	0.32	0.36	0.29	0.26	0.50	0.24	0.19	0.20	0.19	0.13
1	0.11	0.12	0.13	0.14	0.17	0.27	0.32	0.34	0.30	0.28	0.25	0.24	0.21	0.20	0.39	0.18	0.16	0.14	0.19	0.12
										(South)										

used to construct Figure 4, which shows the contours for doses that are 10, 20, 40, 60 and 80% of this maximum.

The estimated sum of the annual doses received by the whole population of the grid is 2.3 man-rem/yr. The total population numbers 1,059,645 people. Thus the average estimated dose is 2.2×10^{-6} rem/yr, which is 39% of the maximum dose. We did not consider possible doses to other nearby populations in this study although we did include Colorado Springs in the exposed population in our earlier investigation.[2] Vertical diffusion and other factors would reduce the dose to this and other adjacent cities to a fraction of the Denver dose.

DISCUSSION AND CONCLUSIONS

After considering the uncertainties in the concentration of tritium in gasoline from oil produced with nuclear explosives, in the amount of gasoline burned, and in the method of calculation, we believe the uncertainties in the calculated doses amount to a factor of between 5 and 10.

The highest estimated annual whole body dose that a continuously exposed individual could receive under the assumptions set forth in this report and through the pathways considered is 0.006 millirem/year. This dose is the same as the highest annual tritium dose to individuals in the Cherokee study.[2] It is quite low compared to the "as low as practicable" whole body limit of 5 millirem/yr which the U.S. Nuclear Regulatory Commission has set for gaseous discharges from light water reactors.[12] It is even lower compared to the standard which has been set by the International Commission on Radiological Protection (500 millirem/year)[9] or to the dose from natural sources, which has been reported[13] to be

164.6 millirem/year for residents of Colorado. In addition the population dose is only 2.3 man-rem/year from this potential radiation source. It appears, therefore, that even if all the gasoline used in a metropolitan area such as Denver were to be contaminated with tritium at the level assumed here, the resulting dose to individuals or to the total population will be small by any of these standards.

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