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KY-749

# PGDP

## PADUCAH GASEOUS DIFFUSION PLANT

**MARTIN MARIETTA**

URANIUM DISCHARGES AT PADUCAH GDP, 1953-1983

R. C. Baker

Personnel Division

June 1985

OPERATED BY  
MARTIN MARIETTA ENERGY SYSTEMS, INC.  
FOR THE UNITED STATES  
DEPARTMENT OF ENERGY

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Prepared by the  
Paducah Gaseous Diffusion Plant  
Paducah, Kentucky 42001  
operated by  
MARTIN MARIETTA ENERGY SYSTEMS, INCORPORATED  
for the  
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PGDP

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## URANIUM DISCHARGES AT PADUCAH GDP, 1953-1983

### PURPOSE

This report describes the history of uranium discharges from the Paducah Gaseous Diffusion Plant and discusses the associated health impacts. This report examines only those impacts realized from uranium releases to the environment. Data on other radionuclides, such as technetium, will be released at a later date.

### SUMMARY

Evaluation of historical releases of uranium from the PGDP shows environmental standards have been met. The public health impact of uranium releases is shown to be low. Since 1952, a total of 33 curies of radioactivity have been discharged into the air, 15 into water, and 1327 buried in solid waste. Concentrations in air and water have been well below applicable guidelines. A calculation of potential health effects that shows a value of 0.1 fatal cancers is expected as a result of airborne releases. It is unlikely that an effect this low has or will occur.

### HISTORY OF URANIUM OPERATIONS

The majority of PGDP facilities are dedicated to the separation of the two major uranium isotopes, U-235 and U-238. This separation is performed by passing gaseous uranium hexafluoride ( $UF_6$ ) through a porous membrane. The first Paducah stages of this process were put on stream in October 1952. Table 1 lists major operational changes and accidents affecting uranium releases and burials.

During the first years of plant operation, there were numerous atmospheric releases of  $UF_6$  resulting from accidents related to feeding  $UF_6$  to the diffusion plant or related to filling  $UF_6$  containers from manufacturing facilities or from the diffusion plant. As experience was gained in handling this volatile and corrosive gas, the releases were minimized. By the end of 1962, operating skill and equipment had advanced to the point that the quantity of uranium lost in accidental releases was negligible. Table 2 shows airborne releases from 1952 through 1983. A total of 59,522 kilograms were released.

Historically, the largest portion of routine uranium discharges has resulted from operation of the C-410 feed plant and the C-340 metals plant. (See map 1 for location.) The feed plant converted uranium trioxide ( $UO_3$ ) to uranium hexafluoride ( $UF_6$ ). The metals plant independently converted  $UF_6$  to uranium tetrafluoride ( $UF_4$ ).

The C-410 feed plant began production of  $UF_6$  from  $UO_3$  in 1953. The production rate peaked at 30,000 tons of  $UF_6$  per year in the early 1960s before plant shutdown in 1964. Table 1 shows that the feed plant was reactivated in 1968 and continued intermittently until April 1977. These periods of operation parallel periods of larger atmospheric uranium releases.

Table 3 shows the liquid effluent releases from 1952 through 1983. A total of 27,000 kilograms (14.95 curies) were released during this period.

The operation of the C-340 metals plant greatly affected the quantity of uranium buried. The process of converting  $UF_4$  to uranium metal also produces large quantities of slag containing small quantities of unreacted  $UF_4$  and granules of uranium metal. This contaminated slag was trucked to the C-404 burial area. In addition, the C-340 uranium metal cleaning and machining operations produced a steady stream of uranium sawdust, oxide and shavings to burial grounds. The activities continued periodically from 1957 to 1973. Table 4 shows uranium waste buried from 1955 through 1983. A total of 3200 metric tons (1327 curies) was buried during this period. The highest values were in 1975 and 1977 resulting from higher uranium machining rates.

#### ENVIRONMENTAL DATA

Data on environmental concentrations of airborne uranium go back to 1958. At this early date, air samples were taken weekly at four perimeter fence locations. Today and since 1961, ambient monitoring is accomplished by a network of eight to ten continuous monitors located along the perimeter fence, the plant boundary, and at locations one mile from the plant. Environmental data (outside the perimeter fence) are shown on Table 6. Weekly analyses of these continuous samples have always shown that the concentration of uranium was far below existing and current standards (see Table 7). In the early 1960s, these emissions on an annual basis averaged as high as 4 percent of the recommended uranium concentration in air. A major source of airborne uranium, the feed plant, was shut down for several years beginning in 1964. This is reflected in the significant reduction of the environmental values shown on Table 6. Since 1980, the EPA 25 mrem/yr standard has applied, but is not directly relatable to a radioactivity concentration guide.

Effluent and environmental water monitoring has also been performed since 1958. Samples continue to be collected from the Little Bayou, Big Bayou, and the Ohio River. Results are shown in Table 8. During the years from 1957 to 1977 discharges were essentially all to the Little Bayou. Releases to the streams have resulted in detectable concentrations in water and stream sediments. Environmental water samples have indicated compliance with existing concentration guides for uncontrolled areas (accessible to the public). The concentrations are not compared to drinking water standards since no water is withdrawn for such use. There is as yet no standard for uranium.

Most of the uranium released to the creeks is transported with suspended solids to the Ohio River. The environmental impact of the release of uranium to the liquid effluents is the increased level of uranium in stream sediments. Because of the natural abundance of uranium in silt and river waters, this addition has not been detectable past the outfall of the creeks (see Table 8). Sediment analyses for ditches and creeks are reported annually; the concentration of uranium in creek sediment is typically 30 parts per million (ppm). During the last four years the concentration in Big Bayou sediment has averaged 23 ppm, and Little Bayou sediment has averaged 30 ppm. The sediment has no known effect on aquatic life or the use of the stream.

Sixteen wells around the uranium burial areas are used to monitor groundwater for uranium and other parameters. Samples indicate there is no migration of uranium through the soil to the aquifer. In 1957, prior to use of this area for burial, a geologist, W. de Laguna, reviewed bore hole data, inspected the site, and indicated the deep clay layers would be an excellent natural barrier. Except for where the well drilling introduced small quantities of uranium, analyses of groundwater show 0.02 ppm or less in the aquifer. Some samples taken near the edge of the burial area from sand and gravel pockets below ground level but 20 to 30 feet above the aquifer have shown low level contamination. These pockets are pumped dry in a few seconds during sampling and thus do not represent an aquifer or a significant pathway to the aquifer. One sample had a concentration of 4 ppm. All other samples have been less than 1 ppm.

Edible fruits and vegetables from the wildlife area and nearby gardens have been analyzed for uranium and the results are included in the annual Environmental Monitoring Report. Most of the results show concentrations near the analytical ability to detect uranium. The maximum concentration was about 2 parts per billion (ppb). No significant radiation exposure would be received from a diet of these fruits and vegetables.

Naturally occurring uranium in soil varies from 1 to 5 ppm in most areas of North America. However, in large areas of eastern Tennessee and Kentucky exposed shale may be as high as 60 ppm. In this area of western Kentucky soil normally is 2 to 4 ppm. Soil at the plant perimeter fence is from 5 to 25 ppm, 3 to 5 ppm at the property boundary, and 3 to 4 ppm at sampling points five miles from the plant.

#### EFFLUENT DATA

Tables 2 through 4 summarize the history of uranium releases at PGDP. These tables indicate the annual mass and curies of uranium emitted to air, water, or buried in the ground.

In general there is very little correlation observable between the emissions shown on Table 2 and the environmental concentrations given on Table 7. One reason for this lack of correlation is the fallout within the plant of large particles produced during major releases.

The annual quantities of uranium buried between 1953 and 1971 are not accurately known because of the inadequate nature of records maintained for deposits and burials made in the C-404 low level waste burial area. (See Map 1.) The cumulative uranium totals reported for this period are believed to be a very close estimate of the actual quantities.

Major accidental releases are given in Table 5. Few  $UF_6$  releases have occurred since 1962. Uranium releases as  $UF_6$  will react with moist air to form a fume of uranyl fluoride ( $UO_2F_2$ ) and hydrogen fluoride (HF). Heavy agglomerated particulates will settle near the release point, but much of the  $UO_2F_2$  is submicron-sized particles and will follow the prevailing air flow. A

large fraction of the material released from powder handling facilities of the feed plant and the uranium foundry did not stay airborne but settled close to the buildings.

#### RADIATION EXPOSURE CALCULATIONS AND ESTIMATED HEALTH EFFECTS

The total radiation exposure of all residents within 50 miles of the Paducah Plant has been calculated\* based on the emissions for each year and the types of uranium compounds emitted during those years. These data indicate 760 person-rem since the plant began operation. This compares to the total population dose of 2.5 million person-rem from natural background radiation in this same 50-mile radius area. Potential health effects (fatal cancers) were estimated by multiplying the total population dose by  $1.65 \times 10^{-4}$  (0.000165) health effect per rem. When the total population dose resulting from 32 years of PGDP operation is multiplied by 0.000165, the resulting estimated health effect, fatal cancers, 0.1, is much less than 1. It is unlikely that this health effect has resulted or will result.

The local effect of emissions may best be judged by the comparison of measured concentrations of long-lived alpha emitters (assumed to be uranium) to the radioactivity concentration guides published by the Atomic Energy Commission and successors. This comparison is made in Table 7, which shows the concentration as a percent of the guide. The highest average concentration in any year prior to the EPA regulation of December 1979 was less than 5 percent of the standard.

After this regulation was issued, this type of comparison became less meaningful. A more appropriate comparison is between the EPA dose limit and estimated public radiation exposure based on effluent data and the AIRDOS model. Calculations of the dose to the maximum exposed individual were made for the years 1980 through 1983. These values, from less than 0.1 to 0.2 mrem, as published in the annual Environmental Monitoring Reports can be compared with an EPA standard of 25 mrem annual dose limit to members of the public.

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\* The calculations were based on the AIRDOS model for person-rem exposures for the three uranium solubility classes.

TABLE 1  
 PLANT OPERATIONS AND ACCIDENTS  
 AFFECTING URANIUM RELEASES AND BURIAL\*

Date	Event
July 1953	C-410 feed plant started
November 1956	C-310 Fire
December 1956	C-340 UF <sub>6</sub> to UF <sub>4</sub> process onstream
January 1957	C-340 uranium metal production started
May 1960	C-340 UF <sub>6</sub> to UF <sub>4</sub> process placed in standby
June 1962	C-340 uranium metal production area shut down
December 1962	Explosion and fire in C-337
July 1964	Feed plant shut down
January 1968	C-340 uranium metal production area reactivated
June 1968	Feed plant restarted
January 1969	C-340 UF <sub>6</sub> to UF <sub>4</sub> process reactivated
March 1973	Cascade Improvement Program (CIP) started
October 1973	C-340 uranium metal production discontinued
May 1977	Feed plant shut down, C-340 UF <sub>6</sub> to UF <sub>4</sub> process shut down
September 1981	CIP Program completed

\* See Map 1 for location of buildings.

TABLE 2  
Airborne Uranium Emissions  
1952 - 1983

Year	Uranium Radioactivity Released (Ci/Yr)	Mass of Uranium Released (Kg/Yr)
1952	0.02	30
1953	0.25	600
1954	2.4	4,800
1955	4.2	8,400
1956	5.2	10,500
1957	2.4	3,900
1958	2.2	3,600
1959	2.1	3,300
1960	2.0	3,000
1961	2.4	3,600
1962	1.3	2,400
1963	1.3	2,400
1964	0.6	900
1965	0.02	20
1966	0.02	30
1967	0.02	20
1968	0.3	600
1969	1.0	1,800
1970	0.5	900
1971	0.7	1,200
1972	0.7	1,200
1973	0.8	1,400
1974	0.6	1,100
1975	0.70	1,100
1976	0.90	1,500
1977	0.40	610
1978	0.04	96
1979	0.02	48
1980	<0.01	22
1981	0.05	140
1982	0.13	300
1983	<0.01	6
TOTALS	33.27	59,522

Note: The ratio of curie/kg varies with uranium enrichment. A curie is defined as 37 billion disintegrations per second.

TABLE 3

Liquid Effluent Uranium Releases  
1952 - 1983

Year	Uranium Radioactivity Released (Ci/Yr)	Mass of Uranium Released (Kg/Yr)
1952	0.02	30
1953	0.08	120
1954	0.02	30
1955	0.08	120
1956	0.02	30
1957	0.5	900
1958	0.5	900
1959	0.5	900
1960	1.1	1,800
1961	0.35	600
1962	1.0	1,800
1963	0.5	900
1964	0.5	900
1965	0.5	900
1966	0.5	900
1967	0.5	900
1968	0.5	900
1969	0.6	1,200
1970	0.6	1,200
1971	0.6	1,200
1972	1.6	3,200
1973	0.5	1,100
1974	0.06	100
1975	0.1	180
1976	0.2	440
1977	1.3	2,400
1978	1.0	1,900
1979	0.5	910
1980	0.3	590
1981	0.2	300
1982	0.1	170
1983	0.12	220
TOTALS	14.95	27,740

Note: A curie is defined as 37 billion disintegrations per second.

TABLE 4

Uranium Contained in Solid Waste Buried on Site  
1955 - 1983

Year	Uranium Radioactivity Buried on Site (Ci/Yr)	Mass of Uranium Buried on Site (1000 Kg/Yr)
1955	1	2.90
1956		
1957		
1958		
1959		
1960		
1961		
1962		
1963		
1964		
1965	700	1700
1966		
1967		
1968		
1969		
1970		
1971		
1972	65	160
1973	84	210
1974	32	80
1975	130	310
1976	39	96
1977	140	340
1978	62	150
1979	60	150
1980	4	9.7
1981	2	3.4
1982	5	11
1983	3	7.2
<b>TOTALS</b>	<b>1327</b>	<b>3230</b>

Note: Individual year data unavailable for 1955-1971. The values presented are cumulative for the identified periods of time.

TABLE 5

## MAJOR ACCIDENTAL URANIUM HEXAFLUORIDE RELEASES AT PGDP

Date	Location	U (kg)	Cause
12/1/52	C-331	92	Valve plugged open.
7/5/53	C-315	460	Leaking thermocouple well.
6/18/54	C-315	660	Cylinder valve packing gland retainer sheared.
9/25/54	C-337	380	Air jet suction valved into feed header.
3/15/55	C-315	400	Flexible connection to cylinder failed when cart collapsed.
5/16/55	C-410	150	Leaking outlet valve on trap.
6/19/55	C-410	92	Insufficient cooling of trap.
5/20/58	C-400	170	Release during valve change.
10/1/58	C-410	160	End plug blew out of heated cylinder.
9/11/59	C-410	90	Cap came off UF <sub>6</sub> manifold.
11/17/60	C-333 (vap.)	3000	Overfilled cylinder hydraulically ruptured when heated.
12/13/62	C-337	1500	Explosion and fire in C-337 process equipment.

Note: See Map 1 for location of buildings.

TABLE 6

Uranium in Air  
Gross Alpha ( $10^{-15}$  microcuries/mL)

Year	One Mile					Boundary		5 Mile				1 1/2 Mi GR
	N	E	S	W	SE	BN	BE	SW	NW	NE	SE	
1961	72	69	73	73								
1962	66	68	62	48								
1963	30	30	30	30	40			42	91	77	53	
1964	54	68	50	77	77			36	77	81	63	
1965	15	18	20	15	18							
1966	10	14	14	13	17							
1967	<20	<20	<20	<20	<20							
1968	10	10	10	10	10							
1969	10	10	10	10	10							
1970	<20	<20	<20	<20	<20							
1971	<20	<20	<20	<20	<20							
1972	<20	<20	<20	<20	<20							
1973	<20	<20	<9	<9	<20	<48						
1974	<0	<9	<9	<9	<9	<11						
1975	<10	<27	<27	18	<18	27						
1976	<30	<36	<32	<27	<40	<22						
1977	<0	<10	<10	<9	<7	<20						
1978	<0	<9	<10	<9	<9	<14						
1979	0	4	4	9	4	<9		<9				<4
1980	0	6	6	6	6	<6		<6				<6
1981	0	3	5	3	3	<4		<4				<4
1982	0	3	4	3	3	<5		<5				<4
1983	0	11	4	5	4	<6		<4				<5

Note: From 1961 through 1974,  $10^{-13}$  microcuries/mL was equivalent to 0.449 alpha disintegrations per minute per cubic meter of air. After 1975, a different definition of the uranium curie was used which results in  $10^{-13}$  microcuries/mL being equivalent to 0.22 disintegrations per minute per cubic meter of air.

TABLE 7

## ENVIRONMENTAL AIR ANALYSES

Gross Alpha as Percent of Uranium  
Concentration Guide in Air

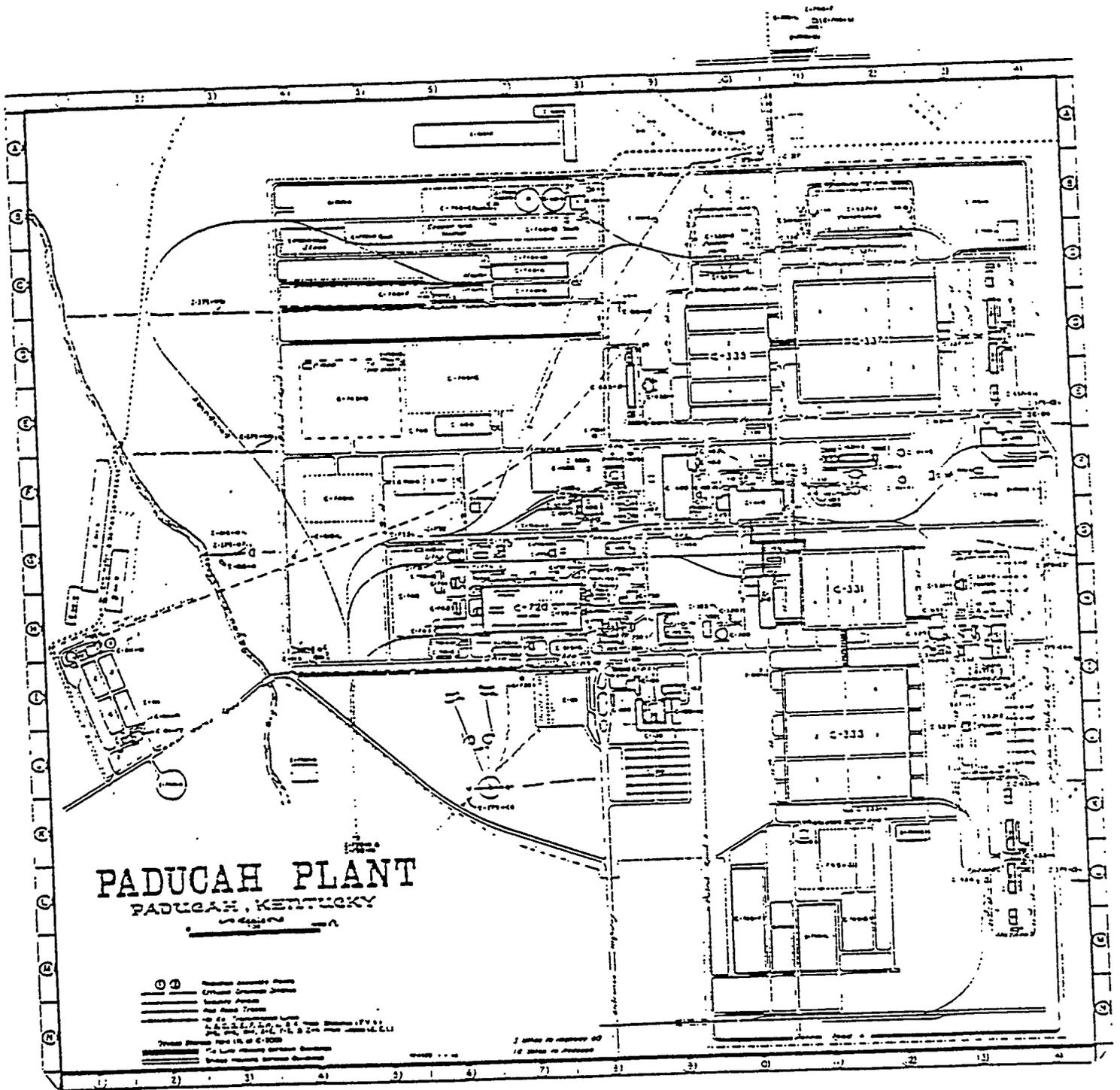
Year	One Mile					Boundary		5 Mile				1 1/2 Mi
	N	E	S	W	SE	BN	BE	SW	NW	NE	SE	GR
1961	3.6	3.5	3.7	3.7								
1962	3.3	3.4	3.1	2.4								
1963	1.5	1.5	1.5	1.5	2			2.1	4.6	3.9	2.7	
1964	2.7	3.4	2.5	3.9	3.9			1.8	3.9	4.1	3.2	
1965	0.75	0.9	1.0	0.75	0.9							
1966	0.5	0.7	0.7	0.7	0.9							
1967	<1	<1	<1	<1	<1							
1968	0.5	0.5	0.5	0.5	0.5							
1969	0.5	0.5	0.5	0.5	0.5							
1970	<1	<1	<1	<1	<1							
1971	<1	<1	<1	<1	<1							
1972	<1	<1	<1	<1	<1							
1973	<1	<1	<0.5	<0.5	<1	<2.4						
1974	<0.44	<0.44	<0.44	<0.44	<0.44	<0.55						
1975	<0.45	0.68	<0.68	0.45	<0.45	0.68						
1976	<0.8	<0.9	<0.8	<0.68	<1	<0.55						
1977	<0.2	<0.25	<0.25	<0.23	<0.18	<0.5						
1978	<0.23	<0.23	<0.23	<0.23	<0.23	<0.35						
1979	0.1	0.1	0.1	0.2	0.1	<0.2		<0.2				<0.1

Note: After 1979, EPA regulations (see Appendix B) are in such a form that the ratio of actual concentration to concentration guide cannot be calculated.

TABLE 8  
 AVERAGE URANIUM CONCENTRATION FOR WATER MONITORING STATIONS  
 mg/liter (ppm)

Sample Point	Ohio River		Big Bayou		Little Bayou
	Upstream (29)	Downstream (30)	Upstream (1)	Downstream (5)	Downstream (10)
1958	.001	.001	.002	.170	.180
1959	.001	.018	.001	.140	.840
1960	<.003	<.003	<.003	1.400	.390
1961	<.003	<.003	<.003	.051	.590
1962	.002	.002	.002	.036	.690
1963	.001	.002	.003	.110	.540
1964	.001	.002	.002	.044	.250
1965	.002	.002	.003	.026	.250
1966	.002	.001	.001	.029	.510
1967	.002	.001	.001	.012	.210
1968	.001	.001	.001	.010	.200
1969	.001	.001	.001	.010	.200
1970	.002	.002	.001	.018	.150
1971	.004	.004	.003	.022	.580
1972	.003	.002	.002	.015	.440
1973	.002	.002	.005	.017	.450
1974	.005	.003	.004	.022	.100
1975	.002	.004	.003	.020	.180
1976	.006	.005	.003	.030	.600
1977	.004	.010	.008	.140	.320
1978	.002	.006	.003	.200	.050
1979	.001	.002	.003	.200	.040
1980	.002	.006	.007	.100	.050
1981	.005	.004	.005	.070	.060
1982	.002	.001	.001	.039	.038
1983	.003	.002	.001	.038	.025

Note: The radioactivity concentration guide for uranium in water was  $2 \times 10^{-5}$  microcuries per milliliter (60 ppm) as published in National Bureau of Standards Handbook 69 and adopted by the AEC and successors. However, the current (April 29, 1981) DOE guide for uncontrolled areas is  $6 \times 10^{-7}$  microcuries per milliliter based on the U-238 content or 1.8 ppm. (See Appendix B, Table 4.)



MAP 1  
PADUCAH PLANT



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APPENDIX A

MEANING OF THE RESULTS

## APPENDIX A

MEANING OF THE RESULTS

## INTRODUCTION

The preceding report, one of a series dealing with historic uranium discharges from DOE facilities, evaluates the discharges and environmental concentrations of this element. It also estimates the size of the health effects (fatal cancers) as a result of these discharges.

Because of its brevity and numerical orientation the body of the report did not deal with more general points such as the meaning of the results, relative risk, uncertainties in the data, and similar questions—the subject of this appendix.

## THE MEANING OF THE RESULTS

These documents on dealing with DOE uranium discharges have shown much data and discussed them at length. What do these numbers mean in terms of health effects? This is what many members of the public will be asking. Our clear responsibility is to answer these questions.

There are at least two ways to evaluate the numbers. First is to consider them by themselves, without reference to any other considerations. This might be called the "headline" approach in which the bare facts are presented without explanation. A second, perhaps more rational, approach is to relate a given health effect to others. This is sometimes called comparative risk analysis or putting risks into perspective.

By comparing the risks to health due to these DOE facilities to other risks encountered in daily life, we are in no way belittling the effects produced by these facilities. For the individual or individuals who suffer from these effects, the fact that they are comparatively small compared to other risks will probably not mean too much.

There are many compilations of comparative and relative risks. One often quoted is "A Catalog of Risks," by B. L. Cohen and I. Lee, Health Physics, Vol. 36, no. 6, p. 707 (1979). Other data is available in annual almanacs such as "Information Please." In the interests of brevity, only a few examples are quoted.

In interpreting the numbers, a specific benchmark can be chosen. The Anderson-Roane County area in Tennessee had a population within 50 miles of the three DOE facilities located there of about 800,000 in 1980. In prior years the population was lower. For simplicity, assume that from 1946, the year of the first recorded uranium emissions data for the Anderson-Roane County facilities, to the present the average population in this region was about 600,000. Then if about 40 years of exposure (from 1946 to 1985) are considered, the number of person-years is about  $40 \times 600,000$ , or 24 million.

We can now estimate the annual number of deaths that would occur in a population of about 600,000 over 40 years. The almanacs will be used for the more common sources of death; the paper by Cohen for the more obscure sources. Note that only mortality is considered here as opposed to non-fatal morbidity.

If the U.S. death rates in the late 1970's had prevailed over the entire period considered, there would have been about 80,000 deaths in the region from heart disease, 43,000 from all types of cancer, and 20,000 from stroke. There would have been about 5700 deaths from influenza and pneumonia, 3400 from cirrhosis of the liver, and 3600 from diabetes. Even an almost-conquered disease like tuberculosis would have produced about 300 deaths.

Note that these and subsequent deaths tabulated in this section refer to the total over the entire 40 year period, not per year. This is to make them comparable in time scale to the health effects estimated as being attributable to uranium releases.

There would have been, at the late 1970's rate, about 11,000 total accident deaths. Of this number, about 5400 would have been due to motor vehicle traffic. Approximately half, or 2700, would have been alcohol-related. There would have been about 860 vehicle-pedestrian deaths. About 140 accidental deaths would have been associated with water transportation, and about 670 due to drowning.

Of the 43,000 cancers, about 3800 would have been in the breast, 5700 in the colon and rectum, and 11,000 in the lung.

The mathematical model used to calculate population doses for DOE facilities implies that the major health effect will be lung cancer from breathing in radionuclides. The expected 40-year total of 11,000 lung cancers in the population area may be compared to the one (or less than one) estimated for uranium releases from these facilities.

In each of the facility reports, mention is made of the natural background radiation dose that is incurred regardless of the presence of DOE facilities. There would have been an estimated 200-390 deaths from background radiation over the 40-year period.

A variety of other sources of death have been tabulated. Translated to the Anderson-Roane County region, they imply 660 deaths directly or indirectly related to drugs, 310 bladder cancer deaths due to coffee, 140 occupational accidental deaths, about ten from severe storms and perhaps ten from major fires and other disasters.

In summary, potential cancers due to uranium releases are, by any description, very small compared to most other sources of mortality.

#### DOSE MODELING AND ITS LIMITATIONS

The data in the accompanying report can be divided into two broad categories: effluents or discharges and measured concentrations.

Neither set of information directly gives the effect on human health. To estimate these effects, some type of mathematical model must be used.

Any model of this type leads further away from the original data, in that assumptions are needed to make the model produce a final result. Needed are data and assumptions about meteorology, population distributions, how radioactive material gets into the body and what it does once it gets there, and a host of other information.

The problem is not unique to calculations dealing with public radiation dose. To estimate air pollution and its effects, the Environmental Protection Agency and other groups use complex models. Oceanographers employ similarly complicated models to project ocean and weather conditions. In general, determining the overall effect of substances moving through air, water, and land will require some type of modeling.

All of the DOE facilities evaluated have monitoring stations. However, they do not have enough stations to precisely state the air concentrations at every point within a 50-mile radius of these facilities. It might take thousands of these stations. Therefore, a model has to estimate concentrations in places where there are no stations. A problem arises when the modeling estimate differs from the measured concentration. As noted below in the discussion of the specific model used, there is often a difference of a factor of two or more between measured and modeled levels.

There is frequently even less correlation between the size of effluent releases and concentration measurements. The rise and fall of the yearly quantities of effluents often do not coincide with the rise and fall of the measurements which are supposed to reflect those effluents. There are many possible reasons for this lack of correlation - weather patterns, possible inappropriate placement of the stations with respect to where the effluents are discharged, and so on. As well, measurements are in many cases so close to background concentrations that they are affected by only the largest variations in effluent discharges.

One area where modeling is especially useful is in estimating the dose to the maximally exposed person. Using the effluent data in combination with the concentration measurements alone will not identify the location of the hypothetical person or what dose he or she receives. A mathematical model can do this more inexpensively than other methods.

In summary, there are many fundamental limitations to any mathematical dose model. Yet there are other limitations, possibly as fundamental, in interpreting some of the concentration and effluent measurements made on uranium. As a result, none of the data or models used here can be (or are) considered perfect.

## AIRDOS-EPA MATHEMATICAL MODEL OF RADIATION DOSE

Noted in the previous section, a mathematical model is needed to estimate the total radiation dose incurred by the population (population dose) surrounding a DOE uranium-discharging facility, as well as to estimate the maximum dose received by any member of the public.

The AIRDOS-EPA model (to be referred to as AIRDOS) is one of a number of computer codes used to estimate radiation dose to the public from air-borne emissions. Liquid effluents and releases from the burial of solid wastes have to be evaluated by other models.

The advantages of the AIRDOS model are two-fold. First, it agrees reasonably well - usually within a factor of two or three - with measurements of radioactivity concentrations in air. Second, the Environmental Protection Agency has used it in setting some of their air quality regulations.

The AIRDOS model calculates annual doses to the public. It does this by estimating radionuclide concentration in air; the rate of deposition of these radionuclides to the ground; their concentration on the ground; concentration in streams into which radionuclides have fallen; human intake of radionuclides by breathing; concentration in meat, milk and fresh vegetables grown in areas where the radionuclides have fallen; and doses to humans from eating this food and breathing this air.

The dispersion of radionuclides into the air from their original source is described mathematically by using a so-called Gaussian plume model. This type of model is common. It is mandated for many regulatory applications by the U.S.E.P.A, and is found in various forms in a variety of "approved" dispersion models. The governing dispersion parameters used in this model have been studied extensively.

AIRDOS has been used in a validation study around the Savannah River Plant at Aiken, South Carolina. Results indicate that the annual predicted ground-level air concentration exceeded the observed value for each of the 13 stations examined. The average factor of overprediction was about two. This suggests that the likelihood of AIRDOS underpredicting doses is probably small. Potential underprediction, or lack of conservatism, is usually avoided by risk analysts whenever possible.

The computer code AIRDOS is available to the public through the Radiation Shielding Information Center at Oak Ridge National Laboratory. Its title is R. E. Moore *et al.*, "AIRDOS-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides," report ORNL-5532, June 1979.

Some of the major assumptions, both numerical and otherwise, used in the AIRDOS model are as follows:

(1) Population. The population within 50 miles of the facility was used to calculate total dose. The 1980 census showed about 800,000 people within this radius for the three major DOE facilities in Anderson and Roane Counties. The 50-mile radius is commonly used in radiological dose assessment calculations. Almost all uranium will have fallen to the ground by that distance.

The uranium discharges in these reports are historic in nature, going back in at least one instance to 1946. It clearly is inappropriate to use present population in evaluating releases of decades ago. Estimates of the population around the facilities were based on censuses going back to 1940, with appropriate interpolation. Because population data on areas smaller than counties is difficult to obtain prior to 1970, the distribution in direction about the facilities in the 1980 census was assumed to prevail in earlier years.

(2) Meteorology. The direction and speed of the wind clearly will affect where and when the radionuclides fall. To avoid the complication of daily or weekly wind data, an annual compilation for the year 1984 was used for Y-12 and ORGDP. The Paducah installation used the year 1981. It is then assumed that this year is representative of previous and subsequent years.

(3) Shielding. Most people spend 80-90% or more of their lives indoors. This will tend to reduce the intake of uranium radionuclides due to breathing outdoor air, although their dose reduction may be reversed by breathing indoor-generated radon which has nothing to do with DOE facilities. The AIRDOS model assumes that the entire population lives outdoors continually, thus maximizing potential uranium intake. This is another example of conservatism, or the likely overestimation of dose.

(4) Food Production. There are few people left who produce all their meat and vegetables. The AIRDOS model assumes that 30% of food eaten in this region originates there, and the rest is imported from outside.

(5) Particle Size. The size of the radionuclide particles, or the dust particles to which they are attached, is of significance in estimating radiation dose. In general, the smaller the particles, the more they stay in the lung, and the greater the dose to the lung. Larger particles are removed in the nasal region. Since breathing usually is the largest source of dose calculated by this model for uranium, the particle size assumption is crucial to the result. In the calculations, a representative radius of one micron was assumed. This is one millionth of a meter, or about one-hundredth the thickness of this page.

(6) Solubility. The degree of solubility of the radionuclides affects the behavior of radionuclides in the body. The faster they dissolve in water, the faster they move away from the lungs to other parts of the

body. The dose to other organs then depends on the solubility. For ORGDP, it was estimated that 90% of the particles were very soluble by the time they entered the body, and 10% of medium solubility. For the Y-12 Plant, it was estimated that equal numbers of particles fall in the high, medium and low solubility classes. For Paducah Gaseous Diffusion Plant, values were about 70% very soluble; 25% medium solubility and 5% low solubility. For RMI, it is estimated that all particles had low solubility. These estimates are based on the chemical nature of the radionuclides emitted from each plant.

(7) Committed Dose. The dose to organs of the body depends on the length of time the radionuclides remain in the organ. For some radionuclides, natural elimination removes them within hours or days; for others, the radionuclides may remain for many years, irradiating the organ in question over this time. In these calculations, a cut-off period of 70 years was assumed as the longest period considered.

(8) Non-airborne Releases. The AIRDOS model considers only airborne releases. Yet the attached report shows data on liquid effluents and concentrations. Should they be included in the dose calculations?

The publication entitled "Environmental Assessment of the Oak Ridge Gaseous Diffusion Plant Site," report DOE/EA-0106, 1979, states that the waterborne doses from DOE facilities are less than one percent of the doses due to air releases. A more recent calculation (memorandum from T. W. Oakes, Oak Ridge National Laboratory, to W. F. Furth, dated May 20, 1985) estimates that, on the basis of measured effluents into nearby creeks and rivers, the ratio of waterborne dose to airborne dose from the Y-12 Plant and Oak Ridge Gaseous Diffusion Plant was 1% - 2%. Even these small ratios are probably higher than reality, since it was assumed that no uranium is removed from the water by a variety of processes, such as water treatment plants before it gets to the consumer. Some undoubtedly is. If these studies are any indication of the relative impact of the ratio of water-borne to airborne uranium effects, then it is reasonable not to include waterborne radioactive doses, at least to a first approximation.

About the same point can be made about burial of solid wastes. In this series of reports on DOE facilities, the largest source of uranium radioactivity, both in terms of weight and curies of activity, is in the solid wastes. The dose produced from these wastes will depend on how much uranium moves from these wastes into water which is subsequently used by the public. Based on measurements, in almost all cases the amount is close to zero. Preliminary calculations done for other locations have confirmed that the doses produced from uranium migration from solid wastes, at their present measured levels, will be extremely small in comparison to airborne-related doses.

(9) Natural Background. The size of the dose from natural radiation background, present regardless of the existence of DOE facilities, does not enter into AIRDOS calculations. However, since the population dose computed by AIRDOS can be compared to that of the background dose, a few words about the assumptions are in order.

Background radiation varies somewhat with location. The farther the population is above sea level, the higher the dose from cosmic rays from outer space. The more uranium and thorium in earth or rocks, the higher the background. For purposes of this study, an average background of 200 millirem per year (effective total body dose) was assumed, made up of (a) about 30 millirem from cosmic rays, (b) 30 from potassium in the body, (c) 80 from radon, and 60 from other sources. This data is shown in United Nations Scientific Committee on the Effects of Atomic Radiation, "Ionizing Radiation: Sources and Effects," New York, 1982. A population of one million would then receive a total dose of  $1,000,000 \times 0.200 = 200,000$  rem annually.

#### CAN THOSE WHO WILL CONTRACT CANCER BE IDENTIFIED?

A key assumption in this analysis is that the deaths, cancers or other health effects are statistical in nature. That is, a particular person or persons who may contract cancer cannot be identified as a result of these uranium emissions. All that can be stated is that there may be X deaths, where X is the number or numbers in the main body of this report.

In this sense, the problem is the same as that facing those who have estimated the risk associated with smoking cigarettes. Yet in general, those who will fall victim to cigarette-induced lung cancer, heart disease, or other ailments cannot be named. In some extreme cases, when for example someone has been smoking four packs a day for 40 years and contracts lung cancer, cigarettes are, with virtual certainty, the cause. But there are other instances where an extremely heavy cigarette smoker does not contract lung cancer. As a result, there is no list of names of these who have been felled by cigarettes.

Because the health effects due to uranium inhalation or ingestion are not peculiar to that element, the new cancer cases which are due to this source cannot be identified. If cancer were both rare and attributable mostly to uranium, it could be done. At present, it cannot.

#### PARTIAL DEATHS

In the reports which this appendix accompanies, the final results in terms of health effects are expressed as partial or fractional fatal cancers. The number of health effects due to uranium releases may be shown as 0.7 or 0.9, for example. This fractional value comes about because of the nature of the mathematical model.

Obviously, there is no such thing as a partial death. In terms of this report, the meaning of these numbers can be visualized as follows: suppose that the uranium releases producing 0.1 death for a given site

had been duplicated in say ten sites, each with exactly the same geography, meteorology, and so on. Within these ten sites, there would have been a strong chance that almost all would have shown no extra cancer due to the uranium releases, a slight chance that one or two sites would have shown one extra cancer, and an almost vanishing chance that one site would have shown two or more. In the language of the mathematician, the fractional values represent the average of a Poisson distribution. As an example, consider tossing a die. On average, six spots should come up one time in six, but it may come up on a specific roll.

#### UNCERTAINTIES IN THE RESULTS

Some of the numbers in the accompanying reports are shown to three or more significant figures. This should not obscure the fact that there is considerable uncertainty in the results and conclusions. In most instances, if not all, these uncertainties are on the down side. That is, the estimates of health effects, such as fatal cancers, are probably overestimated rather than underestimated.

A thorough discussion of all the potential uncertainties would take up considerable room and require much technical detail. For brevity, just a few major sources of uncertainty are noted:

(1) The single number chosen for converting person-rem into fatal cancers (0.000165 deaths per person-rem, taken from "Effects on Populations of Exposures to Low Levels of Ionizing Radiation," National Academy Press, Washington, 1980) may give the illusion of precision. Radiation scientists serving on the committee which drafted the aforementioned report and the International Commission on Radiological Protection usually believe that this value forms an upper limit. The lower limit is unspecified, although some scientists feel it may be as low as zero. While the band of uncertainty cannot be defined mathematically as yet, the fact that it exists makes the overall results less than precise. From the viewpoint of public policy, the number of cancer deaths estimated in the main body of this report is then probably an upper limit.

(2) The entire mathematical modeling process is itself subject to much uncertainty. The physical spread of radionuclides through the air, water and into bodies and specific organs is a complicated process. Some of the specific areas of uncertainty are outlined in the section on the AIRDOS model, which in these respects is similar to other models. The uncertainties include population questions, shielding of humans from radiation, the degree of radiation in food, how body organs react to radiation, the solubility of radionuclides in the body, and others. It is nearly impossible to estimate the overall degree of uncertainty produced as a result of these individual uncertainties. The scientists consulted on this question feel that because of the stringent (or conservative) assumptions used in the model, it will almost certainly yield an overestimate of the population dose.

(3) Much of the data on emissions into air, water and land are themselves uncertain. In the past, the present level of measurement and analysis was sometimes not achieved. This in turn led to estimates, rather than measurements, being made occasionally.

While past measurements are not always up to today's standards, we cannot make the measurements now that (by present practices) would have been wise to have made 39 years ago. Neither can we predict what the requirements 39 years in the future may be. Unfulfillable desires, or annoying uncertainties, were-are-and-will be with us.

(4) Similar statements about uncertainty can be made about the environmental, as contrasted to the effluent, measurements. Over the years, measurement techniques have improved dramatically. These improvements have made earlier measurements relatively uncertain in retrospect. Since the samples are no longer around, there is no way the measurements can be redone using more precise and accurate techniques.

(5) There are three isotopes of uranium, with atomic weights of 234, 235 and 238, which can be emitted from DOE installations. The dose incurred by the public will depend largely on their proportion. In some cases, especially in air emissions, these proportions are or were not known precisely.

(6) The AIRDOS model considers almost exclusively the effects of airborne radioactive emissions. The calculations do not include doses from radioactivity in surface or groundwater or which has leached from solid wastes buried in the ground. As noted above, these pathways contribute only little to total population dose. This source of uncertainty is likely smaller than the other sources in this appendix.

(7) The reports deal only with uranium discharges. It is possible that other radioactive elements may also produce significant population dose, and work is underway to investigate this possibility.

(8) There is a time delay associated with any cancers induced from the calculated radiation dose. This uncertainty in terms of time is not of the same nature as the others in this section, which deal with quantity. Yet it produces uncertainty in the conclusions to be drawn. The implication may have been given in the calculations that any health effects occur shortly after the radionuclides enter the body of the person who will eventually die. This is not the case. While the time delay in the effect depends on the type of cancer induced, specialists have estimated a delay of between 5 and 30 years between the time the dose is received and when the fatal cancer appears. A fatal cancer produced as a result of a dose in 1946, by this estimation, may have shown up as early as 1951 or as late as 1976. Similarly, a dose of today may show up in cancer mortality tables as soon as 1990 or as late as 2015. The type of fatal cancer that will be produced, or when it will occur, is not known. Because a natural way of thinking is to assume that effects follow shortly after cause, the question of time delays produces uncertainty in linking the two.

In summary, these are some of the major and minor sources of uncertainties in both the data and the calculations based on them. Some, like those associated with modeling and the ratio of dose to health effects are probably over-arching. Others, like changes in instrumentation and measurement over the years, probably are smaller areas of uncertainty. While it would be desirable to be able to say, as the statisticians do, that the results have a plus-or-minus of so much attached to them, it cannot be done. The uncertainties are of such a disparate nature that at present they cannot be combined mathematically.

#### VARIATION OF CANCER STATISTICS

The number of cancer deaths vary strongly from year to year and place to place. The health effects of DOE facilities due to uranium discharges are probably so small as to be almost undetectable given this natural variation in cancer rates.

Only a few selected tables and maps are shown. More data is available in W. B. Riggan *et al.*, "U.S. Cancer Mortality Rates and Trends, 1950-79," Vols. 1-3, U.S. Government Printing Office, Washington, 1983, report EPA-600/1-83-015a.

Table 1 shows the variation in cancer mortality among both white and non-white males for counties around Anderson and Roane County, Tennessee (the site of the Y-12 Plant and the Oak Ridge Gaseous Diffusion Plant), for the years 1960-69 and 1970-79. Note that this is the total mortality, including dozens of specific types of cancer. This is not the incidence of cancer, which would include both fatal and non-fatal cases. It is likely that about the same conclusions would be drawn for data on cancer incidence among the same two groups.

Table 2 shows the variation in cancer mortality around the Paducah Gaseous Diffusion Plant for the years 1960-69 and 1970-79. Again we see considerable variation from decade to decade for most counties. A good part of the increases shown in many counties can be attributed to the population increase over the years. The cancer rates per 100,000 have remained more constant.

Statistical tests can be performed to estimate how variable these numbers are with respect to the estimated fatal cancers due to the DOE facilities. However, a mere scanning of the numbers shows that trying to detect one or fewer deaths per year due to these facilities would be futile, given the apparently natural variation in cancer mortality. The number of deaths often change substantially from one decade to the next. The variation would be even greater if particular years were compared to each other rather than decades.

The mathematical model cannot be used to predict, because of the low radiation dose calculated, which county or counties would suffer the one or fewer cancer deaths. It is then close to impossible, on the basis of Tables 1 and 2, to detect mathematically an increase in cancer deaths of the order of one or fewer, and to identify in which county or counties this increase occurred.

It may be contended that the above conclusion is drawn only because the total number of cancer deaths was considered. If the cancer or cancers produced by uranium discharges were concentrated in one or more body organs which otherwise had a low incidence of cancer mortality, detection of changes in rates due to DOE facilities would be easier, in principle. For example, lip cancers produced about one in 915 U.S. cancer deaths from 1950 to 1969 (T. J. Mason *et al.*, "Atlas of Cancer Mortality for U.S. Department of Health, Education and Welfare," Publication NIE-75-780). If cancers due to DOE facilities were concentrated on a specific organ like this which constitutes a small part of total cancer mortality, it would be possible to detect more easily the statistical effect of these facilities.

On the basis of present knowledge, this is highly unlikely. The AIRDOS-EPA mathematical model predicts that most cancers due to airborne releases of radioactivity will occur in the lung. The cancer atlas referred to immediately above notes that about 14 percent, or one in seven, of all cancer deaths from 1950-1969 occurred in the trachea, bronchus and lung.

Tables 3 and 4 show data similar to that of Tables 1 and 2, except that only lung cancer deaths are considered. The total number of deaths is substantially decreased from those of Tables 1 and 2, because lung (and related) cancer deaths are only one segment of total cancer deaths. However, the same difficulty in identifying cancer deaths of the order of one recurs. There is so much natural variation in the numbers that we cannot state with any degree of certainty how many excess lung cancer deaths have occurred, or where they occurred. For example, Sevier County lung cancer deaths for white males rose by 63 during the course of one decade. Those for Hickman County, Kentucky, rose by only one. It should be noted that lung cancer deaths throughout the entire country went up substantially during this period. Tables 3 and 4 reflect this national increase. Data for each of the cancer sites listed in the cancer atlases could be presented, but this is not done for purposes of brevity. Subdividing the total cancer death rate by sites in the body where they occur will still not allow a definitive conclusion that these rates have changed as a result of DOE uranium discharges.

Finally, it might be contended that the overall cancer rates, as opposed to total deaths, may be higher than the national average due to uranium emissions. This is not the case, as shown in the four parts of Figure 1. These maps show that the ratio of total county cancer rates to the U.S. or state average varies considerably, and with a good degree of randomness geographically. The natural variability in county cancer mortality rates arises due to a host of environmental and human factors. The

information in Figure 1 suggests that most of these rates are not substantially above national or state averages.

Table 1. Total Cancers Around Anderson-Roane County, Tennessee

<u>Counties</u>	<u>White Males</u>		<u>Non-White Males</u>		<u>Population (Thousands)</u>	
	<u>1960-69</u>	<u>1970-79</u>	<u>1960-69</u>	<u>1970-79</u>	<u>1960</u>	<u>1970</u>
Anderson	332	523	18	29	60	60
Blount	344	560	26	37	58	64
Campbell	247	347	6	2	28	26
Claiborne	169	219	3	3	19	19
Jefferson	152	200	11	8	21	25
Knox	1677	2430	228	296	251	276
Loudon	173	235	9	7	24	24
Morgan	91	133	0	0	14	14
Roane	233	355	14	18	39	39
Scott	91	149	2	0	15	15
Sevier	168	298	1	2	24	28
Union	51	64	0	0	8.5	9.1

Table 2. Total Cancers Around Paducah Gaseous Diffusion Plant, Kentucky

<u>Counties</u>	<u>White Males</u>		<u>Non-White Males</u>		<u>Population (Thousands)</u>	
	<u>1960-69</u>	<u>1970-79</u>	<u>1960-69</u>	<u>1970-79</u>	<u>1960</u>	<u>1970</u>
Ballard	76	127	5	3	8.3	8.3
Caldwell	114	153	11	14	13	13
Calloway	166	243	9	12	21	28
Carlisle	68	85	1	2	5.6	5.4
Crittenden	69	123	2	5	8.6	8.5
Fulton	115	101	16	15	11	10
Graves	256	348	16	21	30	31
Hickman	68	79	3	8	6.7	6.3
Livingston	88	82	1	0	7.0	7.6
Marshall	143	242	0	0	17	20
McCracken	466	567	55	91	57	58
Trigg	72	90	10	11	8.9	8.6
Weakley, TN	224	300	19	24	24	29
Alexander, IL	123	133	65	57	16	12
Hardin, IL	62	76	0	1	5.9	4.5
Johnson, IL	69	112	1	1	6.9	7.6
Massac, IL	123	169	18	16	14	14
Pope, IL	41	57	0	0	4.1	3.5
Pulaski, IL	81	97	33	40	10	8.7

Table 3. Lung, Trachea and Bronchus Cancer Deaths Around  
Anderson-Roane county, Tennessee

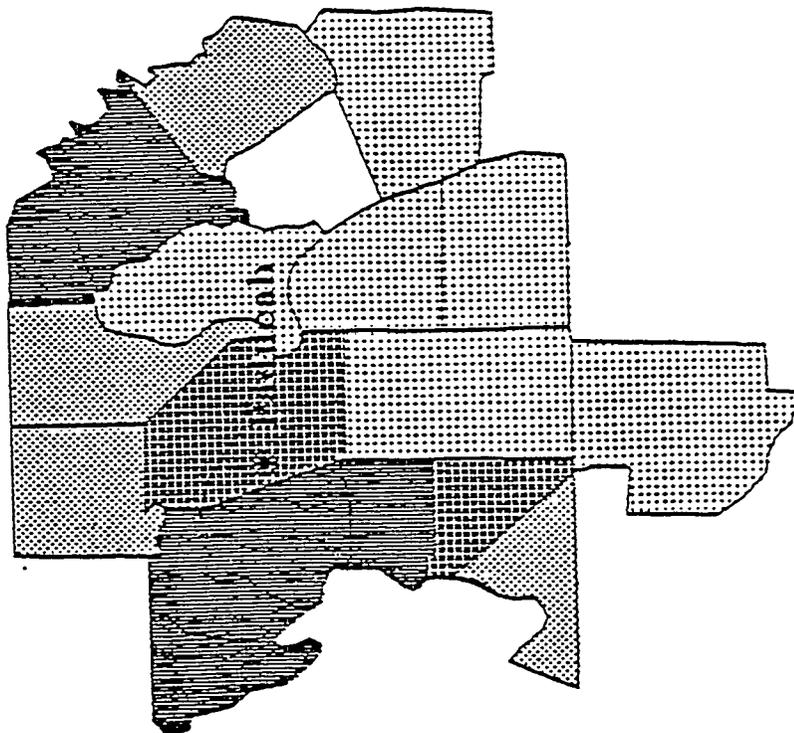
<u>Counties</u>	<u>White Males</u>		<u>Non-White Males</u>		<u>Population (Thousands)</u>	
	<u>1960-69</u>	<u>1970-79</u>	<u>1960-69</u>	<u>1970-79</u>	<u>1960</u>	<u>1970</u>
	Anderson	112	215	6	9	60
Blount	104	204	5	12	58	64
Campbell	74	157	1	0	28	26
Claiborne	63	83	2	1	19	19
Jefferson	28	62	1	1	21	25
Knox	489	922	60	113	251	276
Loudon	50	86	3	0	24	24
Morgan	20	64	0	0	14	14
Roane	72	142	2	7	39	39
Scott	18	63	1	0	15	15
Sevier	41	104	1	0	24	28
Union	12	26	0	0	8.5	9.1

Table 4. Lung, Trachea and Bronchus Cancer Deaths Around  
Paducah Gaseous Diffusion Plant, Kentucky

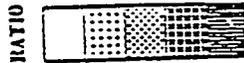
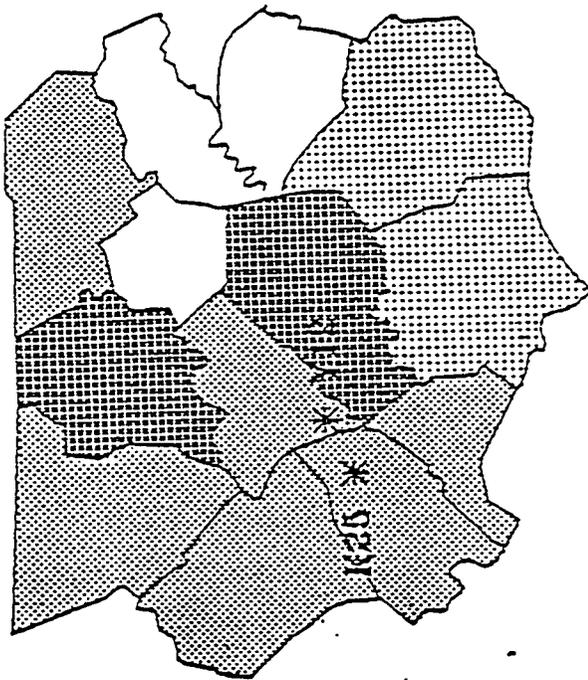
<u>Counties</u>	<u>White Males</u>		<u>Non-White Males</u>		<u>Population (Thousands)</u>	
	<u>1960-69</u>	<u>1970-79</u>	<u>1960-69</u>	<u>1970-79</u>	<u>1960</u>	<u>1970</u>
	Ballard	16	52	1	1	8.3
Caldwell	27	57	2	4	13	13
Calloway	35	82	1	2	21	28
Carlisle	16	33	0	1	5.6	5.4
Crittenden	16	36	0	1	8.6	8.5
Fulton	38	40	4	6	11	10
Graves	59	119	3	9	30	31
Hickman	19	20	0	2	6.7	6.3
Livingston	20	27	0	0	7	7.6
Marshall	35	86	0	0	17	20
McCracken	129	219	13	26	57	58
Trigg	11	27	0	2	8.9	8.6
Weakley, TN	45	92	2	9	24	29
Alexander, IL	37	48	12	22	16	12
Hardin, IL	19	24	0	0	5.9	4.9
Johnson, IL	15	43	0	1	6.9	7.6
Massac, IL	43	57	2	3	14	14
Pope, IL	16	24	0	0	4.1	3.9
Pulaski, IL	27	34	3	12	10	8.7

# Ratio of County Total Cancer Mortality Rate to National Average For White Males, 1970-1979

**Paducah**

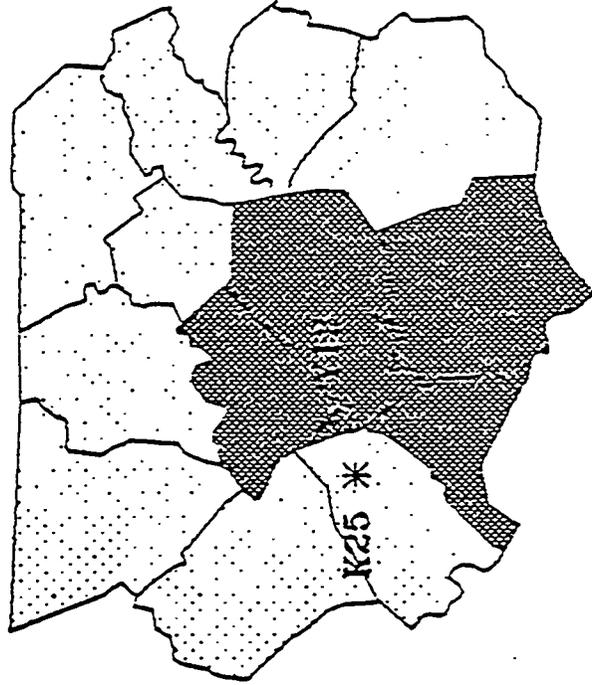


**Oak Ridge**



# Ratio of County Total Cancer Mortality Rate to State Average For Non-White Males, 1970-1979

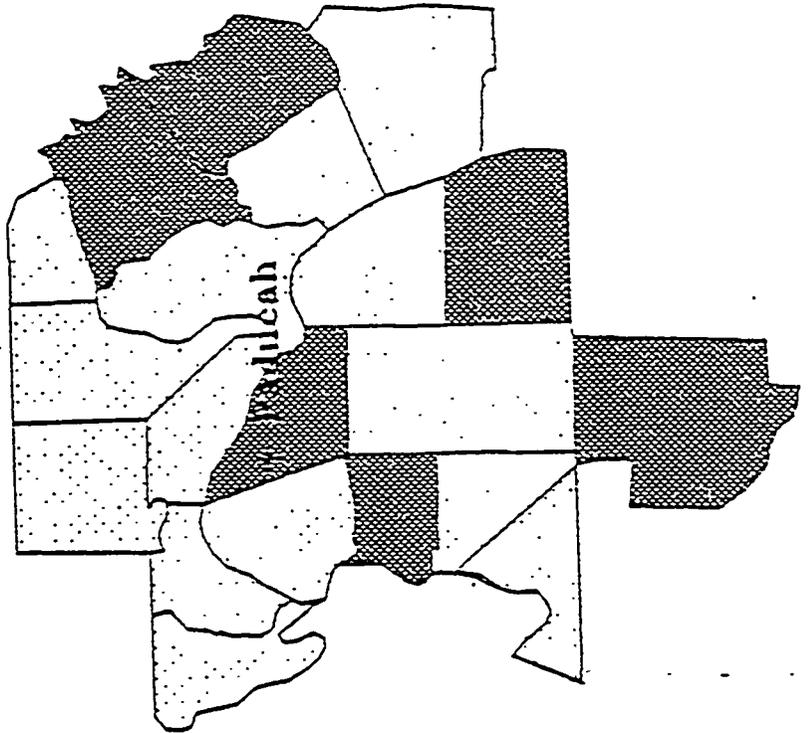
## Oak Ridge



RATIO

	Above Avg.
	Below Avg.

## Paducah



K25 \*

## CONCLUSIONS

The precise conclusions of the preceding report will of course depend on the quantities involved. However, more general conclusions can be drawn on the basis of this appendix.

First, any fatal cancers as a result of uranium discharges will be small compared to other sources of cancer. In addition, these cancers will be very small compared to most other societal risks.

Second, there is no way that we can identify the victim or victims of these cancers, assuming that there is one or more. Cancer is too common. Lung cancer, probably the type produced by these uranium discharges, is also relatively common, especially among smokers.

Third, there is considerable variation from year to year and place to place of cancer death rates. This makes identifying the area where any effects are likely to happen almost impossible, given the low level of the health effects to be expected.

Fourth, there is considerable uncertainty in both the models used and some of the numbers fed into those models. From the viewpoint of public policy, these uncertainties will likely be in the direction of overestimating, rather than underestimating, these risks.

Emissions were higher in previous years, prior to the better control measures used today. Yet the cumulative risk produced by both present and past emissions has been small in comparison to those normally accepted by society.

APPENDIX B

RADIATION STANDARDS AND GUIDELINES

APPENDIX B  
RADIATION STANDARDS AND GUIDELINES

This Appendix presents several of the most important federal radiation standards and guidelines and describes the various ways in which they are applied. State standards are usually consistent with those of the Environmental Protection Agency and the Nuclear Regulatory Commission. States, however, are more directly concerned with the point of application of the standards; thus, their regulations in this regard will be discussed under the appropriate environmental media heading.

The NRC standards are not applicable to DOE operations but are presented to illustrate their similarity with those of DOE and to point out, as well, how their application may differ.

I. Radiation Dose Standards

Public radiation dose standards have been issued by DOE, NRC, and EPA which are intended to limit exposures through all pathways, e.g., breathing air, water consumption, food consumption, and external radiation. The DOE and NRC standards are very similar, having the same basis. The EPA standard, however, is more stringent, since it was largely based upon limiting public exposures to levels which were considered to be "as low as reasonably achievable." Prior to establishing their standard, EPA performed a detailed study of the uranium fuel cycle industry for which the standard applies. This ALARA concept is a part of the DOE and NRC regulations, but it is not specifically quantified. (Several years ago NRC defined ALARA as \$1000 per man-rem. In practice, much larger expenditures are being made to reduce public exposures.)

DOE:

DOE Order 5480.1 states the DOE radiation exposure standards for members of the public. "Exposures to members of the public shall be as low as reasonably achievable levels (and) within the standards prescribed below.

TABLE 1

<u>Type of Exposure</u>	<u>Dose to Individuals at Points of Maximum Possible Exposure</u>	<u>Annual Dose Equivalent or Dose Commitment (mrem)*</u>
Whole body, gonads or bone marrow	500	170
Other organs	1500	500

\*Dose commitment is the internal organ dose equivalent received over a 50-year period following intake of a radionuclide.

\*\*An example of a "suitable sample of the exposed population" might be the residents of a nearby community.

New standards are expected to be promulgated by DOE in the near future consistent with the most recent recommendations of the National Council on Radiation Protection and Measurements. (See EPA air standards for further information on these recommendations.)

NRC:

The NRC radiation exposure standards for members of the public are contained in the Code of Federal Regulations 10 CFR 20.105.

"There may be included in any application for a license or for amendment of a license proposed limits upon levels of radiation in unrestricted areas resulting from the applicant's possession or use of radioactive material and other sources of radiation. Such applications should include information as anticipated average radiation levels and anticipated occupancy times for each unrestricted area involved. The Commission will approve the proposed limits if the applicant demonstrated that the proposed limits are not likely to cause any individual to receive a dose to the whole body in any period of one calendar year in excess of 0.5 rem."

EPA:

EPA has issued environmental standards (40 CFR 190) for the uranium fuel cycle that are applicable to those portions of uranium enrichment operation that directly support the production of electrical power for public use utilizing nuclear energy. These standards came into effect December 1, 1979.

Operations are to be conducted in such a manner as to provide reasonable assurance that the "annual dose equivalent does not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public as the result of exposures to planned discharges of radioactive materials, radon and its daughters excepted, to the general environment and to radiation from these operations."

II. Radioactivity in Air Standards/Guidelines

DOE uses air concentration guides as guidelines only, whereas the corresponding NRC values are considered to be maximum permissible concentrations, or standards. A second difference is that NRC in most licensing actions applies their concentration limits to site boundaries rather than to the location of maximum offsite exposure.

EPA has not issued concentration guides or concentration standards. Instead, they recently issued radiation dose limits which apply to the dose received by the public as a result of airborne emissions from DOE facilities. Compliance with these new EPA standards will generally be based on dispersion calculations rather than through environmental measurements.

DOE:

As previously stated, DOE has established radiation dose standards for members of the public which must be met by DOE operations. Air concentration guides were derived in most cases from these standards and are also presented in DOE Order 5480.1. These guides are reduced by a factor of three when applied to a suitable sample of the population. These guides assume continuous exposure for 168 hours per week, 52 week per year; therefore, they are most meaningful when compared with annual average air concentrations. When a mixture of radionuclides is present these guides must be adjusted so that the maximum individual and population exposures are within the prescribed limits.

TABLE 2

<u>Isotope</u>	<u>Soluble/Insoluble</u>	<u>μCi/mL</u>
U-234	S	$2 \times 10^{-11}$
U-234	I	$4 \times 10^{-12}$
U-235	S	$2 \times 10^{-11}$
U-235	I	$4 \times 10^{-12}$
U-238	S	$3 \times 10^{-11}$
U-238	I	$5 \times 10^{-12}$

NRC:

A licensee shall not release radioactive materials to unrestricted area in concentrations which exceed the limits specified in Appendix B, Table II (Code of Federal Regulations, Chapter 10, Part 20), except as noted below. Concentrations may be averaged over a period not greater than one year.

TABLE 3(Appendix B, Table II)

<u>Isotope</u>	<u>Soluble/Insoluble</u>	<u>μCi/mL</u>
U-234	S	$2 \times 10^{-11}$
U-234	I	$4 \times 10^{-12}$
U-235	S	$2 \times 10^{-11}$
U-235	I	$4 \times 10^{-12}$
U-238	S	$3 \times 10^{-11}$
U-238	I	$5 \times 10^{-12}$

A Licensee will be allowed to apply these same limits at the location of the maximally exposed individual if NRC is satisfied that the licensee has made a reasonable effort to minimize the radioactivity contained in effluents to unrestricted areas. (This exception is rarely granted.)

NRC may reduce licensee effluent limits if it is determined that a suitable sample of an exposed population group would be exposed to radioactive materials, through air, water or food intake, equivalent to that received from continuous exposure to air or water containing one-third of these concentrations.

EPA:

On January 17, 1985, the EPA published final rules (40 CFR 61) for radionuclides in support of Clean Air Act National Emission Standards for Hazardous Air Pollutants. For existing sources the standards take effect 90 days after publication in the Federal Register. These standards limit radionuclide emissions from DOE facilities to an amount that causes a dose equivalent rate of 25 mrem/year to the whole body or a dose equivalent rate of 75 mrem/year to the critical organ of any member of the public. In addition, EPA will grant a waiver of these limits, if a facility operator demonstrates that no member of the public will receive a continuous exposure of more than 100 mrem/year effective dose equivalent and a noncontinuous exposure of more than 500 mrem/year effective dose equivalent from all sources, excluding natural background and medical procedures. (These latter provisions embody the recommendation of the National Council on Radiation Protection and Measurements for exposure to external radiation.) Compliance with the standard will be determined by calculating the dose to members of the public at the point of maximum annual air concentration in an unrestricted area were a member of the public resides or abides. .

III. Radioactivity in Water Standards/Guidelines

As in the case of air, DOE and NRC have concentration guides and maximum permissible concentrations, respectively. In practice, both are applied to the site boundary. Thus, the major difference is that one is a guide and the other a legally imposed limit.

EPA has issued drinking water standards for most radioactive materials, but not uranium. While those standards are issued, apply to the quality of water when it reaches the user of a public water system, they are commonly adopted by states as surface water and groundwater quality standards, e.g., by water quality or hazardous waste organizations. When applied to surface waters, these standards usually apply to all portions of streams classified for drinking water use. Also, streams which have not been classified due to their small size are classified by default for all uses, including drinking water. Groundwaters are also classified for differing uses depending upon factors such as existing water quality and the amount of groundwater which can be pumped for use.

DOE:

The discussion regarding DOE air concentration guides applies to water concentration guides as well. These guides for water, as shown in DOE Order 5480.1, are as follows:

TABLE 4

<u>Isotope</u>	<u>Soluble/Insoluble</u>	<u>μCi/mL</u>
U-234	S	$4 \times 10^{-6}$
U-234	I	$3 \times 10^{-5}$
U-235	S	$4 \times 10^{-6}$
U-235	I	$3 \times 10^{-5}$
U-238	S	$6 \times 10^{-7}$
U-238	I	$4 \times 10^{-5}$

It should be noted that DOE's soluble uranium numerical guides, since 1981, have been more restrictive than those previously in effect reflecting the use of more current data on the uptake of uranium through the gastrointestinal tract.

NRC:

A Licensee shall not release radioactive material to an unrestricted area in concentrations which exceed the limits specified in Appendix B, Table II, (Code of Federal Regulations, Chapter 10, Part 20) except as noted below. Concentrations may be averaged over a period not greater than one year.

TABLE 5(Appendix B, Table II)

<u>Isotope</u>	<u>Soluble/Insoluble</u>	<u>μCi/mL</u>
U-234	S	$3 \times 10^{-5}$
U-234	I	$3 \times 10^{-5}$
U-235	S	$3 \times 10^{-6}$
U-235	I	$3 \times 10^{-5}$
U-238	S	$4 \times 10^{-5}$
U-238	I	$4 \times 10^{-5}$

A Licensee will be allowed to apply these same limits at the location of the maximally exposed individual if NRC is satisfied that the licensee has made a reasonable effort to minimize the radioactivity contained in effluents to unrestricted area. (This exception is rarely granted.)

NRC may reduce licensee effluent limits if it is determined that a suitable sample of an exposed population group would be exposed to radioactive materials through air, water, or food intake equivalent to that received from continuous exposure to air or water containing one-third of these concentrations.

EPA:

EPA has established drinking water standards that include many radionuclides, but not uranium. Nevertheless, the existence of these standards for other radionuclides is relevant to gaining a perspective as to the significance of uranium concentrations in water. Also, for the past few years, EPA has been evaluating an appropriate drinking water standard for uranium. This standard is presently expected to fall within a range of  $10^{-8}$  - 40 picocuries per liter, which equates to  $1.0 \times 10^{-8}$  -  $4.0 \times 10^{-8}$  microcuries/mL.

These EPA radiation standards, as promulgated in 40 CFR 141, apply in water which is delivered to the free flowing outlet of the ultimate user of a public water system.

IV. Radioactivity in Soil Guidelines

The NRC has established guidelines for uranium in soil in unrestricted areas. DOE's determinations are on a case-by-case basis. Experience to date shows both agencies to be using similar guidance.

DOE:

The Department of Energy's Formerly Utilized Sites Remedial Action Program establishes uranium soil clean-up criteria on a case-by-case basis in conjunction with the state agencies involved. Since potential land use will vary, small differences in clean-up criteria may result. To date, uranium criteria for unrestricted use have been in the 30 - 40 pCi/g range.

NRC:

The Nuclear Regulatory Commission has issued a Branch Technical Position on uranium in soil levels permissible for unrestricted use of property. These levels are as follows: