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AUTHOR(S): L. C. Schwendiman, W. J. Madia, J. Mishima, S. L. Sutter, P. C. Owzarski, T. J. Bander, E. W. Schmidt and J. D. Yesso

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William R. Lahs
Systems Performance Branch
Div. of Safeguards, Fuel Cycle & Environmental Research

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NRC Research and Technical
Assistance Report

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INTERIM REPORT

Quarterly Progress Report Covering Period January 1 Through March 30, 1979— The Study of Plutonium Oxide Leak Rates from Shipping Containers

May 1979

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NRC Research and Technical
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QUARTERLY PROGRESS REPORT

January 1 - March 30, 1979

STUDY OF PLUTONIUM OXIDE LEAK RATES FROM SHIPPING CONTAINERS

INTRODUCTION

This study was initiated in October 1976, as outlined in the 189 research proposal submitted previously. Several tasks are to be undertaken in this study which, when combined, have the end objective of defining the leak rates of plutonium oxide powder from characterized leaks.

This is the tenth quarterly report of this work. Previous reports were issued as BNWL-2260-1, -2, -3, -4, -5, -6, -7, -8 and -9. Each task will be identified and the progress during the reporting period briefly described.

PROGRESS TO DATE

TASK A -- Review literature and theoretical work relating to transmission of particles through channels

Task objective has been fulfilled, and two reports issued: Supporting Information for the Estimation of Plutonium Oxide Leak Rates Through Very Small Apertures, by L. C. Schwendiman, BNWL-2198; and Transport of Particles Through Gas Leaks -- A Review, by L. C. Schwendiman and S. L. Sutter, BNWL-2218, January 1977.

TASK B -- Investigate the relationship of gas flow rates, leak geometries, pressures and temperatures

Milestone 1. Review literature on topic.

Milestone 2. Report on technical literature.

These milestones were reached and a document, Estimation of Gas Leak Rates Through Very Small Orifices and Channels, by H. J. Bomelburg, BNWL-2223, was issued.

Milestone 3. Select method and design apparatus for flow experiments.

Milestone 4. Fabricate and assemble apparatus.

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Milestone 5. Test apparatus.

Milestone 6. Conduct first test.

Milestones 1 through 6 were completed in FY 1977.

Milestone 7. Complete test series (orifices). January 1978.

Milestone 8. Draft report. March 1978.

Milestone 9. Issue report.

The document Measured Airflow Rates Through Micro-orifices and Flow Prediction Capability, NUREG/CR-0066 (PNL-2611), was issued in July 1978.

Milestone 10. Fabricate microcapillaries.

Milestone 11. Complete test series. April 1978.

Milestone 12. Draft report.

The following document has now entered clearance procedures: Measured and Predicted Gas Flow Rates Through Rough Capillaries, by P. C. Owzarski, S. L. Sutter, J. Mishima, L. C. Schwendiman and T. J. Bander, NUREG/CR-0745 (PNL-2623), Pacific Northwest Laboratory, Richland, WA 99352. The document compares experimental flow data through 50 to 250-micrometer-diameter metal capillaries, 0.76 to 2.54 cm long, with data generated by a computer model, Code CAPIL. This code can predict gas flow in capillaries for adiabatic, isothermal and maximum heat transfer conditions in the capillaries. As shown in the document, agreement between measured and predicted flow rates was very good in most cases.

The document also includes a detailed description of the flow theory that provides a technical basis for CAPIL. Of noteworthy importance is the inclusion of entrance and exit pressure losses in the model. These losses are of paramount importance in the overall flow resistance, which must be identical to orifice flow resistance for "zero"-length capillaries.

TASK C -- Measure transmission of a well-characterized simulant (UO_2 powder) through leaks characterized in Task B

Milestone 1. Pressure vessel for simulating container available for experiments. June 1978.

Milestone 2. Convert airflow apparatus. Completed January 1978.

Milestone 3. First experiment completed.

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Experiments to measure the transmission of depleted UO_2 when the leakpath is above (APLA) or below (UPL) the powder level continued in the second quarter FY 1979. Experiments with orifices were completed and any further tests will involve capillaries when they have been satisfactorily fabricated.

- Leakpaths Above the Static Powder Level With Powder Agitation (APLA)

Uranium measurements from 164 APLA experiments were received during this reporting period, and results are shown in Table A-1 (see Appendix). The quantity of depleted uranium dioxide (herein signified as DUO) measured is reported as total μg DUO transmitted, μg DUO/min and μg DUO/cc airflow.

-- APLA Statistical Analysis

The results of the APLA statistical matrix were received and are now being analyzed. A preliminary study of the initial APLA orifice data indicates that the natural logarithm (ln) (DUO μg/min) provided the best insight into the significance of the data. Four variables, and the natural logarithm of each, were investigated:

1) DUO, total μg transmitted
2) DUO/min, DUO per unit time
3) DUO/m^2, DUO per unit cross-sectional area
4) DUO/min/m^2, DUO per unit time per area.

The results of single, multiple-time constant and multiple-time varying runs are plotted in Figure 1. The time-constant value is the average of all the orifices tested in one run. Since there was no assurance that shutting off the flow control downstream of the sampler shut off transmission to the sampler, the impact of the time of shutoff on the time-varying runs is questionable. Therefore, for the time-varying runs, $\overline{TV} = \ln [\Sigma DUO/\text{max time}]$ was selected as the best value to compare with the single- and time-constant averages.

The data are plotted as a function of DUO ln μg/min against the ln of the characterized airflow rate. The relationships among the five orifices with single, multiple and time-varying treatments are shown in the figure. It appears that a piecewise linear model (for the ln data) might be appropriate for relating the data.

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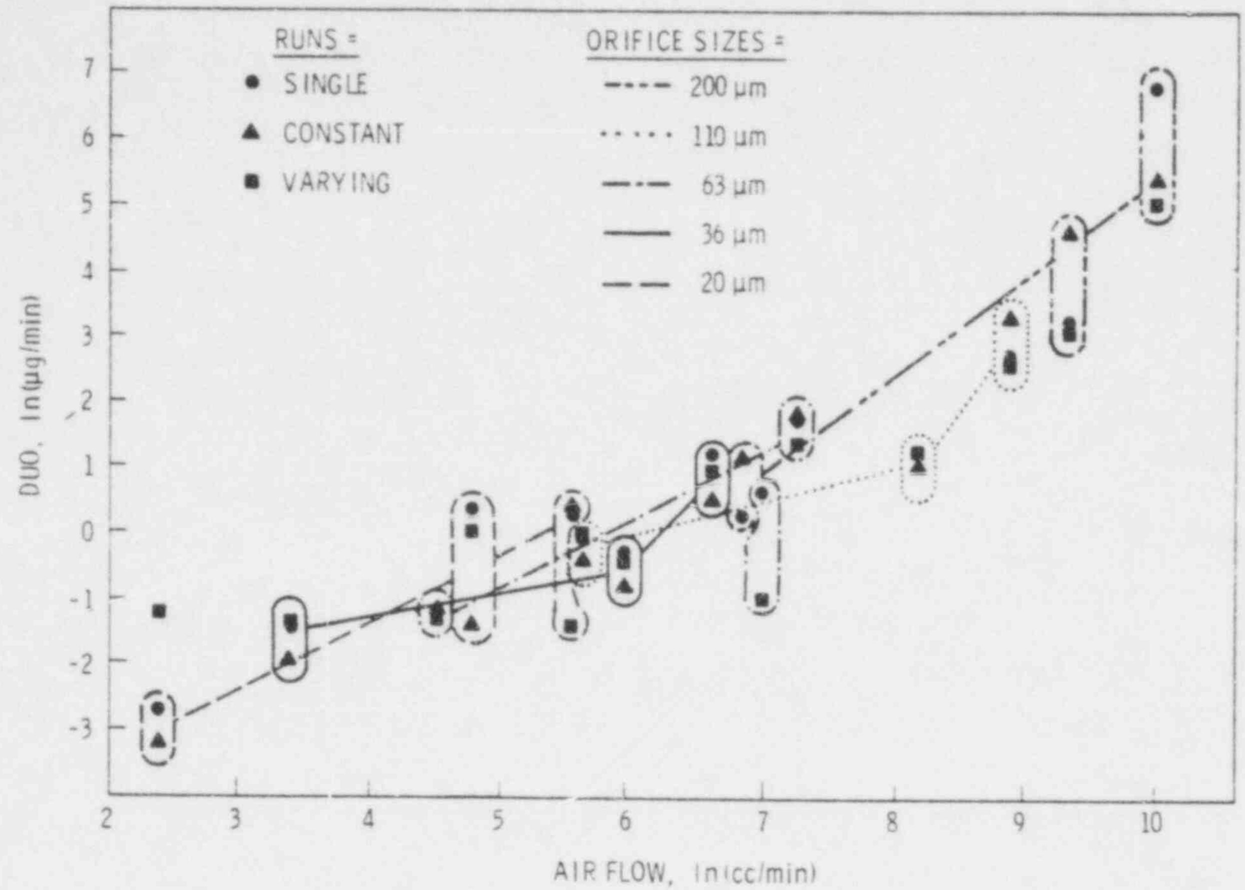

FIGURE 1. Comparison of APLA Treatments Indicating Diameter Relationships

-- Extended Time Runs

The nominal 110-µm orifice at 100 psig upstream pressure was used in runs to evaluate APLA powder transmission for extended time periods. One experiment (and a replicate) were made at extended times of 24 and 6 hr.

The airflow rate during the first 24-hr run showed a gradual decrease during the first 4 hr, then a slow restoration of flow to 95% of the original flow rate, as illustrated in the plot in Figure 2. In this experiment, the orifice apparently plugged and a plug of powder built up, lessening flow. The plug subsequently seemed to erode as airflow was restored. At the minimum flow rate, the calculated apparent diameter of the orifice was 85 µm. Other runs were started but aborted because adequate airflow could not be achieved; flows were 50 and 100 cc/min (~700 cc/min was desired). Chemical analysis of samples from these runs

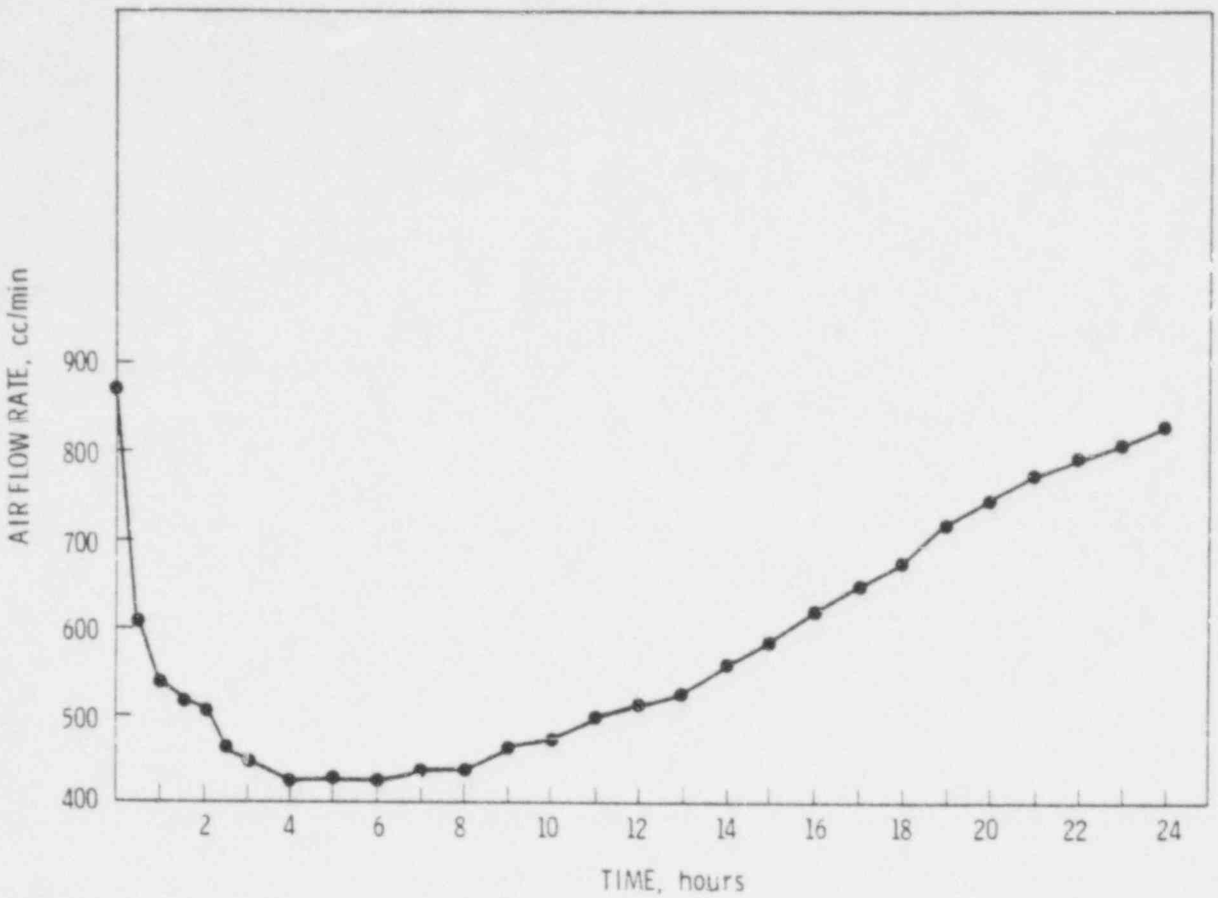

FIGURE 2. APLA Airflow Rate as a Function of Time During a 24-hr Run, Orifice 1-110, 100 psig

yielded 15.2 to 38.7 μg DUO, even with some plugging evident during microscopic examination of the orifice. However, an adequate flow was achieved with orifice 6-110, and a second 24-hr run was made. A constant airflow rate was maintained through the entire run with no evidence of plugging.

The total DUO transmitted in the extended time runs and shorter time experiments are compared in the plots in Figure 3, showing the total DUO transmitted with upper limit values connected (1 hr omitted). The DUO collected from the run exhibiting plugging and subsequent release of the plug showed the highest result for 24 hr, 305 μg. The 105 μg collected in the second 24-hr run is comparable to the highest collection from

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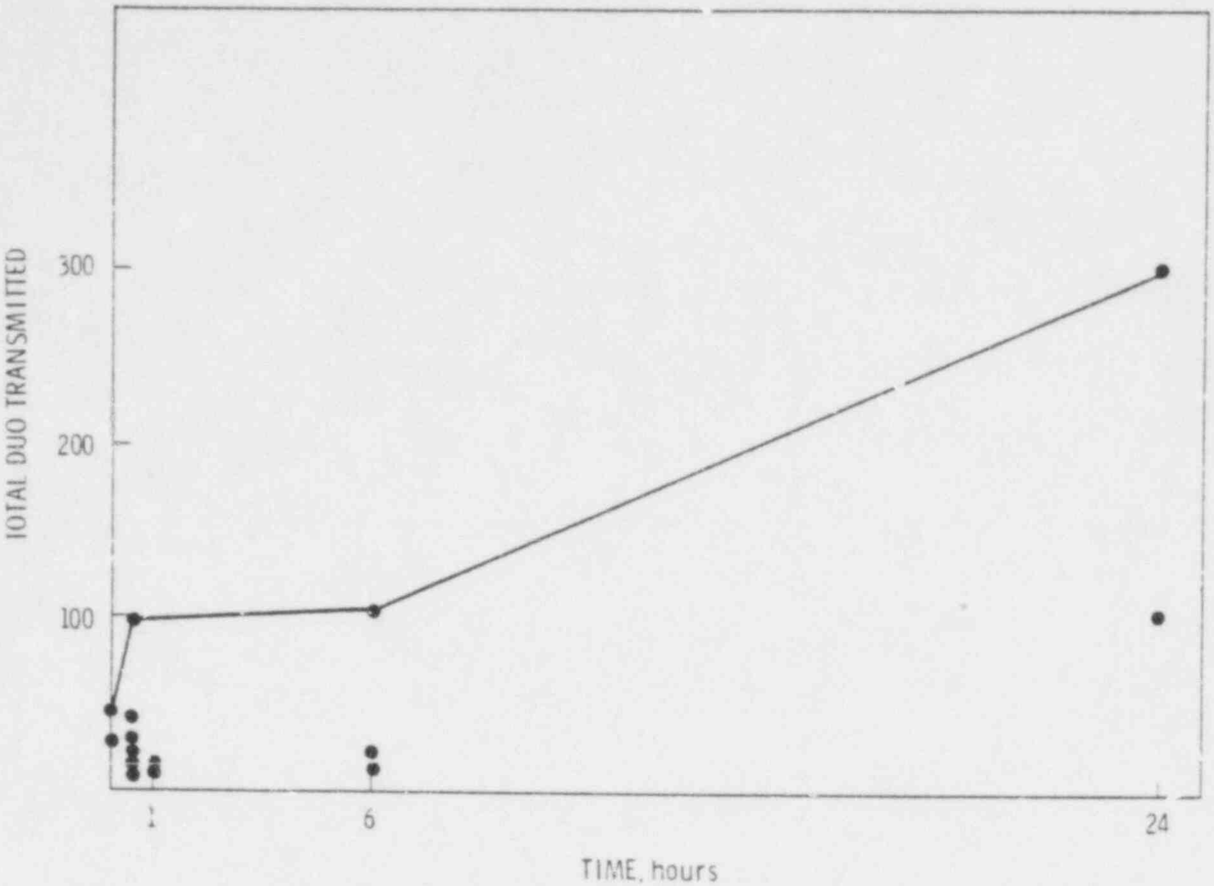

FIGURE 3. Total DUO Transmitted Through 110 μm Orifice During APLA Runs at 100 psig, as a Function of Time

individual runs for shorter time periods: it appears that the maximum powder leakage occurs early in any run. The average leakage during the 1-min pressurization/depressurization time was 30 μg. If this leakage had persisted for 24 hr, 5.5 x 10^4 μg DUO would have leaked.

Figure 4 illustrates the maximum leakage occurring early in any run by plotting leak rate as a function of time. The maximum flow rate occurs in the first hour, then seems to stabilize at a lower rate for the remainder of the time.

-- Slow Pressurization

Since up to 80 min may be required to pressurize the vessel to 1000 psig after an accident,(1) experiments using 1-110 and

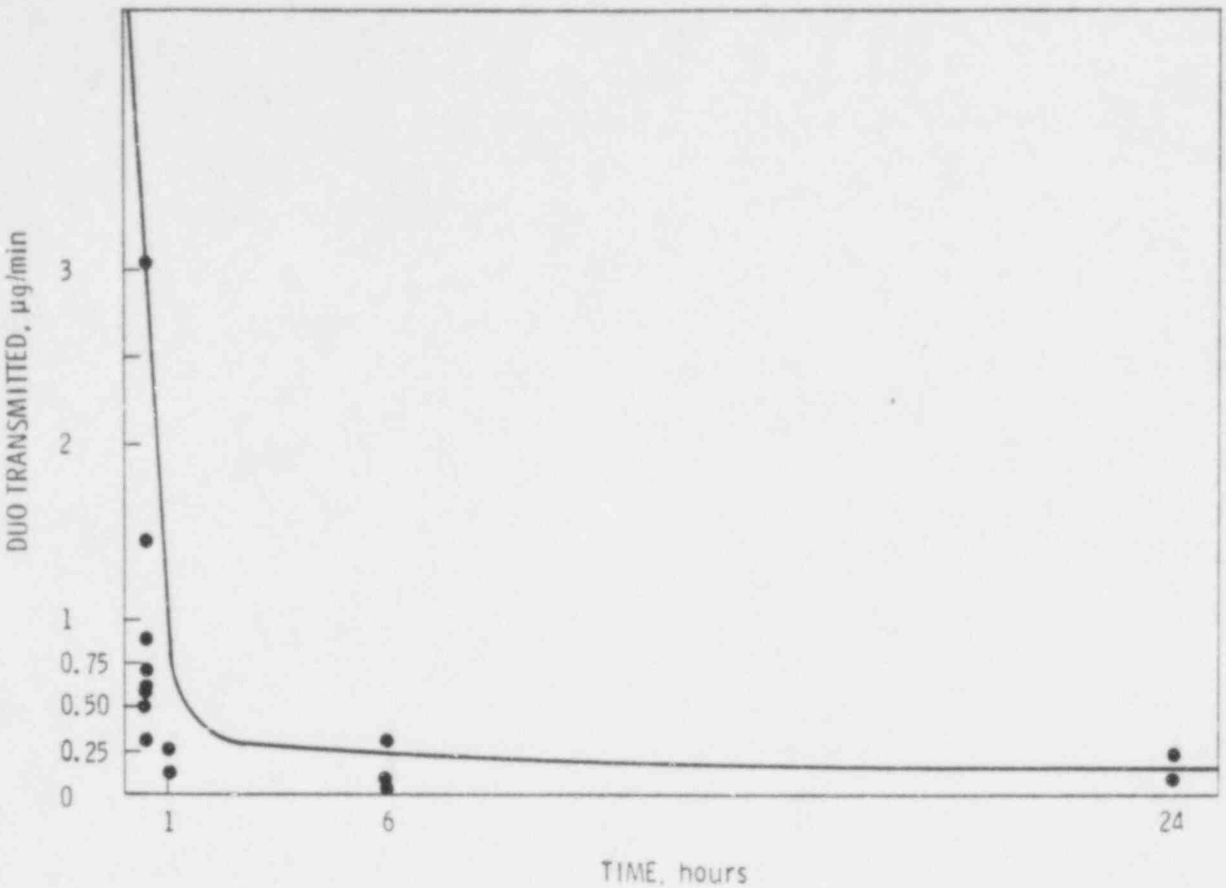

FIGURE 4. DUO Leak Rate Through 110-micron Orifices During APLA Runs at 100 psig, as a Function of Time

1-200 µm orifices investigated slow pressurization (80 min) in contrast to immediate pressurization. The results are compiled in Table I.

TABLE I

TOTAL DUO TRANSMITTED AT IMMEDIATE PRESSURIZATION AND 80-MINUTE PRESSURIZATION

Orifice	Immediate Pressurization µg/min	80-Min Pressurization µg/min
1-110	574	468
1-200	3705	1248

The results of Table I infer that less powder is transmitted during slow pressurization; slow-pressurization DUO transmission through the 1-200 orifice is one third that of immediate pressurization. However, with the smaller diameter orifice there is essentially no difference in DUO transmitted. The results of Table I seem to indicate that more powder can be airborne in immediate pressurization than 80-min pressurization. The 200-μm orifice diameter is sufficiently large to allow powder flow. The same DUO transmitted during two runs using the smaller 110-μm orifice diameter could indicate that this diameter does not allow free flow and that even with powder flow from an environment with higher airborne concentrations (immediate pressurization), limited DUO can be transmitted.

- Leakpath Underneath the Static Powder Level (UPL)

Results from 56 UPL experiments were received during this reporting period and are tabulated in Table A-2 in the Appendix.

These experiments looked at pressure and powder depth effects, time required for pressurization, powder leakage as a function of time, orientation and slow pressurization effects, and effects of turning the powder reservoir end for end.

-- Depth Effects

The DUO transmitted below the static powder level through leaks covered with 1.5, 7.4 and 21.8 cm of DUO powder is shown in Figure 5 (30-min runs; μg/min as a function of airflow rate). For the lowest airflow rate at 100 psig, the DUO transmitted was the same for all depths, and at 1000 psig DUO transmitted at all depths was comparable. However, at 500 psig (4500 cc/min) the 7.4-cm depth (100 g) had about five times the leakage of the other two depths. This result is supported by replicate tests that agree by 50%. The lowest of the replicate values arrived at was 2.3 times the value for the other depths. These high results are, therefore, considered valid and illustrate the vagaries of powder flow: the pressure/depth combination apparently minimizes arching and maximizes fluidization effects.

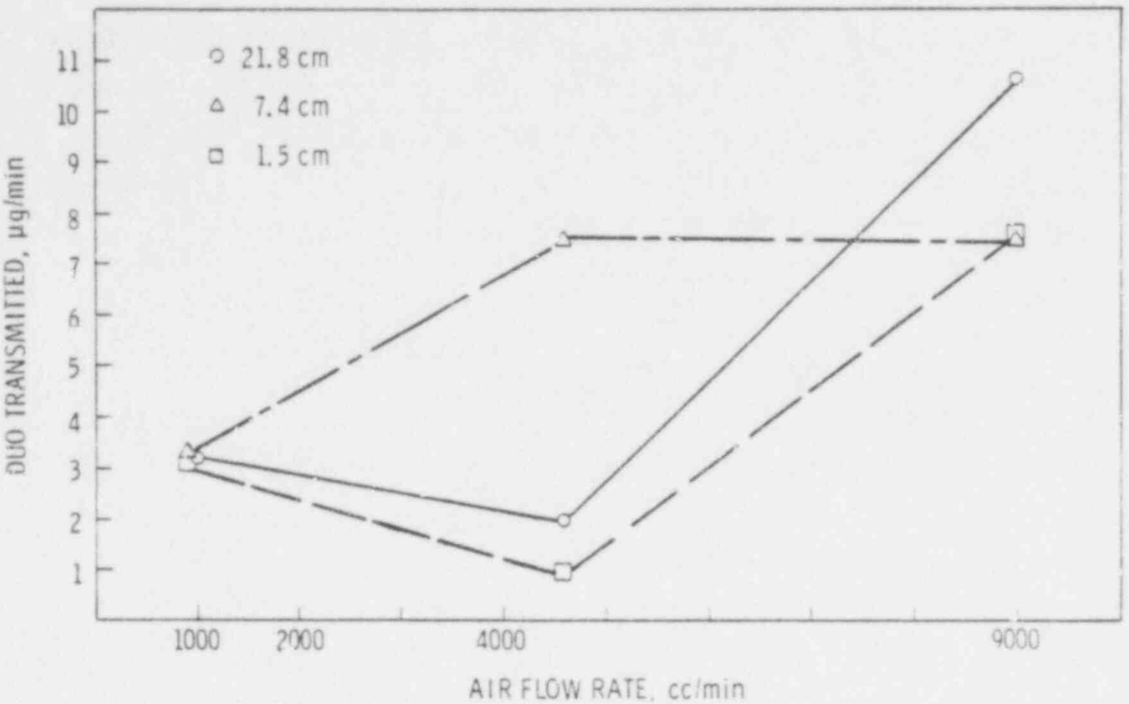

FIGURE 5. DUO Transmitted Through Leaks Below the Static Powder Level for Three Powder Depths

Increasing the pressure to 1000 psig (9000 cc/min) seemed to increase the powder flow somewhat; although, as noted, 500 psig for the 7.4-cm depth also optimized flow. Increased depth did not contribute to the powder leak rate.

-- Pressurization Time

Following an accident, time up to 80 min could be required for the vessel to reach an internal pressure of 1000 psig.[1] Two experiments evaluated the impact of slow versus immediate pressurization on a leak below a 21.8-cm deep powder bed. In the slow-pressurization experiments, the DUO compacted half as much as during immediate pressurization. The slow pressurization-compacted depth was 15.5 cm as opposed to 10.2 cm after immediate pressurization. The total DUO transmitted in each of two slow-pressurization runs was 933 and 210 μg contrasted to an average of 224 μg in two immediate pressurization runs. Whereas more powder can pass through an orifice during a longer span of pressurization time, the powder will not necessarily do so. Only one value is high (933 μg) and more data would be desirable to make a better assessment. This compaction phenomenon is probably associated with the initial packing--the interstices in one packing encouraging freer particle movement.

-- Leakage For an Extended Time

The amount of DUO powder leakage from leaks underneath the powder level does not increase with time. Replicate experiments using the same 2-110 orifice used for all runs (100 psig pressure) and completed with 7.4-cm DUO over the orifice show that the amount collected in 24 hr was less than the 30-min runs. The results are shown in Table II.

TABLE II

TOTAL DUO COLLECTED FROM LEAKS UNDERNEATH THE STATIC POWDER LEVEL FOR DIFFERENT COLLECTION TIMES

30-min μg DUO Transmitted	360-min (6 hr) μg DUO Transmitted	1440-min (24 hr) μg DUO Transmitted
123	94.5	41.5
72.4	45.5	10.2

One of the replicate 360-min runs had the same powder passage as the 30-min runs; however, the amount collected in 24 hr was less than the 30-min runs. This "slow down" effect would indicate that the particles are first jetted through the leak passage, and then aggregates of small particles block the transport of a significant number of other particles. Therefore, the precise orientation of the particles in the reservoir could contribute to the lower flow in the 24-hr runs.

-- Reservoir Orientation and Slow Pressurization

In an attempt to find effects that might maximize powder leakage, the orientation of the powder reservoir was changed. In earlier experiments the reservoir was in an upright (90°) position; this position was changed to horizontal (180°) and intermediate (45°) orientations. Twenty-five grams of DUO powder were placed in the reservoir while it was in the upright position; the reservoir was then tipped to the desired angles. In these positions, the DUO no longer covered the orifice. Half-hour runs at 1000 psig were made at slow and immediate pressurization. In a final set of experiments, the reservoir was equipped with a flexible high-pressure hose. The reservoir (25 g DUO at 1000 psig) was rotated end for end three times per min for 30 min, a 180° oscillation allowing the powder to drop from one end of the reservoir to the other.

None of these various orientation strategies yielded an increase in the DUO transmitted through the orifice. The results are displayed in a bar graph in Figure 6 that includes APLA and UPL results (110-µm orifice) from experiments using two reservoirs,[2] all at 1000 psig. The APLA results are from single orifice(s), time constant (TC), time varying (TV) and statistical matrix (M) runs. The UPL runs are for Reservoir 1 with 0.5- and 1.5-cm powder coverage, and Reservoir 2 with 1.5-cm coverage in 90°, 180°, 45°, and turning-end-for-end orientations. The runs were for 30 min after pressure was reached, and the µg/min were calculated for this time period.

The average leak rate from Reservoir 1 (1.5-cm coverage), 115 µg/min, was the largest leak rate value. The other leak rates were comparable, with APLA leak rate of 26 µg/min the closest to the highest value. No efforts to maximize powder flow were successful.

How valid are these results? Replicate 10-min experiments gave an average transmission of 1150 µg. The leak rate of powder does not increase with time (as has been noted); therefore, a better test would be 30-min duration runs. At 30-min with the same powder transmission, the leak rate would be 38 µg/min, fairly comparable to the 26 µg/min APLA rate, but still three times the average of all other UPL experiments and twice the highest of the other UPL transmission rates. Therefore, it appears that this configuration (1.5-cm powder depth in Reservoir 1) can give the highest powder leak rates.

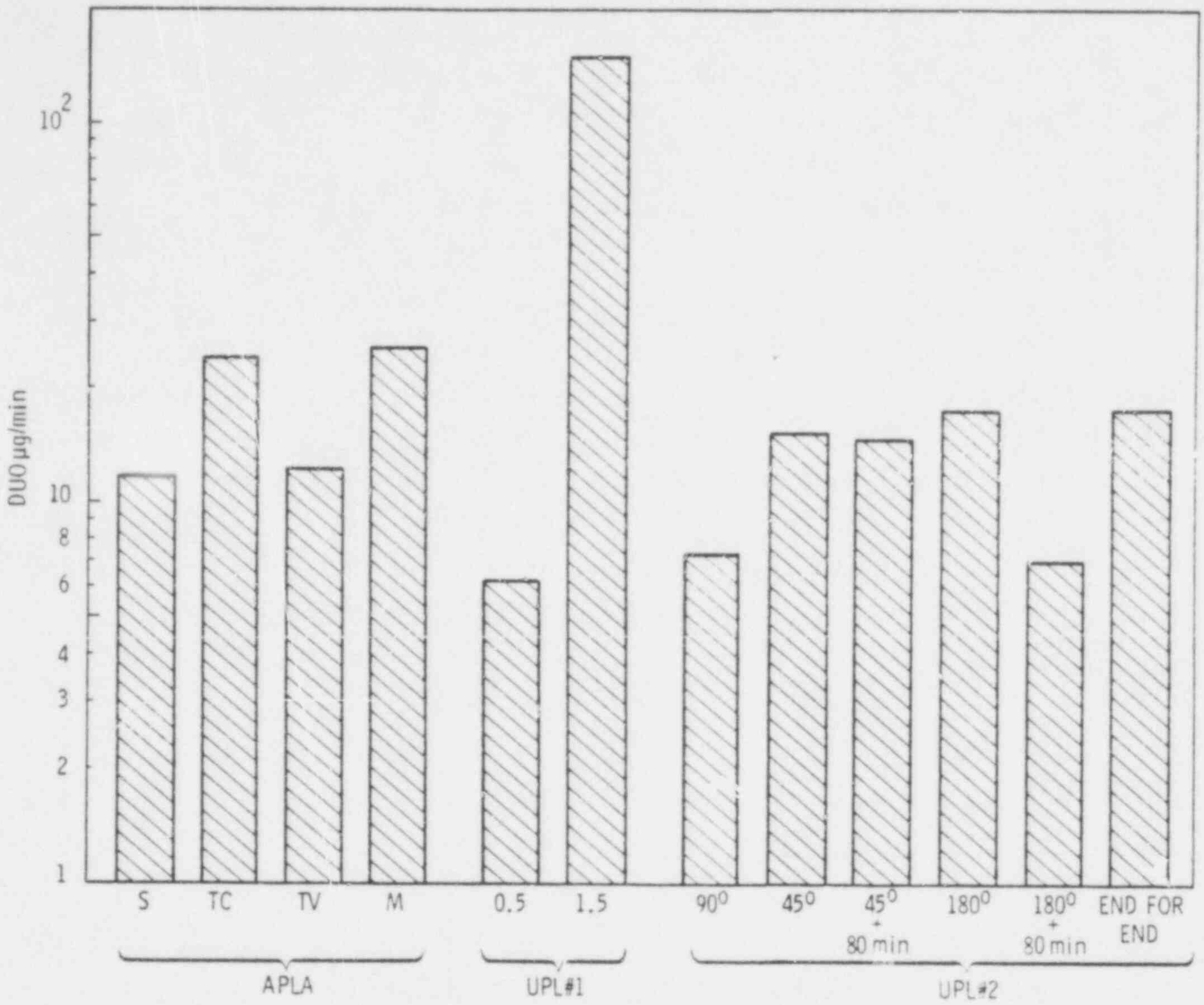

FIGURE 6. DUO Leak Rate Through 110-micron Orifices at 1000 psig at Different Parameters

Reservoir 1 appears to have the highest leak rate, as illustrated in the plot in Figure 7 which compares leaks below the powder level for the two reservoirs (tests at 1000 psig with 25 g DUO in reservoirs). The 25 g of powder filled Reservoir 1 completely and left about 20 cm of void space in Reservoir 2. At every pressure the second powder reservoir transmitted less DUO.

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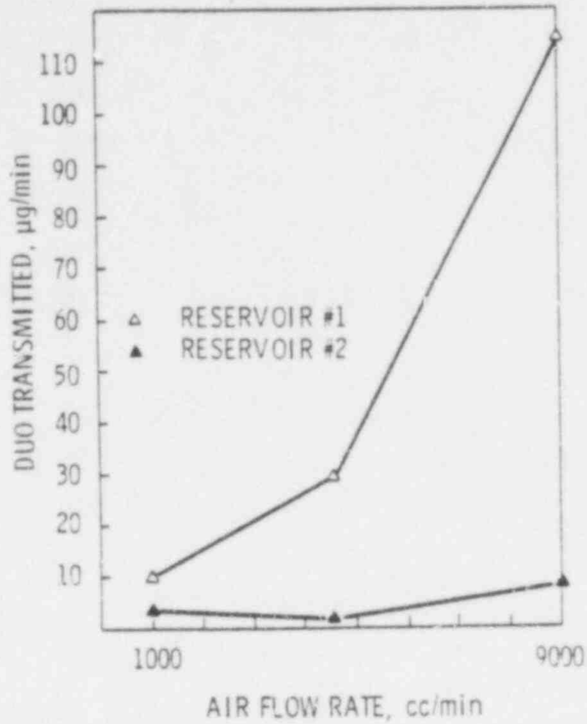

FIGURE 7. DUO Leak Rate From Leaks Below the Static Powder Level, Comparison of Two Powder Reservoirs with 25 g Powder, 1.5-cm Depth, 2-110 Orifice

A question arises from this experiment: does the DUO depth (completely full) or the shape of the reservoir (or an interaction of both) promote increased powder flow? Unfortunately, 1.5-cm DUO is the maximum capacity of Reservoir 1 and, thus, this problem could not be investigated. However, two experiments with Reservoir 2 completely filled with powder had a leak rate of 10.6 µg/min (ave), compared to 7.6 µg for the 1.5-cm depth in the same reservoir, values really about the same indicating that the interior configuration might influence the leak rate.

There was no correlation of DUO leakage with airflow rate through the reservoir during these experiments.

In order to investigate the question of reservoir shape, the interior of the reservoirs are sketched in Figure 8. Reservoir 1 has a bell-shaped expanding section, whereas Reservoir 2 has an abrupt

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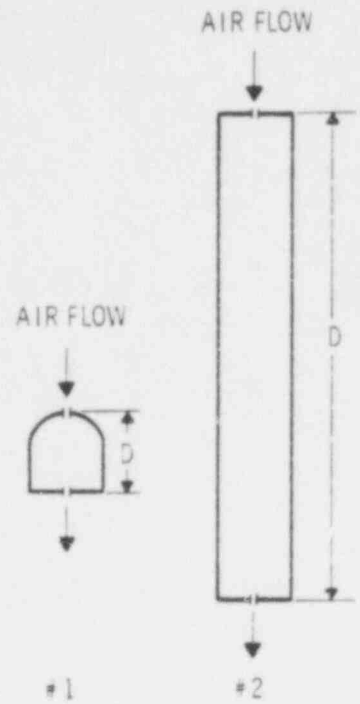

FIGURE 8. Reservoir Shapes

expansion. The second reservoir has about 15 times the fetch from air entry to the orifice, D, in Figure 8. The 1000 psig airflow entering the chamber would have a jet effect, setting up turbulent flow patterns. In the distance from the jet to the orifices, these patterns would modify, and in Reservoir 2, with longer fetch and abrupt expansion, would have different flow patterns than those in Reservoir 1. Since flow is mixed with the powder, DUO leakage would not be the same for each reservoir.

- Rheological Tests

During this study, replicate results have often been disparate and difficult to predict. It has been assumed that much of this problem might be attributed to innate properties of the DUO powder. The depleted uranium dioxide used in the experiments is a small (mass median diameter: 1 μm), easily-packed, irregular powder that would tend to flow with difficulty.

In an effort to gain information on the innate "flowability" of the DUO powder, a rheological test was performed that demonstrated that the powder would not flow. A rheological test evaluates the interparticle friction (angle of internal friction, α) which is important in gravity flow and could play a role in leaks under the static powder level. The DUO powder was tested and compared to tests on sand with a mass median diameter of 64 μm.

A bin-flow test[3] measures the angle with the horizontal assumed by the moving core of solids in a vessel provided with a central opening in the bottom through which the contents can flow in free fall.

The vessel is rectangular with a clear front wall, as illustrated in Figure 9. The angle, α, can be measured at the line of demarcation between stationary and flowing solids.

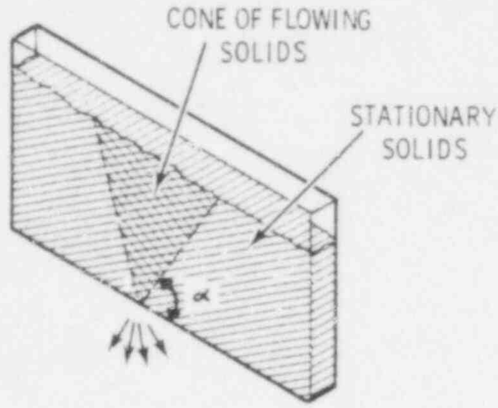

FIGURE 9. Bin-Flow Test Vessel

A clear, plastic bin 8.5 x 1 x 7 in. was fabricated. A 1/2- x 1-in. hole in the bottom was covered with a sliding plastic cover that could be opened to allow powder flow. This bin was filled with DUO powder to a depth of approximately 5 in. As the bottom cover was removed, a marginal amount (<5 g) of DUO dropped out, as shown in Figure 10.

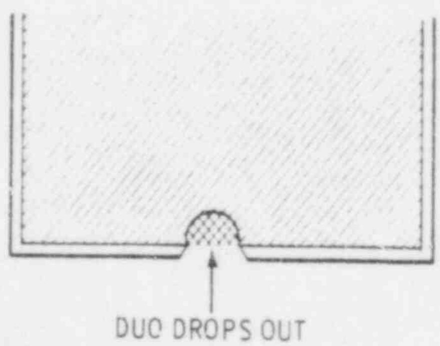

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FIGURE 10. Area Where DUO Dropped From Bin

A Q-tip was inserted to manually force the DUO out and a core was formed, as shown in Figure 11.

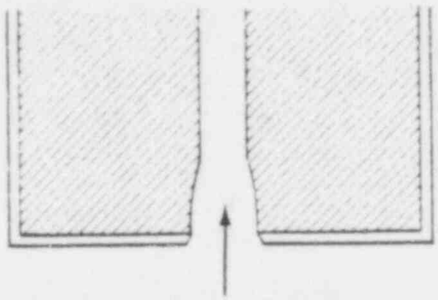

FIGURE 11. Core Formed in Powder to Allow Ejection of DUO

The bin was rapped briskly with a hammer and a flow formed, but continued only with constant agitation. Since flow was really clumps of powder breaking off, no measurements of α could be made on the DUO.

In order to compare DUO with powder that could flow, sand to a depth of 6 in. (mass median diameter: 64 μm) was tested in the same bin. As soon as the bottom hole was opened, fast flow became apparent, the line of demarcation between the core of flowing solids and the stationary solids was visible, and the angle of internal friction was measured as 80°.

This test is a visual demonstration of the difficulty with which DUO flows and could, in turn, account for much of the anomalous behavior in many of the powder leak tests to date.

TASK D -- Measure Fuel Grade PuO_2 Leaks Through a "Standard Leak" Incorporated into a Suitable Container

Milestone 1. Design of experimental equipment. Completed.
Milestone 2. Assembly of experimental system. Completed.
Milestone 3. Simulant experiments. Completed.
Milestone 4. Transfer to glovebox. Completed.
Milestone 5. Conduct "hot" experiments.

- Conduct "Hot" Experiments (Phase One)

A recurring source of difficulty in the analysis of the PuO_2 leak-rate data has been the extreme variability in the results obtained from replicate

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experiments. The variability does not appear to follow any consistent pattern and is so large that any effects of parametric interactions are masked. In an attempt to define more clearly the quantities of PuO_2 emitted and to provide insight into the nature of the variance of the data, a series of experiments was planned to provide a small data base for a given set of experimental conditions. The conditions chosen were: 1) pressure: 995 psig; 2) position: up; 3) vibration: no; and 4) orifice size: 20 μm. Fifteen experiments were conducted under these conditions with collection times of 10 min each. Particular care was taken to insure that no controllable variables were altered between runs.

Inspection of the data (Table III and Figure 12) reveals that considerable variability remains. The one obvious parameter that changes between runs but is not controlled is the helium flow rate. Inspection of the data reveals no obvious relationship between the helium flow rates and quantities of PuO_2 emitted, although some relationship may exist since the helium leak rates recorded in Table III are determined by the pressure decay method at the midpoint of the run and do not realistically define the total helium gas flow in this system where the flow rate is not necessarily constant. The helium flow rate must be known throughout the course of each run in order to determine whether any correlation exists between the flow rate and the quantity of PuO_2 emitted.

In order to compare the effects of varying run times on the total quantity of PuO_2 emitted, a series of 15 runs was planned using three different run times: 1 hr, 2 hr and "zero time." "Zero time" refers to those experiments conducted with the minimum feasible run time. For these "zero time" experiments, the leak tube is pressurized as in all other experiments with longer run times. Once the desired pressure is reached, the pressure is immediately bled off through a needle valve located on the upstream side of the leak tube. The total elapsed time using this technique is less than 1 min from the beginning of pressurization to complete depressurization. Helium leak rates have not been recorded for the "zero time" runs since this is generally done by the pressure decay method at the midpoint of the run and the short run times do not permit such an operation.

TABLE III

SUMMARY OF PuO_2 LEAK RATE EXPERIMENTS USING A 20-μm ORIFICE

Run Number	Tube Position	Helium Pressure, psig	Vibration	Helium Leak Rate[b] cc/sec	Quantity of PuO_2 Detected, μg[a] Inlet Nozzle	Final Filter	Total	Net Total[c]
B64B[d]	Sideways	--	--	--	0.00143	0.00040	0.00183	--
Pu107	Up	995	No	6.1	0.00063	0.08074	0.08136	0.07953
Pu107 A	Up	995	No	2.2	0.00062	0.01672	0.01734	0.01551
Pu107 B	Up	995	No	2.4	0.00027	0.00501	0.00527	0.00344
Pu107 C	Up	995	No	10.6	0.00069	0.00135	0.00204	0.00021
Pu107 D	Up	995	No	2.6	0.00021	0.00113	0.00134	0.00000
Pu107 E	Up	995	No	3.0	0.00200	0.02129	0.02329	0.02146
Pu107 F	Up	995	No	2.2	0.00203	0.00305	0.00507	0.00324
Pu107 G	Up	995	No	13.4	0.00044	0.04939	0.04979	0.04796
Pu107 H	Up	995	No	6.5	0.00059	0.00089	0.00148	0.00000
Pu107 I	Up	995	No	2.6	0.00048	0.00155	0.00203	0.00019
Pu107 J	Up	995	No	8.3	0.00013	0.00104	0.00117	0.00000
Pu107 K	Up	995	No	6.5	0.00019	0.00119	0.00137	0.00000
Pu107 L	Up	995	No	16.8	0.00016	0.00019	0.00035	0.00000
Pu107 M	Up	995	No	5.2	0.00037	0.00122	0.00159	0.00000
Pu107 N	Up	995	No	2.2	0.00086	0.00107	0.00193	0.00010

(a) Based on a specific activity of 0.096 Ci/g for the PuO_2 powder.
(b) Helium leak rate determined by pressure decay method at the midpoint of the run.
(c) The net total is the amount above the containment box background of 0.000183.
(d) Containment box background.

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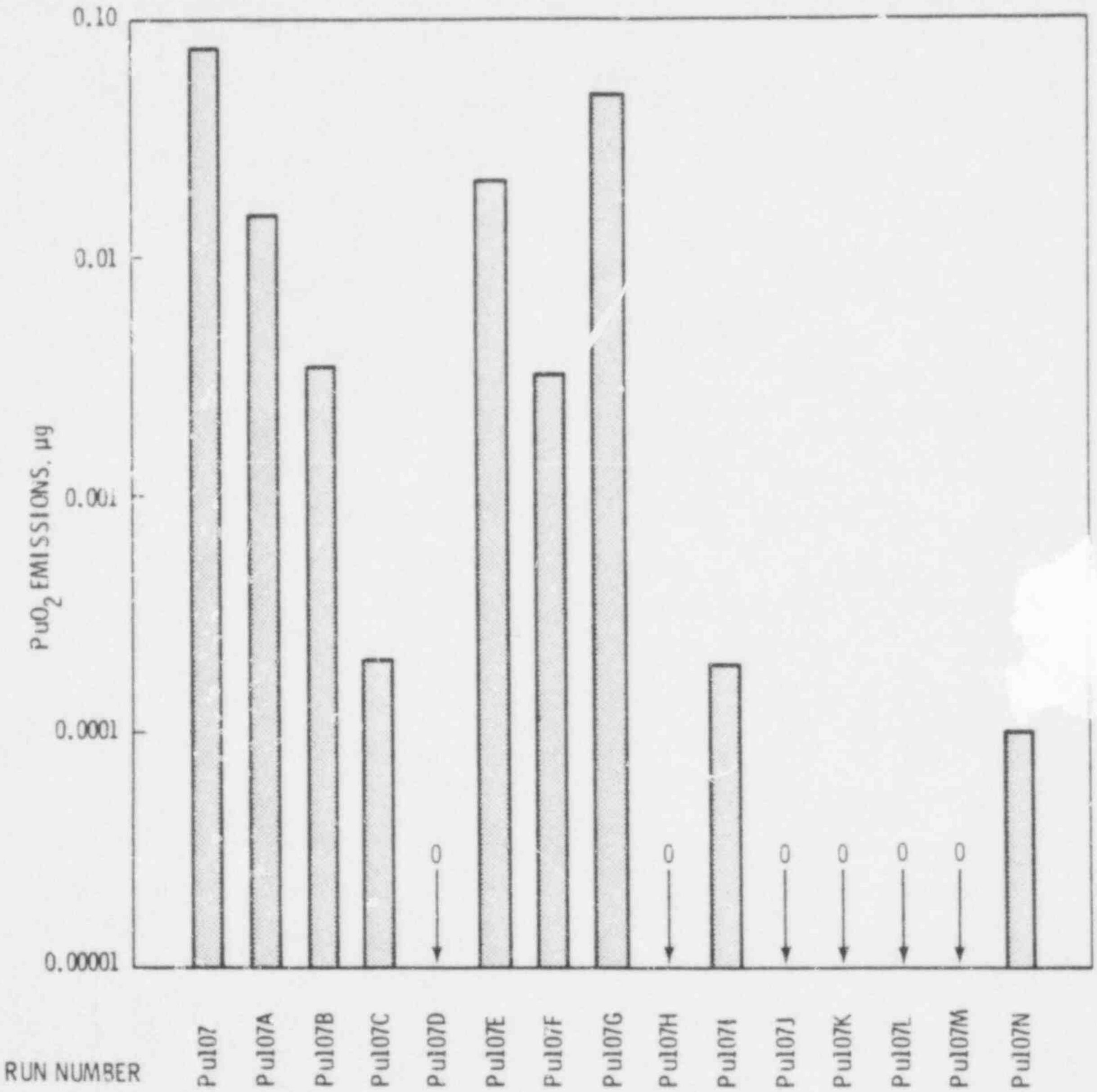

COLLECTION TIMES WERE 10 MIN FOR Pu107 THROUGH Pu107N. THE EXPERIMENTAL CONDITIONS FOR ALL RUNS WERE IDENTICAL: PRESSURE -- 995 psig; POSITION -- UP, NO VIBRATION.

FIGURE 12. PuO_2 Emissions Through a 20-μm Orifice

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The data from the varying time runs are presented in Table IV and Figure 13. A comparison of the average PuO_2 emissions and the associated variance for these three run times, and the 10-min runs of Table III, indicates that there is not readily discernible run-time dependence. However, the extreme variability of the data may be masking such dependence and a definite statement cannot be made at this time.

-- <u>In-Line Helium Flowmeter</u>

The extreme variability of the helium flow rate data indicates that there may be some factor influencing the PuO_2 emissions that is not being considered. One such factor may be plugging of the orifice during the course of a run, which would result in a decrease of the effective size of the orifice and decrease of flow. Continuous monitoring of the flow rate would provide information pertaining to the total flow of helium during the course of a run and an indication when any plugging or subsequent unplugging might occur. Although a flow rate is reported for each run, the rate is determined using the pressure decay method at the midpoint of the run, which provides no information concerning any flow change during the run and consequently is no measure of the total flow.

Therefore, to allow monitoring of the helium flow, an Omniflow® turbine flowmeter,[a] an in-line metering device that provides digital flow information, was installed in the experimental system. Flow rates obtained from the flowmeter are in terms of actual volumes of gas flowing through the system; in order to compare data obtained at various pressures, the volumes must be converted to standard flow rates. The flowmeter was calibrated in the experimental system using the pressure decay method to insure that flow rate information could be related to previous runs. Thirty data points were used in the calibration and were fitted to a straight line with a linear correlation coefficient of 0.995. The calibration curve reveals that the minimum flow that can be detected by the flowmeter is approximately 0.1 acc/sec.

(a) Flow Technology Inc., P.O. Box 21346, Phoenix, AZ 85036.

TABLE IV

SUMMARY OF PuO_2 LEAK RATE EXPERIMENTS USING A 20-μm ORIFICE

Run Number	Tube Position	Helium Pressure, psig	Vibration	Helium Leak Rate[b] cc/sec	Quantity of PuO_2 Detected, μg[a] Inlet Nozzle	Final Filter	Total	Net Total[c]
B64B[d]	Sideways	--	--	--	0.00143	0.00040	0.10275	--
×Pu108	Up	995	No	1.7	0.00123	0.10153	[illegible]	0.00501
×Pu108 A	Up	995	No	16.8	0.00072	0.00613	0.00684	0.00501
×Pu108 B	Up	995	No	5.6	0.00987	0.00301	0.01288	0.00000
×Pu108 C	Up	995	No	2.6	0.00106	0.00000	0.00106	0.00000
×Pu108 D	Up	995	No	3.9	0.00095	0.00296	0.00391	0.00208
*Pu109	Up	995	No	--	0.00371	0.00409	0.00779	0.00596
*Pu109 A	Up	995	No	--	[illegible]	0.00033	0.00127	0.00000
*Pu109 B	Up	995	No	--	0.00112	0.00199	0.00311	0.00128
*Pu109 C	Up	995	No	--	0.00049	0.00055	0.00105	0.00000
*Pu109 D	Up	995	No	--	0.00156	0.00129	0.00283	0.00100
+Pu110	Up	995	No	1.3	0.00052	0.04501	0.04553	0.04370
+Pu110 A	Up	995	No	24.3	0.00167	0.00597	0.00764	0.00581
+Pu110 B	Up	995	No	0.9	0.00200	0.00176	0.00375	0.00192
+Pu110 C	Up	995	No	1.7	0.00141	0.03563	0.03704	0.03521
+Pu110 D	Up	995	No	1.7	0.00214	0.00611	0.00825	0.00642

(a) Based on a specific activity of 0.096 Ci/g for the PuO_2 powder.
(b) Helium leak rate determined by pressure decay method at the midpoint of the run.
(c) The net total is the amount above the average containment box background of 0.00183 g.
(d) Containment box background.
× 1-hr collection time.
* "Zero time" runs.
+ 2-hr collection time.

274 099

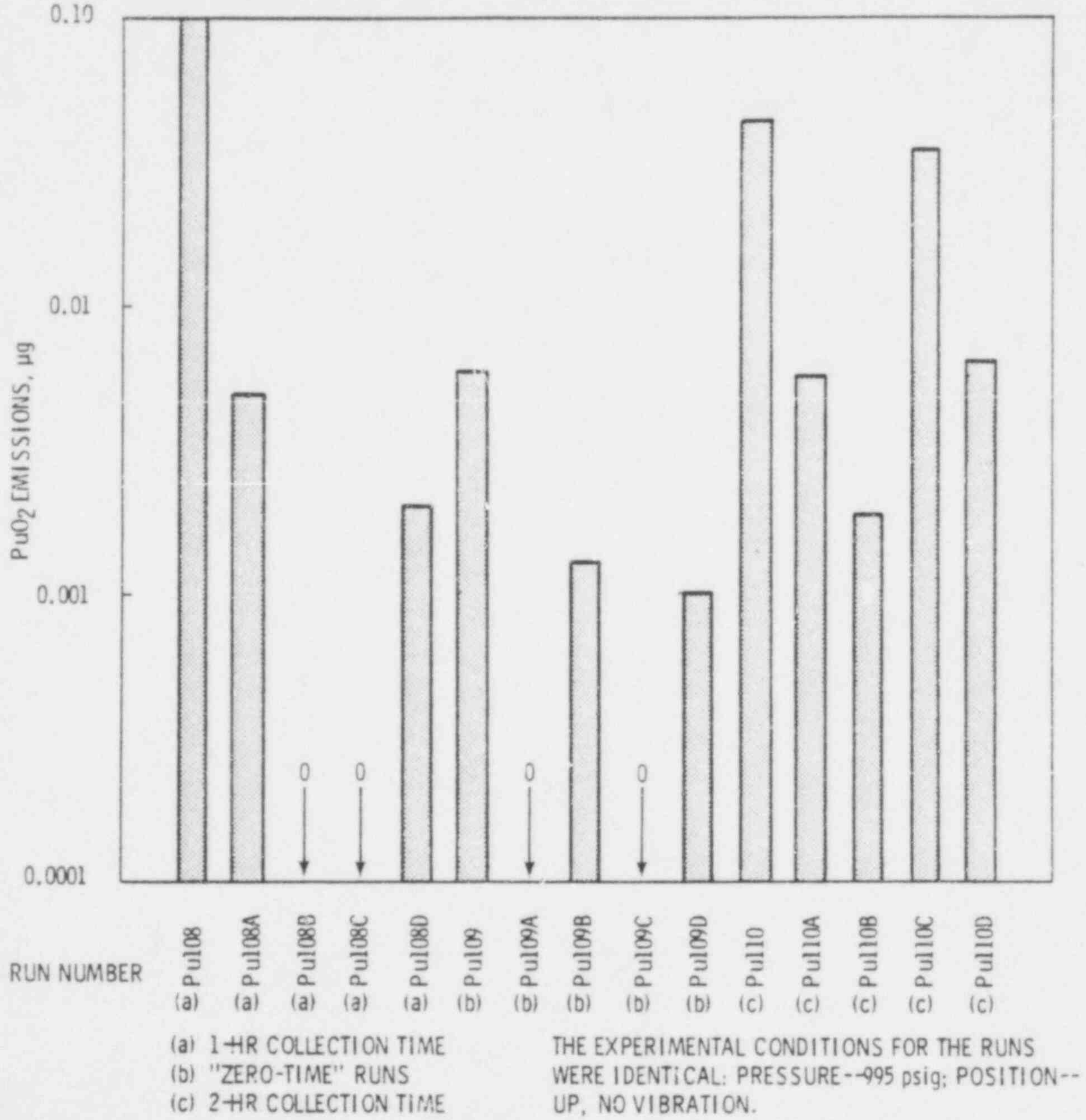

FIGURE 13. PuO_2 Emissions Through a 20-µm Orifice

274 100

-- <u>50-μm Orifice</u>

The first experiments conducted after the installation of the flowmeter were with the 50-μm-dia orifice. After the orifice was installed in the leak tube, the tube was pressurized to 995 psig and the flow rate monitored. The initial flow rate was 1.4 acc/sec (94 scc/sec). After approximately 5 min the flow dropped off to 1.0 acc/sec (69 sec/scc). The tube pressure was released and the tube repressurized, at which time the flow rate was 0.5 acc/sec. Subsequently, the flow rate dropped off to 0.3 acc/sec after 5 min and slowly decreased to <0.1 acc/sec after 40 min. It was assumed that PuO_2 particles had plugged the orifice and attempts were made to reopen it, such as rapidly changing the system pressure, vibrating the leak tube for prolonged periods and tapping on the leak tube with a metal rod. These attempts were unsuccessful, and the helium flow remained <0.1 acc/sec, which was below the threshold of the flowmeter.

A series of 16 (8 replicates) experiments were planned using a 50-μm orifice to provide data in establishing a correlation between Battelle, Columbus Laboratories experiments using PuO_2 and Pacific Northwest Laboratory experiments using UO_2. In actuality, 20 experiments were completed (some with more than two replicates), during each of which the helium flow was continuously monitored. At no time did the flow rate increase above the threshold level of the flowmeter. The conditions for these experiments and their results are presented in Table V and Figure 14. The helium leak rates shown in Table V were determined using the pressure decay method and are given in standard cc/sec. All but two of the runs (Pu112 and Pu114) exhibited very low emissions of PuO_2; 12 of the 20 runs showed no net PuO_2 emission. A thorough analysis of these data will be conducted in the near future.

<u>TASK E</u> -- <u>Investigate PuO_2 Leaks Through Simulated Defected Containers</u>

Milestone 1. <u>Fabricate leaky container.</u> Completed.

Milestone 2. <u>Simulant tests.</u> Completed.

Milestone 3. <u>PuO_2 test series.</u> Completed.

274 101

A statistical analysis of the results of this completed test series is being performed. More experiments will be identified when this analysis is accomplished.

TABLE V

SUMMARY OF PuO_2 LEAK RATE EXPERIMENTS USING A 50-μm ORIFICE

Run Number	Tube Position	Helium Pressure, psig	Vibration	Helium Leak Rate[b] cc/sec	Quantity of PuO_2 Detected, μg[a] Inlet Nozzle	Final Filter	Total	Net Total[c]
B65[d]	Sideways	--	--	--	0.00031	0.00257	0.00288	--
B66[d]	Sideways	--	--	--	0.00030	0.00031	0.00061	--
Pull1	Up	995	Yes	8.7	0.00000	0.00059	0.00059	0.00000
Pull1 A	Up	995	Yes	37.2	0.00036	0.00030	0.00065	0.00000
Pull1 B	Up	995	Yes	2.6	0.00038	0.00029	0.00067	0.00000
Pull1 C	Up	995	Yes	3.5	0.00024	0.00192	0.00216	0.00042
Pull2	Down	995	Yes	2.6	0.01217	0.00571	0.01788	0.01614
Pull2 A	Down	995	Yes	3.5	0.00000	0.00085	0.00085	0.00000
Pull2 B	Down	995	Yes	2.6	0.00000	0.00049	0.00049	0.00000
Pull3	Up	495	Yes	1.3	0.00023	0.00114	0.00137	0.00000
Pull3 A	Up	495	Yes	1.3	0.00000	0.00000	0.00000	0.00000
Pull4	Down	495	Yes	1.3	0.00108	0.02823	0.02931	0.02757
Pull4 A	Down	495	Yes	1.3	0.00013	0.00035	0.00048	0.00000
Pull4 B	Down	495	Yes	1.3	0.00055	0.00056	0.00111	0.00000
Pull5	Up	1250	Yes	4.8	0.00096	0.00246	0.00342	0.00175
Pull5 A	Up	1250	Yes	4.8	0.00065	0.00003	0.00068	0.00000
Pull6	Down	1250	Yes	5.4	0.00022	0.00036	0.00058	0.00000
Pull6 A	Down	1250	Yes	5.2	0.00050	0.00297	0.00347	0.00173
Pull7	Up	Ambient	Yes	--	0.00031	0.00046	0.00077	0.00000
Pull7 A	Up	Ambient	Yes	--	0.00025	0.00167	0.00192	0.00018
Pull8	Down	Ambient	Yes	--	0.00081	0.00509	0.00590	0.00416
Pull8 A	Down	Ambient	Yes	--	0.00009	0.00214	0.00224	0.00050

(a) Based on a specific activity of 0.096 Ci/g for the PuO_2 powder.
(b) Helium leak rate determined by the pressure decay method at the midpoint of the run.
(c) The net total is the amount above the average containment box background of 0.00175 μg.
(d) Containment box background.

274 102

274 103

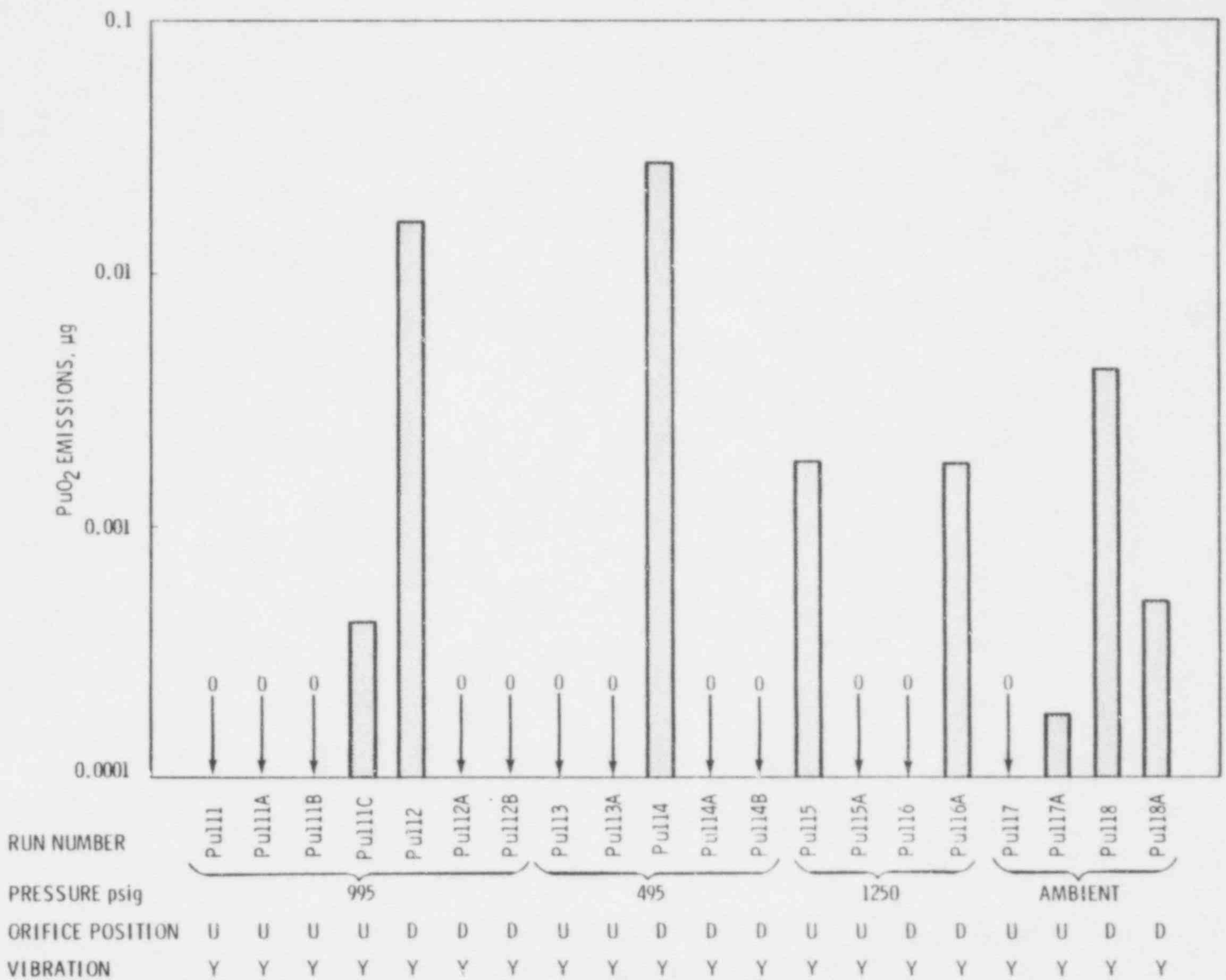

FIGURE 14. Effects of Experimental Conditions on PuO_2 Emissions Through a 50-µm Orifice

REFERENCES

(1) Plutonium Air Transportable Package Model PAT-1, NUREG-0361, U.S. Nuclear Regulatory Commission, June 1978.

(2) L. C. Schwendiman, et al., Quarterly Progress Report Covering Period October 1 Through December 29, 1978 -- The Study of Plutonium Oxide Leak Rates From Shipping Containers. PNL-2260-9, February 1979, Pacific Northwest Laboratory, Richland, WA 99352.

(3) F. A. Zenz and D. F. Othmer, Fluidization and Fluid Particle Systems. Reinhold Publishing Corporation, New York, NY. 1960.

APPENDIX A

TABLES

TABLE A.1

DEPLETED URANIUM DIOXIDE TRANSMISSION RATES FOR LEAK PATHS ABOVE THE POWDER LEVEL

APLA	ORIFICE OR CAPILLARY DESIGNATION	MEASURED DIAMETER µm	CHAMBER PRESSURE psig	TIME, min	AIRFLOW cc/min	TRANSMITTED[1] DUO, µg	DUO, µg/min	DUO, µg/cc
82								
82-2	2-200	200	30	60	960[2]	1.29±0.39	0.02	2.2×10^{-5}
83	250B	274	100	30	3463	0.67±0.27	0.02	6×10^{-6}
84	1-50A	48	100	30	1150	0.877±0.27	0.03	2.6×10^{-5}
86	150B	176	100	30	1150	0.462±0.27	0.02	1.3×10^{-5}
87	200S	228	100	30	2430[3]	1.04±0.31	0.03	1.4×10^{-5}
89	1-50A	48	100	30	45	0.655±0.27	0.02	4.9×10^{-4}
90								
90-1	250B	231	500	30	16,080[3]	2.00±0.60	0.07	4×10^{-6}
91								
91-1	1-110	100	100	10	640	7.21±2.2	0.72	1.1×10^{-3}
91-2	2-110	125	100	30	900	20.7±6.2	0.69	7.7×10^{-4}
91-3	3-110	100	100	60	638	15.0±4.5	0.25	3.3×10^{-4}
92								
92-1	1-110	100	100	30	640	8.71±2.6	0.29	4.5×10^{-4}
92-2	2-110	125	100	30	900	0.656±0.27	0.02	2.2×10^{-5}
92-3	3-110	100	100	30	638	20.6±6.2	0.69	1.1×10^{-3}
93								
93-1	1-63.5	66	100	10	255	0.788±0.27	0.08	3×10^{-4}
93-2	2-63.5	61	100	30	225	0.696±0.27	0.02	1×10^{-4}
93-3	3-63.5	65	100	60	265	1.75±0.53	0.03	1×10^{-4}

(1) THE ± IS THE UNCERTAINTY IN THE URANIUM ANALYSIS AT THE 2σ CONFIDENCE LEVEL

(2) PLUGGED

(3) PLUGGED BUT FLOW MAINTAINED

274 106

TABLE A.1 (contd)

APLA	ORIFICE OR CAPILLARY DESIGNATION	MEASURED DIAMETER µm	CHAMBER PRESSURE psig	TIME, min	AIRFLOW cc/min	TRANSMITTED DUO, µg	DUO, µg/min	DUO, µg/cc
94								
94-1	1-63.5	66	100	30	255	1.03±0.31	0.03	1.3×10^{-4}
94-2	2-63.5	61	100	30	225	0.361±0.27	0.12	5.3×10^{-4}
94-3	3-63.5	65	100	30	265	2.50±0.75	0.08	3.0×10^{-4}
95								
95-1	250B	274	30	60	1200	8.55±2.6	0.14	1.2×10^{-4}
95-2	250S	274	30	60	1650	0.652±0.27	0.01	6.6×10^{-6}
96								
96-1	150B	176	30	60	520	0.883±0.27	0.015	2.8×10^{-5}
96-2	150S	182	30	60	640	9.65±2.9	0.16	2.5×10^{-4}
96-3	3-200	200	30	60	1000	16.7±5.0	0.28	2.8×10^{-4}
97								
97-1	250B	274	1000	10	31,880 (2)	3.02±0.9	0.3	9.5×10^{-6}
101								
101-1	1-20	22	100	30	25	8.23±2.5	0.27	1×10^{-2}
101-2	1-20a	23	100	30	29	3.02±0.9	0.10	3.5×10^{-3}
101-3	2-20	20	100	30	22	1.45±0.43	0.05	2.2×10^{-3}
101-4	3-20	23	100	30	32	2.39±0.72	0.08	2.5×10^{-3}
103								
103-1	1-20	22	100	10	25	3.13±0.94	0.31	1.3×10^{-2}
103-2	1-20a	23	100	30	29	3.33±0.99	0.11	3.8×10^{-3}
103-3	2-20	20	100	60	22	1.26±0.38	0.02	9.5×10^{-4}
103-4	3-20	23	100	120	32	1.52±0.45	0.01	4×10^{-4}

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TABLE A.1 (contd)

APLA	ORIFICE OR CAPILLARY DESIGNATION	MEASURED DIAMETER μm	CHAMBER PRESSURE psig	TIME, min	AIRFLOW cc/min	TRANSMITTED DUO, μg	DUO, μg/min	DUO, μg/cc
106								
106-1	3-30	33	100	30	74	3.26±0.98	0.11	$1.5x10^{-3}$
106-2	1-36	43	100	30	77	3.04±0.91	0.10	$1.3x10^{-3}$
106-3	2-36	33	100	30	64	4.62±1.4	0.15	$2.4x10^{-3}$
106-4	3-36	38	100	30	106	4.51±1.4	0.15	$1.4x10^{-3}$
107	3-20	23	1000	10	220*	3.18±0.95	0.32	$1.4x10^{-3}$
108	3-36	38	1000	10	996*	3.76±1.1	0.38	$3.8x10^{-4}$
109	3-20	23	1000	10	30*	4.02±1.2	0.40	$1.3x10^{-2}$
110	3-36	38	1000	10	57*	6.85±2.0	0.68	$1.2x10^{-2}$
111	3-63.5	65	1000	10	660*	52.7±16	5.27	$8.0x10^{-3}$
114	3-20	23	500	30	35*	2.88±0.87	0.10	$2.7x10^{-3}$
115	3-36	38	500	30	270*	4.09±1.2	0.14	$5x10^{-4}$
116	3-63.5	65	500	30	320*	8.3±2.5	0.28	$8.6x10^{-4}$
117	3-110	100	500	30	2250*	24.2±7.3	0.80	$3.6x10^{-4}$
119	3-20	23	100	30	42.5*	1.13±0.34	0.04	$8.9x10^{-4}$
120	3-36	38	100	30	28*	2.77±0.83	0.09	$3.3x10^{-3}$
121	3-63.5	65	100	30	195*	8.03±2.4	0.27	$1.4x10^{-3}$
122	3-110	100	100	30	415*	14.0±4.1	0.47	$1.1x10^{-3}$
123	3-200	200	100	30	2260*	109.0±33	3.60	$1.6x10^{-3}$
124	1-36	43	1000	PRESSURE DECAY		1.45±0.43		
126	3-36	38	30	30	28*	3.52±1.1	0.12	$4.2x10^{-3}$
127	3-63.5	65	30	30	98*	2.22±0.67	0.07	$7.6x10^{-4}$

*MEASURED ONLY

274 108

TABLE A.1 (contd)

APLA	ORIFICE OR CAPILLARY DESIGNATION	MEASURED DIAMETER μm	CHAMBER PRESSURE psig	TIME, min	AIRFLOW cc/min	TRANSMITTED DUO, μg	DUO, μg/min	DUO, μg/cc
128	3-110	100	30	30	120*	29.8±8.9	0.99	$8.3x10^{-3}$
130	3-20	23	1000	10	15.2*	2.78±0.83	0.28	$1.8x10^{-2}$
131	3-36	38	1000	10	385*	6.29±0.19	0.63	$1.6x10^{-3}$
132	3-63.5	61	1000	10	690*	34.6±10	3.46	$5.0x10^{-3}$
135	3-30	33	1000	PRESSURE DECAY		1.83±0.55		
136	3-20	23	500	STOPPED	PLUGGED	1.44±0.43		
137	3-36	38	500	30	230*	6.56±2	0.22	$9.5x10^{-4}$
138	3-63.5	65	500	30	1020*	14.3±4.3	0.48	$4.7x10^{-4}$
139	3-110	100	500	30	680*	62.9±19	2.1	$3.1x10^{-3}$
141	3-20	20	100	STOPPED	PLUGGED	1.45±0.44		
142	3-36	33	100	30	19*	1.92±0.58	0.06	$3.4x10^{-3}$
143	3-63.5	65	100	30	165*	3.27±0.98	0.11	$6.6x10^{-4}$
144	3-110	100	100	30	370*	20.3±6.1	0.68	$1.8x10^{-3}$
145	3-200	200	100	30	2300*	89.2±27	3.0	$1.3x10^{-3}$
148	3-36	38	30	30	35*	0.861±0.27	0.03	$8.2x10^{-4}$
149	3-110	100	30	30	177*	2.91±0.87	0.10	$5.5x10^{-4}$
150	3-63.5	65	30	30	98*	4.85±1.5	0.16	$1.6x10^{-3}$
151	3-200	200	30	30	870*	9.18±2.8	0.31	$3.5x10^{-4}$
152	1-36	43	1000	PRESSURE DECAY		7.88±2.4		

*MEASURED ONLY

274 109

TABLE A.1 (contd)

APLA	ORIFICE OR CAPILLARY DESIGNATION	MEASURED DIAMETER µm	CHAMBER PRESSURE psig	TIME, min	AIRFLOW cc/min	TRANSMITTED DUO, µg	DUO, µg/min	DUO, µg/cc
165	1-110	100	30	0		11.1±3.3		
167	1-20a	23	PRESSURE DECAY			3.37±1.0		
168	1-20	22	1000	0		1.45±0.44		
169	1-36	43	1000	0		2.09±0.63		
170	1-63.5	66	1000	0		10.9±3.3		
174	3-110	100	500	0		40.6±12		
175	1-63.5	66	500	0		9.53±2.9		
176	1-36	43	500	0		5.81±1.7		
177	1-20	22	100	0		1.81±0.54		
178	1-20a	23	30	0		1.85±0.56		
179	1-110	100	100	0		26.5±8.0		
180	3-200	200	100	0		24.9±7.5		
181	3-63.5	65	100	0		6.92±2.1		
182	1-36	43	100	0		3.58±1.1		
183	1-63.5	66	30	0		5.27±1.6		
184	3-36	38	30	0		7.17±2.2		
185	1-200	226	1000	0		$4.75x10^3$±$1.1x10^3$		
186	1-110	111	1000	0		574±140		
187	1-20	26	1000	0		4.51±1.4		
188	3-20	20	1000	0		2.14±0.64		
189	1-110	111	500	30	10,200	602±140[4]		
190	2-36	20	1000	30	1300	6.85±2.1	0.23	$1.6x10^{-4}$

(4) LEAK AROUND SEAL

274 110

TABLE A.1 (contd)

APLA	ORIFICE OR CAPILLARY DESIGNATION	MEASURED DIAMETER µm	CHAMBER PRESSURE psig	TIME, min	AIRFLOW cc/min	TRANSMITTED DUO, µg	DUO, µg/min	DUO, µg/cc
191	1-200	226	500	30	13,100	1430±330	47.7	3.6×10^{-3}
192	3-110	89	1000	30	12,400	40.2±12	1.34	1.1×10^{-4}
193	1-110	111	500	30	2150	124±32	4.1	1.9x10[illegible]
194	2-36	32	1000	30	660	8.43±2.5	0.28	4.3×10^{-4}
195	1-200	226	500	30	11,400	1260±290	42	3.7×10^{-3}
196	3-110	89	1000	30	2200	73.3±21	2.4	1.1×10^{-3}
197	1-200	226	30	30	1000	205±51	6.8	6.8×10^{-3}
199	3-30	22	500	30	370	3.9±1.2	0.13	3.5×10^{-4}
200	3-110	89	500	30	3360	46.7±14	1.56	4.6×10^{-4}
201	1-110	111	1000	30	7100	607±140	20.2	2.8×10^{-3}
202	3-30	22	1000	30	690	6.61±2.0	0.22	3.2×10^{-4}
203	3-30	22	30	30	28	9.21±2.8	0.31	1.1×10^{-2}
204	3-200	190	1000	30	22,000	2170±500	72.3	3.3×10^{-3}
205	3-200	190	500	30	11,000	696±160	23.2	2.1×10^{-3}
206	2-36	32	30	30	24	4.88±1.5	0.16	6.8×10^{-3}
207	1-200	226	1000	30	2800	2830±650	94.3	3.4×10^{-2}
208	3-200	190	30	30	940	99±27	3.3	3.5×10^{-3}
210	2-36	32	500	30	275	4.49±1.3	0.15	5.4×10^{-4}
211	3-110	89	30	30	235	16.5±5.0	0.55	2.3×10^{-3}
212	1-200	226	1000	30	25,200	3060±710	102	4.0×10^{-3}
213	1-110	111	500	30	3060	103±28	3.4	3.3×10^{-2}
214	3-200	190	30	30	1000	30.7±9.2	1.02	1.0×10^{-3}

274 111

TABLE A.1 (contd)

APLA	ORIFICE OR CAPILLARY DESIGNATION	MEASURED DIAMETER µm	CHAMBER PRESSURE psig	TIME, min	AIRFLOW cc/min	TRANSMITTED DUO, µg	DUO, µg/min	DUO, µg/cc
215	2-36	32	500	30	285	3.49±1.0	0.12	4.1×10^{-4}
216	3-110	[illegible]	500	30	3100	20.4±6.1	0.68	2.2×10^{-4}
218	1-110	111	30	30	245	105±32	3.50	1.4×10^{-2}
219	1-200	226	500	30	12,200	1710±40	57	4.6×10^{-3}
220	2-36	32	1000	30	580	33.2±10	1.11	1.9×10^{-3}
221	3-30	22	30	30	28	2.04±0.6	0.07	2.4×10^{-3}
222	3-200	190	500	30	11,000	822±1.90	27.4	2.5×10^{-3}
223	1-110	111	1000	30	7100	957±230	31.9	4.5×10^{-3}
224	3-30	22	1000	30	695	12.0±3.6	0.4	5.8×10^{-4}
225	1-200	226	30	30	1000	722±170	24.1	2.4×10^{-2}
227	3-200	190	1000	30	2200	1190±280	39.7	1.8×10^{-2}
228	2-36	32	30	30	24	1.93±0.58	0.06	2.7×10^{-3}
229	3-110	89	1000	30	5500	194±49	6.5	1.2×10^{-3}
230	3-30	22	500	30	350	6.82±2	0.23	6.5×10^{-4}
231	3-110	89	30	30	245	20.2±6.1	0.67	2.7×10^{-3}
232	3-200	190	30	0		189±47		
233	3-110	89	1000	0		245±60		
234	3-30	22	30	0		6.81±2.0		
235	2-36	60	500	0		8.18±2.5		
236	1-200	226	1000	0		3690±850		
237	3-200	190	500	0		276±68		

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TABLE A.1 (contd)

APEA	ORIFICE OR CAPILLARY DESIGNATION	MEASURED DIAMETER μm	CHAMBER PRESSURE psig	TIME, min	AIRFLOW cc/min	TRANSMITTED UO_2, μg	UO_2, μg/min	UO_2, μg/cc
238	1-110	111	500	0		96.0±29.0		
239	3-110	89	30	0		19.2±3.1		
240	3-30	22	1000	0		8.91±2.7		
241	3-110	89	1000	0		175±44		
242	3-30	22	30	0		7.42±2.2		
243	3-200	190	500	0		131±34		
244	3-30	22	1000	0		5.79±1.7		
245	2-36	32	500	0		9.69±2.9		
246	3-200	190	30	0		110±30		
247	3-110	89	30	0		6.87±2.1		
248	1-200	226	1000	0		3720±860		
249	1-110	111	500	0		213±53		
250	1-110	111	30	30	245	26.4±7.9	1.0	$4.1x10^{-4}$
251	1-110	111	100	360	640	10.5±3.2	0.03	$4.6x10^{-3}$
252	1-110	111	100	360	640	23.2±7.0	0.06	$1.0x10^{-4}$
253	1-110	111	100	30	870	42.9±13.0	1.43	$1.6x10^{-3}$
254	1-110	111	100	0		49.0±15.0		
255	1-110	111	100	1440	700	305±77	0.21	$3.0x10^{-4}$
256	6-110	111	100	1440	700	103±29	0.07	$1.0x10^{-4}$
261	1-110	111	100	30	795	96.7±27	3.22	$4.1x10^{-3}$
262	6-110	111	100	30	695	30.9±9.3	1.03	$1.5x10^{-3}$
263	1-110	111	100	360	625	107±29	0.03	$4.8x10^{-4}$
264	1-200	226	1000	80*		1890±460		
265	1-110	111	1000	80*		770±190		
266	1-200	226	1000	80*		992±240		
267	1-200	226	1000	80*		861±210		
268	1-110	111	1000	80*		166±44		

*TO PRESSURIZE TO 1000 psig

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TABLE A.2

DEPLETED URANIUM DIOXIDE TRANSMISSION RATES FOR LEAK PATHS UNDER THE POWDER LEVEL

UPL	ORIFICE CAPILLARY	MEASURED DIAMETER μm	CHAMBER PRESSURE psig	AGITATION (1)	TIME, min	AIRFLOW cc/min	TRANSMITTED (2) DUO, μg	DUO, μg/min	DUO, μg/cc
85	2-110	125	100	YES	30	645	360±87	12	1.9×10^{-2}
87	2-20	20	100	YES	30	19.5	83.7±25	2.79	1×10^{-1}
88	3-63.5	61	100	NO	30	145	31.0±9.3	1.03	7×10^{-3}
94	3-63.5	61	100	YES	30	ND	31.5±9.4	1.05	
95	2-110	125	50	NO	60	115	84.0±2.5	1.4	1.2×10^{-2}
99	2-20	20	50	NO	60	3.7	26.5±8.0	0.44	1.2×10^{-1}
102	2-110	125	15		60	23.5	17.2±5.2	0.29	1.2×10^{-2}
103	2-36	33	50		60	13	43±13	0.72	5.5×10^{-2}
109	2-110	125	500		30	2750	894±210	29.4	1.1×10^{-2}
110	2-36	33	1000		10	106	18.5±5.6	1.85	1.7×10^{-2}
111	1-200	200	1000		10	13,600	4520±1000	452	3.3×10^{-2}
112	3-63.5	61	1000		10	425	80.6±22	8.1	1.9×10^{-2}
113	1-20	22	1000		10	ND	4.95±1.5	0.50	1.2×10^{-3}
114	1-200	200	500		30	4000	4870±1130	162	4.1×10^{-2}
115	3-63.5	61	500		30	435	10.4±3.1	0.35	8.0×10^{-4}
116	2-36	33	500		30	NO READING	17.1±5.1	0.57	
117	1-20	22	500		30	NO READING	7.48±2.2	0.25	
118	3-63.5	65	50		60	3.4	5.22±1.6	0.09	2.6×10^{-2}
119	1-20	22	50		60	ND	2.83+0.85	0.05	
120	2-36	33	15		60	0.23	6.74±2.0	0.11	0.49
121	3-63.5	65	15		60	3.5	39.7±12.0	0.66	0.19
122	1-20	22	15		60	ND	5.20±1.6	0.09	

(1) AGITATION DISCONTINUED AFTER RUN 100

(2) THE ± IS THE UNCERTAINTY IN THE URANIUM ANALYSIS AT THE 2σ CONFIDENCE LEVEL

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TABLE A.2 (contd)

UPL	ORIFICE OR CAPILLARY	WT DUO g	CHAMBER PRESSURE psig	TIME, min	AIRFLOW cc/min	TRANSMITTED DUO, µg	DUO, µg	DUO, µg
123	2-110	100	1000	30	2000	75.1±21	2.5	1.3×10^{-3}
124	2-110	247	500	30	730	69.7±20	2.3	3.2×10^{-3}
125	2-110	25	100	30	210	157±40	7.0	3.3×10^{-2}
126	2-110	100	100	30	305	123±32	4.1	1.3×10^{-2}
127	2-110	300	100	30	147	55.1±14	1.8	1.2×10^{-2}
128	2-110	300	1000	30	2090	304±74	10.1	4.8×10^{-3}
129	2-110	25	1000	30	5600	196±49	6.5	1.2×10^{-3}
130	2-110	100	500	30	2600	289±70	9.6	3.7×10^{-3}
131	2-110	25	500	30	1080	37.2±1.1	1.24	1.2×10^{-3}
132	2-110	25	1000	30	4800	258±63	8.6	3.3×10^{-3}
133	2-110	100	500	30	2350	158±40	5.3	2.2×10^{-3}
134	2-110	100	100	30	135	72.4±20	2.4	7.8×10^{-2}
135	2-110	281.9	100	30	345	138±36	4.6	1.3×10^{-2}
136	2-110	282.8	1000	30	5050	331±80	11.0	2.2×10^{-3}
137	2-110	27.2	500	30	465	17.2±5.2	0.57	1.2×10^{-3}
138	2-110	275.7	500	30	535	48.7±14.0	1.62	3.0×10^{-3}
139	2-110	57.5	1000	30	3200	198±49	6.6	2.1×10^{-3}
140	2-110	25	100	30	152	28.7±8.6	0.96	6.3×10^{-3}
141	2-110	100	1000	30	4650	373±90	12.4	2.7×10^{-3}
142	2-110	281	1000	80 +30	5150	993±230	31.1	6.0×10^{-3}
143	2-110	284	1000	80 +30	5050	210±54	7.0	1.4×10^{-3}
144	2-110	100	100	1440	225	41.5±12.0	0.03	1.3×10^{-4}
145	2-110	100	100	1440	66	10.2±3.1	0.007	1.1×10^{-4}
146	2-110	100	100	360	320	94.5±26	0.26	8.2×10^{-4}
147	2-110	100	100	360	320	45.5±14	0.12	3.8×10^{-4}

TABLE A.2 (contd)

UPL	ORIFICE	SAMPLER ORIENTATION	WT DUO g	CHAMBER PRESSURE psig	TIME, min	AIRFLOW cc/min	TRANSMITTED DUO, µg	DUO, µg/min	DUO, µg/cc
154	2-110	180^0	25	1000	30	5400	398±99	13.3	$2.5x10^{-3}$
156	4-110	180^0	25	1000	30	3850	628±160	20.9	$5.4x10^{-3}$
157	4-110	45^0	25	1000	80+30	5400	476±120	15.9*	
158	2-110	45^0	25	1000	30	3200	764±190	25.5	$8.0x10^{-3}$
159	4-110	45^0	25	1000	30	7700	119±32	4.0	$5.7x10^{-4}$
160	2-110	45^0	25	1000	80+30	7900	396±99	13.2*	
161	4-110	180^0	25	1000	80±30	1400	215±55	7.2*	
162	2-110	TURNED END	25	1000	30	2325	552±140	18.4	$7.9x10^{-3}$
163	4110	FOR END	25	1000	30	8850	492±120	16.4	$1.9x10^{-3}$

*µg/min CALCULATED ON 30 MIN TIME ONLY

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