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Particle Size Distribution of Yellowcake Emissions at the United Nuclear-Churchrock Uranium Mill

PARTICLE SIZE DISTRIBUTION OF YELLOWCAKE EMISSIONS AT THE UNITED NUCLEAR-CHURCHROCK URANIUM MILL

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PREFACE

This study was conducted by the Office of Radiation Programs - Las Vegas Facility (ORP-LVF) of the U.S. Environmental Protection Agency. The purpose of the study was to evaluate the particle size distribution of yellowcake (uranium concentrate) emissions from the yellowcake processing stacks at a uranium mill. This is one of a series of similar studies that are being conducted at several uranium mills.

As a follow-on study to yellowcake emission rate tests at six uranium mills, this work supports the requirements of Section 122 of the Clean Air Act Amendments of 1977, Public Law 95-95. Section 122 directed EPA to review all relevant information and determine if emissions of radionuclides cause or contribute to air pollution. The uranium milling industry is one of the source categories being considered by the Office of Radiation Programs in implementing the Clean Air Act.

The field work for this study was conducted by Mr. Charles W. Fort with the assistance of Mr. Richard Douglas. The samples were analyzed by Dr. Emil Kalil at Uranium-West Laboratories. Following initial analysis of the resulting data by Mr. Fort, Dr. Andrew McFarland, consultant to ORP-LVF, and Mr. Randy Gauntt performed the final data analysis and report preparation. Dr. McFarland is a Professor of Civil Engineering at Texas A&M University and Mr. Gauntt is a research associate at Texas A&M.

We would appreciate receiving any comments on this report that readers may have to offer.

Donald W. Hendricks
Director, Office of
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ABSTRACT

Tests were conducted to characterize the particle size distribution of yellowcake dust from the packaging and dryer stacks of a uranium mill in New Mexico. A multistage inertial impactor was used to sample the particulate matter to provide a basis for determining particle size distributions and emission rates. The principal results, from four tests with the packaging stack and eight tests with the dryer stack, are as follows:

Parameter	Packaging Stack	Dryer Stack
Mass median aerodynamic particle diameter	1.62 μm	1.19 μm
Respirable fraction (U_{tot} activity associated with sizes $\leq$ 2.5 μm)	69%	90%
Concentration of U_{tot} (equivalent U_3O_8) in stack	558 ± 192 pCi/dscm (0.971 ± 0.335 mg/dscm)	6120 ± 1070 pCi/dscm (10.7 ± 1.86 mg/dscm)
Total emission rate of U_{tot} (equivalent U_3O_8)	1.19 ± 0.397 μCi/hr (2.07 ± 0.692 g/hr)	62.5 ± 15.8 μCi/hr (109 ± 27.1 g/hr)

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LIST OF ABBREVIATIONS AMD SYMBOLS

A combination of both English units and the International System of Units (SI) are used in this report. For the most part the units dealing with mass and particle size follow SI; however, since gas flow rates are typically measured in the English system, certain flow parameters are expressed correspondingly. In addition, gas volumes can be presented either dry or moist. A summary of the special gas volume, flow rate, and radioactivity units and abbreviations used herein follows:

acf = actual cubic feet. The units of gas volume that include the moisture component and that correspond to the actual pressure and temperature of the gas.

dscf = dry standard cubic feet. Gas volume, with moisture fraction removed, that would exist if the temperature were 68°F and the pressure were 29.92 in. Hg.

acfm = actual cubic feet per minute. Units of volumetric flow rate of gas based on actual conditions.

dscfm = dry standard cubic feet per minute. Flow rate of gas that would exist if moisture were deleted and if temperature and pressure were as given above for units of dscf.

dscm = dry standard cubic meters. Identical to dscf except converted to SI. 1 dscm = 35.3 dscf.

U_{tot} = total uranium activity, i.e., the sum of U-238, U-234, and U-235 activities.

pCi = picocurie = 10^{-12} curie.

μm = micrometer = 10^{-6} meter.

ACKNOWLEDGMENTS

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INTRODUCTION

From May 16 to May 21, 1979, a series of tests were conducted to determine the size distributions of the yellowcake* particles vented from the dryer and packaging stacks at the United Nuclear Corporation uranium mill near Churchrock, New Mexico. The exhaust gases from both the packaging and dryer operations are passed through air pollution control equipment before being discharged through the stacks. A Joy venturi wet scrubber is used on the packaging gases and a Sly "Impi-Jet" scrubber is used for the dryer stack.

The basic sampling tool used in these tests was an eight-stage inertial impactor fitted with an after-filter (Andersen, 1977). This device collects particles in a manner compatible with determining the mass distributions of particles as a function of aerodynamic diameter (D_a).**

EPA is considering the adoption of size standards for airborne particulate matter (Miller et al., 1979). Recommended is a standard based on inhalable particulate matter defined as $\leq$15 μm with emphasis also on the $\leq$2.5 μm fraction. Particles in this latter size range are capable of penetrating the gas-exchange region of the lower respiratory tract and will be referred to in this report as respirable particulate matter.

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* Yellowcake is the generic name given the packaged uranium concentrate produced by uranium mills. It is generally a dry, powdery material having a variety of chemical forms ranging in color from bright yellow through olive green to black, depending on each mill's process. The uranium content of yellowcake is typically expressed as an equivalent mass of one of these compounds, U_3O_8, as in this report. However, since the chemical form of the United Nuclear yellowcake is unknown, it is important for the reader to realize this material may not be U_3O_8 or have the solubility characteristics of U_3O_8.

** Aerodynamic diameter relates the aerodynamic behavior of irregularly shaped particles with varying densities to the diameter of a unit density spherical particle that would behave identically under the same conditions. All particle size references in this report are to aerodynamic diameters.

Data from an inertial impactor can be used to characterize the respirable fraction. However, the inertial impactor used in these studies does not does not provide size resolution for particles larger than approximately 10 μm. Highly definitive information, therefore, is not obtainable on material in the inhalable/non-inhalable fractions.

SAMPLING METHODOLOGY

Four sampling locations at 90° intervals (one in each of the four quadrants) were used for the dryer stack. Prior to each test, the velocity distribution for the quadrant of interest was determined with a pitot tube (USEPA, 1977). A sampling point was selected corresponding to the location at which the dynamic pressure was equal to the average pressure for that quadrant. By coincidence, each of the four sampling points was 3.4 inches from the stack wall. Duplicate tests were conducted at each of the four points. The inside diameter of the stack is 33.5 inches.

The packaging stack, which is 11.25 inches in diameter, would not accommodate the entire impactor without causing undue flow blockage; therefore, the criterion for location of a sampling point was that the impactor be inserted into the stack to a depth whereby the flow blockage would be less than 2 percent. Two locations were used with the points 90° apart and 3.75 inches from the wall. Duplicate tests were conducted at each of the two points.

In preparation for a test, glass fiber collection substrates and a glass fiber after-filter were placed in the impactor, and the impactor was then inserted into the stack. The unit was equipped with heater tapes to enable the impactor to operate well above the stack dew-point temperature. Before sampling began, the impactor was allowed to equilibrate with the stack temperature for 30 minutes. The sampling flow was then started, and sampling continued for a period of 30 to 75 minutes.

At the completion of particle collection, the impaction substrates and after-filter were removed and sent to Uranium-West Laboratories (15515 Sunset Blvd., Suite B07, Pacific Palisades, California 90272) for determination of the total uranium deposited on each element. Samples were analyzed by a delayed-neutron counting technique. This method has a detection sensitivity of 0.17 pCi U_{tot} (0.25 μgm U_{tot}).

A program was developed for the Hewlett Packard 97 calculator (Fort, 1979) to compute impactor stage cut-points. The program incorporates the effects of such sampling variables as flow rate, temperature and pressure as well as the most current impactor calibration data published by Cushing et al. (1976). The program has been validated through an independent cross-check (McFarland, 1979).

ANALYSIS AND RESULTS

The basic test parameters and variables are summarized in Table 1. For each test, the sampler was operated for a period of 30-75 minutes at a flow rate of approximately 0.5 acfm. Total flow rate through the packaging stack ranged from 1217 to 1275 dscfm and through the dryer stack from 4930 to 7130 dscfm.

The particle size data from use of the inertial impactor are tabulated in Appendix A, where the quantity of uranium associated with each stage of the impactor is given as a function of the cut-point particle size of the stage (aerodynamic particle diameter for which the particular impactor stage has a 50 percent collection efficiency). For example, in Test A of the packaging stack, 90.4 μg of uranium was collected on the stage that has a cut-point of 11.0 μm. Similarly, 1.7 μg was collected on the stage with a cut-point of 10.2 μm. Thus, of the material collected during Test A, 90.4 μg of uranium had aerodynamic sizes $\leq$11.0 μm, and 1.7 μg had aerodynamic sizes between 10.2 and 11.0 μm.

Normalized cumulative size distributions were calculated for each test. The results for the packaging stack are plotted in Figure 1 and those for the dryer stack in Figure 2. Smooth composite curves fitted through the data points can be used as a basis for estimating the mass median aerodynamic particle size (corresponding to the 50th percentile) and the fraction of material in the respirable range. These values (Table 2) show the mass median sizes to be 1.62 and 1.19 μm for the packaging and dryer stacks, respectively. The corresponding values for the respirable fractions are 69 and 90 percent.

Cumulative distributions for the individual tests were also plotted, and determinations were made of the mass median sizes and the respirable fractions. A summary of these data appears in Appendix B.

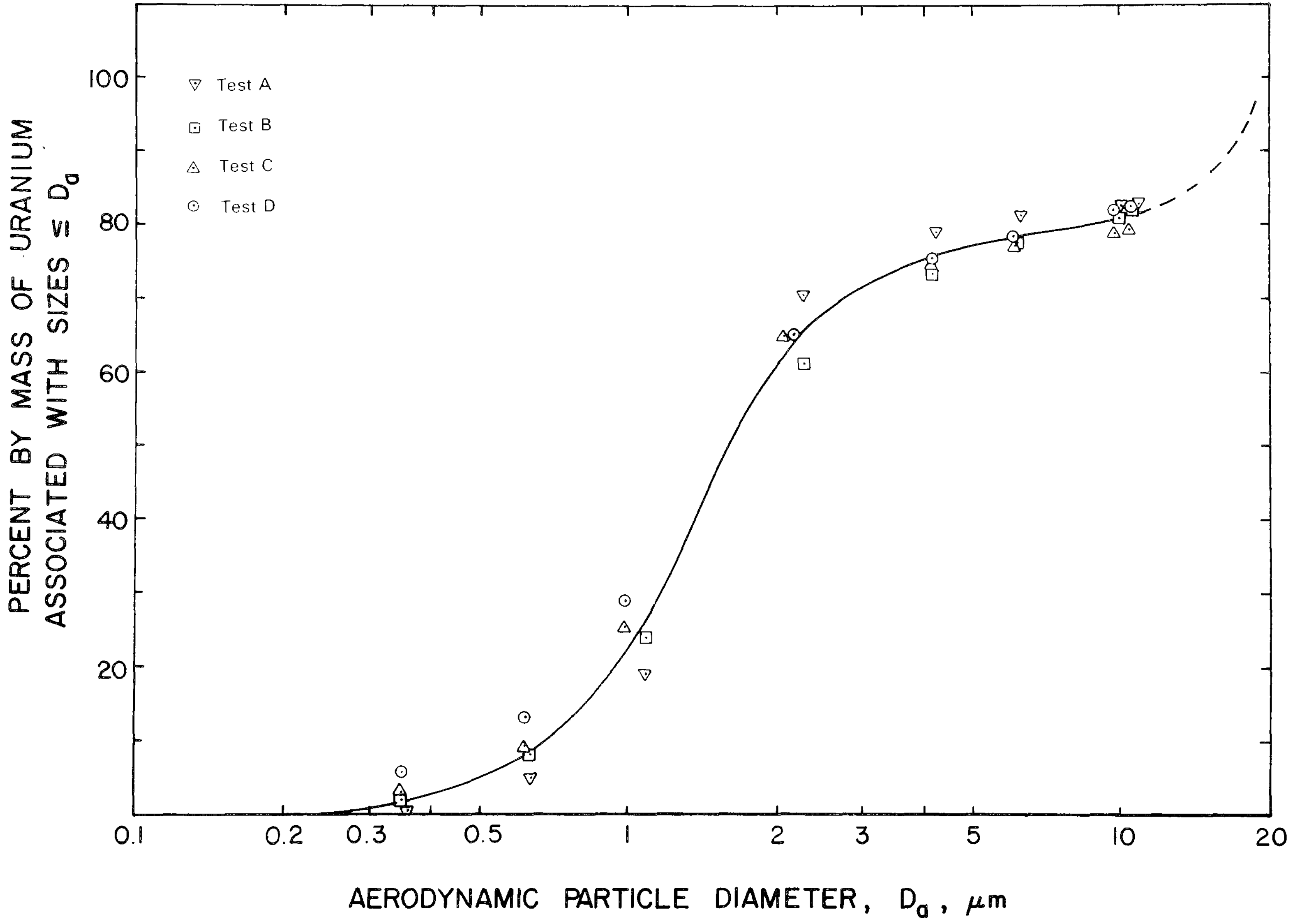

FIGURE 1. CUMULATIVE SIZE DISTRIBUTION OF YELLOWCAKE PARTICLES IN PACKAGING STACK

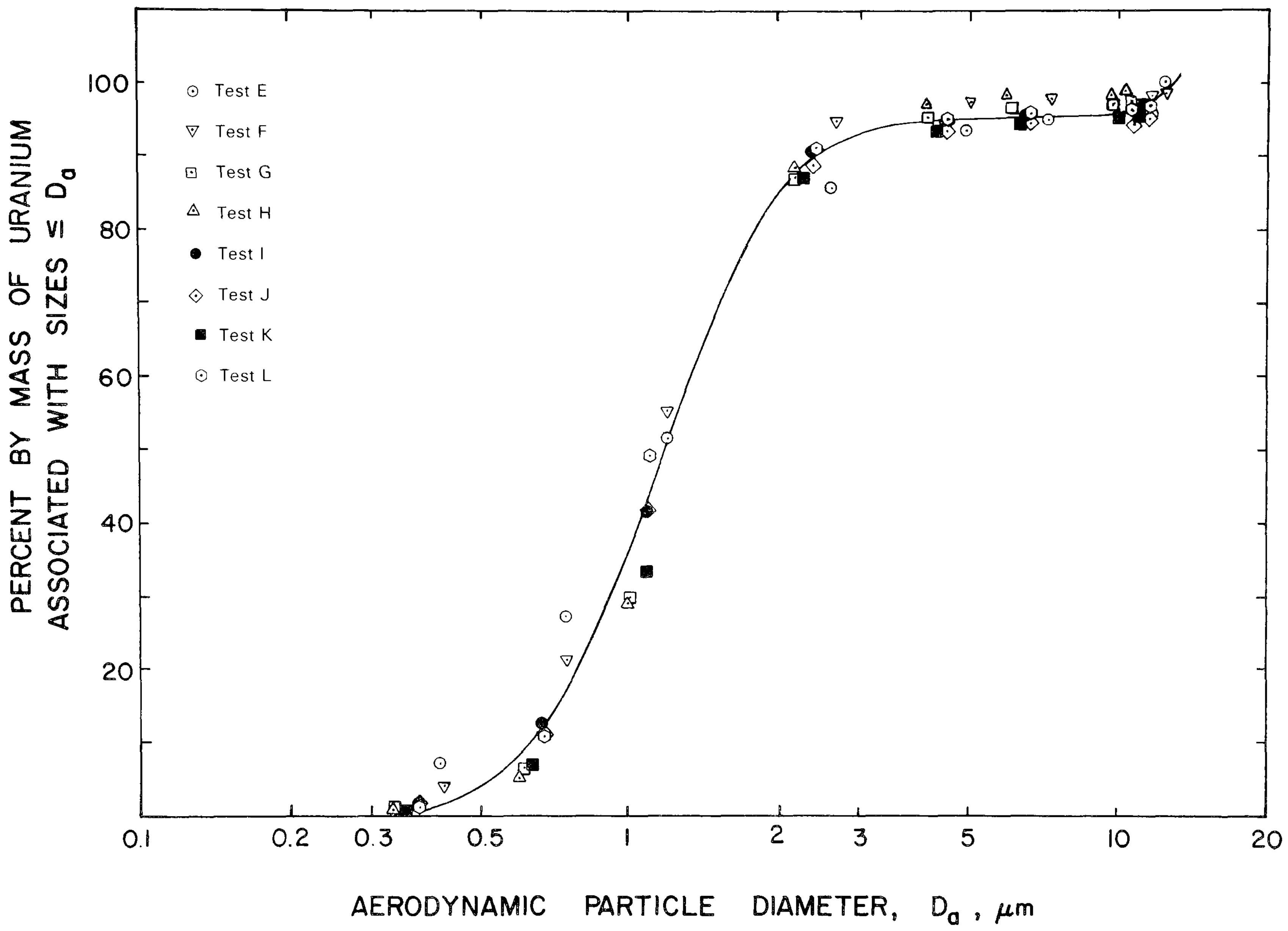

FIGURE 2. CUMULATIVE SIZE DISTRIBUTION OF YELLOWCAKE PARTICLES IN DRYER STACK

TABLE 1. TEST PARAMETERS AND INFORMATION

Stack	Test	Sampling Point	Test Time Minutes	Temperature (degrees F)	Flow Rate (acfm)	Stack Moisture Mol Fraction	Stack Flow Rate (dscfh)
Packaging	A	1	45	91	0.507	0.029	1217
	B	1	60	77	0.520	0.026	1260
	C	2	60	77	0.532	0.025	1265
	D	2	75	84	0.539	0.027	1275
Dryer	E	1	60	132	0.419	0.060	4970
	F	1	75	166	0.419	0.060	4930
	G	2	30	152	0.594	0.060	7020
	H	2	30	139	0.601	0.058	7130
	I	3	45	146	0.502	0.060	5830
	J	3	30	154	0.495	0.058	5700
	K	4	30	139	0.536	0.051	6320
	L	4	30	140	0.498	0.070	5830

TABLE 2. EMISSION CHARACTERISTICS OF PACKAGING AND DRYER STACKS

Parameter	Packaging Stack	Dryer Stack
Mass Median Aerodynamic Diameter	1.62 μm	1.19 μm
Average Respirable Fraction	0.688	0.902
Geometric Mass Mean Aerodynamic Diameter	2.19 μm	1.28 μm
Geometric Standard Deviation	2.95	1.92
Total Concentration of U_{tot}, (U_3O_8)*	558 ± 192 pCi/dscm (0.971 ± 0.335 mg/dscm)	6120 ± 1070 pCi/dscm (10.7 ± 1.86 mg/dscm)
Respirable Concentration of U_{tot}, (U_3O_8)	382 ± 123 pCi/dscm (0.665 ± 0.215 mg/dscm)	5750 ± 760 pCi/dscm (10.01 ± 1.32 mg/dscm)
Average Emission Rate of U_{tot}, (U_3O_8)	1.19 ± 0.397 μCi/hr (2.07 ± 0.692 g/hr)	62.5 ± 15.8 μCi/hr (109 ± 27.1 g/hr)
Average Respirable Emission Rate of U_{tot}, (U_3O_8)	0.812 ± 0.253 μCi/hr (1.41 ± 0.441 g/hr)	56.3 ± 14.2 μCi/hr (98.1 ± 24.7 g/hr)

* Quantities in parentheses represent U_{tot} expressed as equivalent U_3O_8.
** Error terms are one standard deviation of replicate tests.

The composite curves, Figures 1 and 2, were each divided into size intervals of approximately equal logarithmic increments, $\Delta \ln(D)$, and derivative approximations at the interval midpoints (geometric means) were formed as $\Delta G(D)/\Delta \ln(D)$, where $\Delta G(D)$ represents the difference of the cumulative distribution values at the interval upper and lower particle size boundaries. The results of this procedure appear in Appendix C and are plotted in Figures 3 and 4 as $\Delta G(D_a)/\Delta \ln(D_a)$ versus aerodynamic diameter, D_a. Since the impactor does not provide information on the distribution of particles with sizes greater than approximately 10 µm, an upper boundary size was assumed for the largest fraction. The values selected were 20 µm for the packaging stack and 13 µm for the dryer stack data. The bimodal appearance of these mass densities may be due, in part, to the selection of the upper limit of the largest size interval; however, the plot of the packaging stack data, Figure 3, illustrates that considerable material is associated with particle sizes $\leq$10µm. Figure 1 shows that approximately 20 percent of the uranium mass from the packaging stack is associated with these larger sizes. Correspondingly, only 5 percent of the uranium mass collected from the dryer stack is seen to be associated with particles larger than 10 µm.

The geometric mass mean aerodynamic diameter, D_g, and the geometric standard deviation, s_g, for the distributions in Figures 3 and 4 were computed using:

$$\ln D_g = \Sigma (\ln D_{i,mp}) * \Delta G_i$$

where $D_{i,mp}$ = midpoint size of ith interval

$D_{i,mp} = (D_{i,u} * D_{i,L})^{1/2}$

$D_{i,u}$ = interval upper boundary

$D_{i,L}$ = interval lower boundary

and:

$$\ln^2 s_g = \Sigma (\ln D_{i,mp} - \ln D_g)^2 * \Delta G_i \qquad \text{(McFarland,1978)}$$

in conjunction with the data tabulations of Appendix C. The results are given in Table 2.

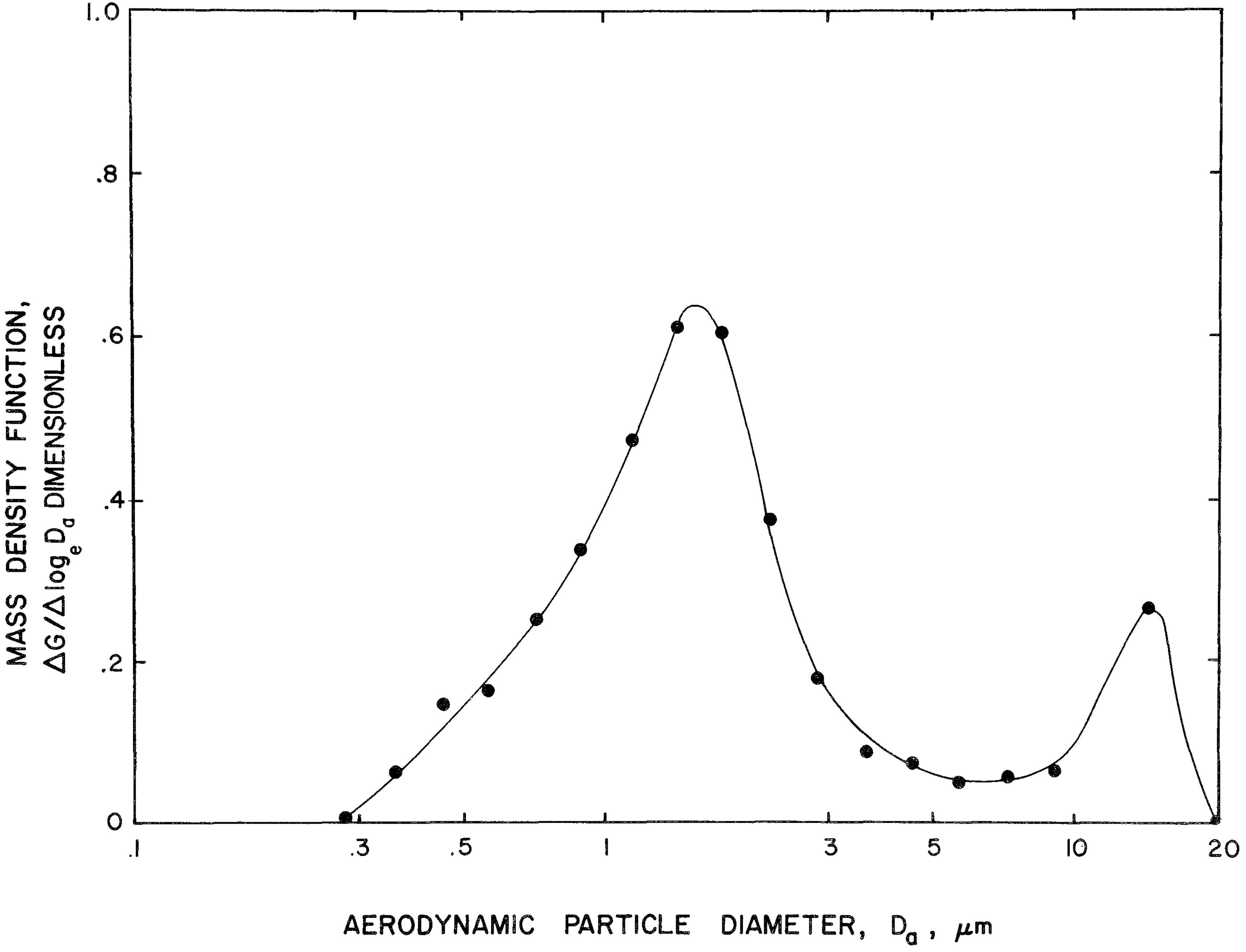

FIGURE 3. MASS FREQUENCY OF PARTICULATE MATTER FROM PACKAGING STACK

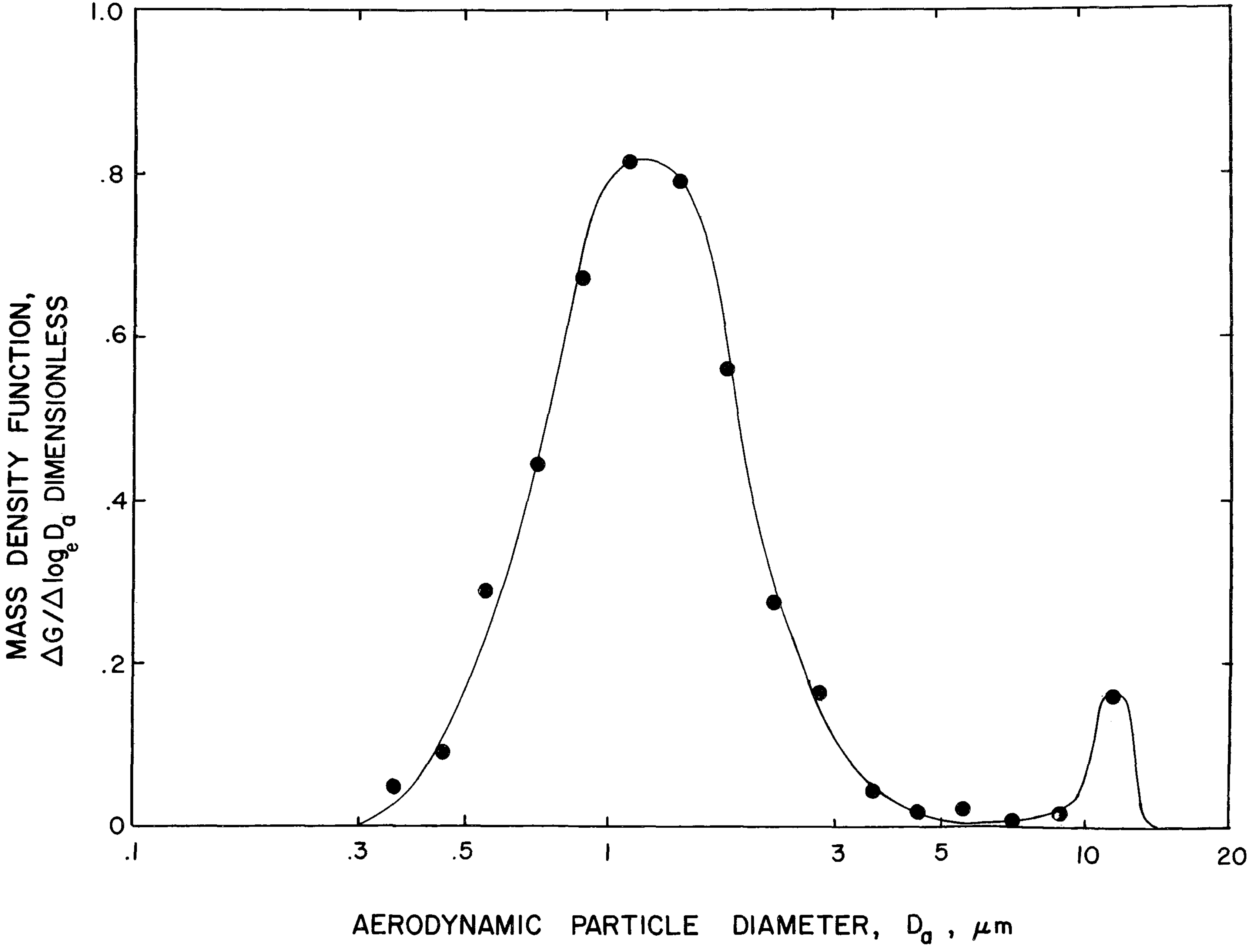

FIGURE 4. MASS FREQUENCY OF PARTICULATE MATTER FROM DRYER STACK

Using the procedure outlined in Appendix D, total concentrations and respirable concentrations were computed for each test. Concentrations were calculated in terms of pCi U_{tot}/dscm and mg U_3O_8/dscm. Total and respirable emission rates (pCi U_{tot}/hr and g U_3O_8/hr) were then calculated for each test using the dry standard concentrations and the dry standard stack flow rates. The basic assumptions used in calculating emission rates from impactor data are (1) a homogeneous yellowcake concentration exists throughout the stack, and (2) the gas velocity at the sampling point is the average velocity for the stack. These results are summarized by test in Table 3. The values of the parameters for each stack in Table 3 were averaged, and a standard deviation was calculated. These values are listed in Table 2.

SUMMARY AND CONCLUSIONS

The yellowcake particle emissions from the uranium mill packaging and dryer stacks can be characterized by mass median aerodynamic diameters of 1.62 and 1.19 μm, respectively. If respirable particulate matter is defined as particles with aerodynamic sizes $\leq$2.5 μm, then the packaging stack has a respirable fraction of 69 percent while that of the dryer is 90 percent. Since both stacks are controlled with scrubbers, the actual size distributions and respirable fractions are quite dependent upon the scrubber performance.

Approximately 20 percent of the particulate mass emitted by the packaging stack was associated with aerodynamic particle sizes larger than 10 μm. A scrubber should efficiently remove these larger particles from the distribution, so it appears that the packaging stack scrubber may have abnormal mist carryover or may have other operational or design problems.

The packaging stack discharges an average of 1.19 μCi U_{tot}/hr (2.07 g U_3O_8/hr) to the atmosphere. The rate for the dryer stack is 62.5 μCi U_{tot}/hr (109 g U_3O_8/hr).

TABLE 3. SUMMARY OF EMISSION CHARACTERISTICS FOR INDIVIDUAL TESTS

Stack	Test Number	Total Uranium Concentration (pCi U_{tot}/dscm)	Respirable Uranium Concentration (pci U_{tot}/dscm)	Total Uranium Emission Rate (µCi U_{tot}/hr)	Respirable Uranium Emission Rate (µCi U_{tot}/hr)
Packaging	A	626.23	456.90	1.296	0.946
	B	767.44	491.34	1.636	1.047
	C	527.51	363.92	1.138	0.785
	D	310.53	214.68	0.679	0.468
Dryer	E	4760.76	4047.85	40.161	34.137
	F	6266.36	5827.25	52.521	48.739
	G	6706.62	6035.61	79.958	71.962
	H	6272.10	5707.86	76.026	68.804
	I	6351.88	5778.46	62.949	57.283
	J	7475.20	6727.85	72.391	65.152
	K	6813.95	6063.74	73.128	65.230
	L	4287.78	5772.14	42.495	39.095

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APPENDIX A

Basic Impactor Data

Stack	Test	Sampling Point	Impactor Aerodynamic Cut-Point Size, μm	Uranium Collected, μg
Packaging	A	1	11.0	90.4
			10.2	1.7
			6.4	9.0
			4.3	13.0
			2.3	48.5
			1.1	285.4
			0.65	80.2
			0.36	24.8
			0 (Filter)	5.8
Packaging	B	1	10.8	166.8
			10.0	10.4
			6.2	37.8
			4.2	37.1
			2.3	118.2
			1.1	358.3
			0.64	151.8
			0.35	58.8
			0	24.6
Packaging	C	2	10.6	137.1
			9.9	3.2
			6.2	11.9
			4.2	12.6
			2.2	70.3
			1.0	265.7
			0.63	112.3
			0.35	41.3
			0	23.2
Packaging	D	2	10.6	84.5
			9.9	4.1
			6.2	16.2
			4.2	15.4
			2.2	52.2
			1.0	179.6
			0.63	77.6
			0.35	37.4
			0	31.0

APPENDIX A (continued)

Basic Impactor Data

Stack	Test	Sampling Point	Impactor Aerodynamic Cut-Point Size, μm	Uranium Collected, μg
Dryer	E	1	12.5	0*
			11.6	186.8
			7.2	16.0
			4.9	55.2
			2.6	336.7
			1.2	1442.4
			0.74	1014.5
			0.41	872.0
			0	295.5
Dryer	F	1	12.7	87.4
			11.8	16.1
			7.4	24.7
			5.0	35.0
			2.7	182.9
			1.2	2544.4
			0.75	2277.7
			0.42	1160.1
			0	268.8
Dryer	G	2	10.6	89.6
			9.8	23.4
			6.1	31.8
			4.1	52.0
			2.2	316.9
			1.0	2338.4
			0.61	966.0
			0.33	227.1
			0	28.9
Dryer	H	2	10.4	34.3
			9.7	11.8
			6.0	22.4
			4.1	40.4
			2.2	338.2
			1.0	2343.6
			0.60	936.6
			0.33	182.3
			0	26.7

*Uranium on first impactor stage combined with second stage.

APPENDIX A (continued)

Basic Impactor Data

Stack	Test	Sampling Point	Impactor Aerodynamic Cut-Point Size, μm	Uranium Collected, μg
Dryer	I	3	11.5	163.9
			10.6	17.1
			6.6	22.8
			4.5	30.8
			2.4	222.5
			1.1	2401.1
			0.67	1450.0
			0.37	546.5
			0	74.5
Dryer	J	3	11.6	163.5
			10.8	14.8
			6.7	21.7
			4.5	30.8
			2.4	187.1
			1.1	1771.3
			0.68	1163.5
			0.37	373.7
			0	45.3
Dryer	K	4	11.1	164.1
			10.2	17.5
			6.4	28.0
			4.3	45.5
			2.3	238.2
			1.1	2050.1
			0.64	1022.6
			0.35	252.7
			0	29.5
Dryer	L	4	11.5	63.6
			10.6	10.0
			6.6	11.9
			4.5	18.1
			2.4	85.8
			1.1	926.8
			0.67	842.5
			0.37	213.5
			0	28.9

APPENDIX B

Summary of Size Parameters and
Total Mass for Individual Tests

Stack	Test	Mass Median Aerodynamic Diameter, μm	Respirable Fraction, %	Total Uranium Collected, mg
Packaging	A	1.55	73.0	0.5588
	B	1.77	64.0	0.9638
	C	1.56	69.0	0.6776
	D	1.52	69.0	0.4980
Dryer	E	1.17	85.0	4.2191
	F	1.11	92.8	6.5471
	G	1.25	90.0	4.0741
	H	1.27	90.5	3.9363
	I	1.21	91.0	4.9372
	J	1.18	90.0	3.7717
	K	1.35	89.2	3.8484
	L	1.18	92.0	2.2011

APPENDIX C

Composite Size Distribution Data

C.1 Packaging Stack

Interval Lower Size D_L	$\ln D_L$	$G(D_L)$	$\Delta \ln(D)$	$\Delta G(D)$	$\frac{\Delta G(D)}{\Delta \ln(D)}$	Interval Midpoint D_{mp}, μm
0.25	-1.3863	0.008				
			0.2469	0.002	0.00810	0.280
0.32	-1.1394	0.010				
			0.2231	0.015	0.06722	0.358
0.40	- .9163	0.025				
			0.2231	0.034	0.1524	0.447
0.50	- .6931	0.059				
			0.2469	0.041	0.1661	0.566
0.64	- .4463	0.100				
			0.2231	0.058	0.2599	0.716
0.80	- .2231	0.158				
			0.2231	0.077	0.3451	0.894
1.0	0	0.235				
			0.2469	0.118	0.4780	1.131
1.28	0.2469	0.353				
			0.2231	0.139	0.6229	1.431
1.60	0.470	0.492				
			0.2231	0.108	0.4840	1.789
2.0	0.6931	0.600				
			0.2231	0.085	0.3809	2.236
2.5	0.9163	0.685				
			0.2469	0.045	0.1823	2.828
3.2	1.1632	0.730				
			0.2231	0.020	0.0896	3.578
4.0	1.3863	0.750				
			0.2231	0.018	0.0807	4.472
5.0	1.6094	0.768				
			0.2311	0.012	0.0519	5.612
6.3	1.8405	0.780				
			0.2389	0.015	0.0628	7.099
8.0	2.0794	0.795				
			0.2231	0.015	0.0672	8.944
10.0	2.3026	0.810				
			0.6931	0.190	0.2741	14.142
20.0	2.9957	1.000				

APPENDIX C

Composite Size Distribution Data

C.2 Dryer Stack

Interval Lower Size D_L	$\ln D_L$	$G(D_L)$	$\Delta \ln(D)$	$\Delta G(D)$	$\frac{\Delta G(D)}{\Delta \ln(D)}$	Interval Midpoint D_{mp}, μm
0.25	-1.3863	0				
			0.2469	0	0	0.280
0.32	-1.1394	0				
			0.2231	0.01	0.0448	0.358
0.40	- .9163	0.01				
			0.2231	0.02	0.0896	0.447
0.50	- .6931	0.03				
			0.2469	0.07	0.2836	0.566
0.64	- .4463	0.10				
			0.2231	0.10	0.4481	0.716
0.80	- .2231	0.20				
			0.2231	0.15	0.6722	0.894
1.0	0	0.35				
			0.2469	0.20	0.8102	1.131
1.28	0.2469	0.55				
			0.2231	0.175	0.7842	1.431
1.60	0.470	0.725				
			0.2231	0.125	0.5602	1.789
2.0	0.6931	0.850				
			0.2231	0.060	0.2689	2.236
2.5	0.9163	0.91				
			0.2469	0.040	0.1620	2.828
3.2	1.1632	0.95				
			0.2231	0	0	3.578
4.0	1.3863	0.95				
			0.2231	0.002	0.0089	4.472
5.0	1.6094	0.952				
			0.2311	0.003	0.0130	5.612
6.3	1.8405	0.955				
			0.2757	0.001	0.0036	7.099
8.3	2.1163	0.956				
			0.1863	0.002	0.0107	9.110
10.0	2.3026	0.958				
			0.2624	0.042	0.1601	11.402
13.0	2.5649	1.0				

APPENDIX D

Example of Calculations for Determination of Particle Concentration and Emission Rate

1. Select Packaging Stack Test A for sample calculation.

2. From Table I and Appendix B:

   Stack flow rate = 1217 dscfm
   Moisture = 0.029 (mol fraction)
   Temperature = $91^{o}F$
   Total mass of U_3O_8 collected = 0.6589 mg
   Respirable fraction = 73%
   Sampling rate = 0.507 acfm
   Test time = 45 min

3. Calculate the volume of air sampled based on dry conditions.

$$Q_{dscf} = (1 - x) \left(\frac{T_{std}}{460 + T}\right) Q_{acf}$$

Q = volume sampled
x = moisture, mol fraction
T_{std} = standard temperature = $530^{o}R$
T = actual temperature, ^{o}R

thus:

$$Q_{dscf} = (1 - 0.029) \left(\frac{530}{460 + 91}\right) (0.507 \text{ acfm} * 45 \text{ min})$$

= 21.3 dscf
= 0.6034 dscm

4. Conversion of U_{tot} to equivalent U_3O_8:

$$6.77 \times 10^5 \text{ pCi } U_{tot}/\text{gm } U_{tot} * 0.848 \text{ gm } U_{tot}/\text{gm } U_3O_8$$
$$= 5.74 \times 10^5 \text{ pCi } U_{tot}/\text{gm } U_3O_8$$

5. Total concentration of U_{tot} or U_3O_8 in stack:

$$\text{Total concentration } U_{tot} = 378 \text{ pCi } U_{tot} \div 0.6034 \text{ dscm}$$
$$= 627 \text{ pCi } U_{tot}/\text{dscm}$$
$$\text{Total concentration } U_3O_8 = 627 \text{ pCi } U_{tot}/\text{dscm} \div 5.74 \times 10^5 \text{ pCi } U_{tot}/\text{g } U_3O_8$$
$$= 1.092 \text{ mg/dscm}$$

6. Respirable concentration of U_{tot}:

$$\text{Respirable concentration} = 627 \text{ pCi } U_{tot}/\text{dscm} * 0.73$$
$$= 458 \text{ pci } U_{tot}/\text{dscm}$$

7. Total emission rate of U_{tot}:

$$\text{Total emission rate} = 627 \text{ pCi } U_{tot}/\text{dscm} * 1217 \text{ dscfm} * 1 \text{ m}^3/3531 \text{ ft}^3$$
$$= 2.16 \times 10^4 \text{ pCi } U_{tot}/\text{min}$$
$$= 1.30 \times 10^6 \text{ pCi/min} * \mu\text{Ci}/10^6 \text{ pCi}$$
$$= 1.30 \mu\text{Ci } U_{tot}/\text{hr}$$

8. Emission rate of respirable U_{tot}:

$$\text{Respirable emission rate} = 0.73 * 1.30 \mu\text{Ci } U_{tot}/\text{hr}$$
$$= 0.95 \mu\text{Ci } U_{tot}/\text{hr}$$

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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4. TITLE AND SUBTITLE Particle Size Distribution of Yellowcake Emissions at the United Nuclear-Churchrock Uranium Mill		5. REPORT DATE January 1980
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15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Tests were conducted to characterize the particle size distribution of yellowcake dust from the packaging and dryer stacks of a uranium mill in New Mexico. A multistage inertial impactor was used to sample the particulate matter to provide a basis for determining particle size distributions and emission rates. The principal results, from four tests with the packaging stack and eight tests with the dryer stack, are as follows:

Parameter	Packaging Stack	Dryer Stack
Mass median aerodynamic particle diameter	1.62 μm	1.19 μm
Respirable function (U_{tot} activity associated with size $\leq$ 2.5 μm)	69%	90%
Concentration of U_{tot} (equivalent U_3O_8) in stack	558 ± 192 pCi/dscm (0.97 ± 0.335 mg/dscm)	6120 ± 1070 pCi/dscm (10.7 ± 1.86 mg/dscm)
Total emission rate of U_{tot} (equivalent U_3O_8)	1.19 ± 0.397 μCi/hr (2.07 ± 0.692 g/hr)	62.5 ± 15.8 μCi/hr (109 ± 27.1 g/hr)

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Particle Size Distribution Uranium Isotopes	Yellowcake	1407 1802

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