This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the laboratory.

LAWRENCE LIVERMORE LABORATORY

University of California/Livermore, California

**PERMEABILITY OF A NUCLEAR CHIMNEY AND SURFACE ALLUVIUM
AT THE AEC NEVADA TEST SITE**

D. F. Snoeberger

J. Baker

C. J. Morris

R. B. Rozsa

April 17, 1974

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

MASTER

Prepared for U. S. Atomic Energy Commission under contract no. W-7405-Eng-48

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CONTENTS

Abstract	1
Introduction	1
Experiment	1
Site	1
Equipment, Software, and Performance	2
Data	4
Calculations and Mathematical Model	4
Results	8
Acknowledgments	8
References	17

PERMEABILITY OF A NUCLEAR CHIMNEY AND SURFACE ALLUVIUM
AT THE AEC NEVADA TEST SITE

ABSTRACT

We have conducted permeability tests at a fourth nuclear-chimney site in alluvium and tuffs at the Nevada Test Site (NTS), and in nearby surface alluvium at NTS. The calculated value of pressure diffusivity for both experiments is $0.1 \text{ m}^2/\text{s}$. We used previously described methods for the measurement of atmospheric pressure and underground gas pressure, analysis of data, and fitting of calculated curves to measured pressure-time curves.

INTRODUCTION

This report gives the results of field permeability tests made at a fourth nuclear-explosion-chimney site in Yucca Flat at the AEC Nevada Test Site (NTS). The purpose of this program of chimney tests is to obtain a permeability data base on nuclear chimneys as well as to further develop the test method. This experiment differs from prior ones primarily in that the chimney had not collapsed fully to the ground surface and was in a region including several tuff strata under surface alluvium rather than in alluvium alone. (The three earlier experiments were in alluvium only.) The tests included pressure measurements through a tube into the chimney and through a hose into nearby surface alluvium. The location is in area 9. The chimney site is designated DH-7, and the nearby surface-alluvium test site is designated DH-8. Data were taken in February and March, 1974.

We used previously described experimental^{1,2} and calculational^{2,3} methods. Pressure was measured at the surface and from below ground by means of a tube or hose. Data were transmitted to Livermore and recorded, via equipment including a computer system and a leased telephone line. Permeability results were obtained by fitting calculated curves to measured curves of underground pressure versus time. Calculated pressure was obtained from an analytic solution for Darcy flow in a semi-infinite slab with stepwise, time-varying surface pressure (superposition).

EXPERIMENT

Site

The site was selected as the best available for our purposes after a survey of similar sites without surface collapse.

Figure 1 shows test arrangements underground and is approximately to scale for major features.

The site, in area 9, is in the northeast part of Yucca Flat. The immediate region is made up of alluvium from the surface to a depth of approximately 73 m, and then several tuff strata to the Paleozoic contact at approximately 320 m, which is well above the static water table.⁴

There has been no surface collapse (no crater) at the chimney site DH-7. The top of the chimney may extend into the surface alluvium. Collected data on such chimneys suggest the top could be 60 m from the surface,⁵ an uncertain value, which in this instance is also nearly the depth to the tuff contact. The chimney may be bulked full. Permeability of materials beyond the chimney also may have been modified by surface spall and successive shocks from past tests.

The uncased postshot drill hole (drill size 0.25 m (9-7/8 in.)) enters the chimney at an estimated vertical depth of 216 m. The postshot hole and steel-tube installation are similar to prior ones for these tests except that the annulus about the tube and above 166 m is cement filled. Free gas flow through the chimney tube was verified on January 18, 1974 by attaching a blower and observing an outward air flow of $0.02 \text{ m}^3/\text{s}$ (50 cfm).

The surface alluvium test hole was drilled with a 15-cm-diam (6-in.) bit to 9.1 m (30 ft). Cuttings were blown to the surface with air without additives to avoid modification of permeability of the hole wall. The hole was approximately 1 m from the instrument shack, and approximately 70 m horizontally from the projected chimney boundary. A 2.5-cm-i.d. (1-in.) hose was placed in the hole and the hole was backfilled with a 1.5-m gravel section followed by low-permeability LLL stemming mix. (The measured permeability of the mix is $2 \times 10^{-12} \text{ m}^2$, or 2 D (where D is the symbol for darcy).)⁶

As in prior tests, connections to pressure instruments were made with insulated hose lying on the ground surface. Dimensions and details are noted on the sketch, Fig. 1.

Equipment, Software, and Performance

The instrumentation and data-acquisition systems were used in the previous two tests, CB-2 and -3.^{1,2} (The CB sequential test-site numbers are listed in Table 1.)

Each transducer, of two, alternately measures downhole and atmospheric pressure by means of computer-controlled solenoid valves. We set the transducer systems to give an output of 0 to 10 V for the range of 85.3 to 89.3 kPa (640 to 670 mm Hg). Accuracy and precision are $\pm 67 \text{ Pa}$ and $\pm 13 \text{ Pa}$ ($\pm 0.5 \text{ mm Hg}$ and $\pm 0.1 \text{ mm Hg}$), respectively. By comparison with a precision mercury barometer in the instrument shack, we estimate drift over a 14-day period to be $\pm 40 \text{ Pa}$ ($\pm 0.3 \text{ mm Hg}$). As in test CB-3, thermistors were used to monitor the temperatures in the hose, the instrument shack, and the thermostatted pressure-transducer enclosure.

Fig. 1. Schematic of arrangements underground for the tests in the nuclear chimney, DH-7, and in surface alluvium, DH-8.

Reviewing the data-acquisition system^{1,2,7,8} briefly, an ALPHA-16* computer at Livermore transmits valve-control and data-request commands to the PDP-16 computer (at the test location), which digitizes and returns data. The two are linked by Prentice data couplers and a dedicated Bell System telephone line. Data were recorded on punched paper tape and as teletypewriter printout.

Two problem areas arose during operation: (1) an intermittent ground (possibly on the phone line) and (2) software bugs. Line maintenance continued throughout the test. Part of the line, two twisted pairs of wires on the ground in area 9, was thought to be questionable. Program modifications were made to eliminate bugs as they arose. The problems in signal transmission helped us find the bugs.

Data transmission was faultless for 8 days at the outset. During the next 10 days we lost 4 days of data in 12- to 24-hr amounts due to the problems mentioned. Shorter outages occasionally occurred, 2 to 9 hr each, during the balance of the test.

The ALPHA-16, PDP-16, data couplers, and pressure transducers operated without apparent fault throughout the test period.

Data

Pressure data in this report and as recorded during measurement are in volts, d.c. From calibrations at atmospheric pressure, the range of 0 to 10 V represents 85.22 to 89.22 kPa (639.2 to 669.2 mm Hg). Output is linear. We did not convert values from volts to absolute pressure units. For purposes of curve fitting, either unit is appropriate. Figures 2 and 3 are graphs of the measured atmospheric and downhole pressures versus time for the chimney and surface-alluvium experiments, respectively. The surface-alluvium data we used for calculations were taken between February 8 and 16, 1974. The chimney data interval was the longest yet undertaken and ran between February 7 and March 23, 1974. We had not planned this long a test, but the transmission problems occurring during the first 500 hr of testing necessitated the extension.

The interval between data sets (atmospheric and downhole pressures, plus monitoring temperatures and valve-position data) was normally 1 hr. More frequent measurements were made on occasion for performance observation.

CALCULATIONS AND MATHEMATICAL MODEL

The simplest mathematical model to describe the pressure response at depth in a homogeneous medium is that for linearized, one-dimensional, isothermal, compressible gas flow in a uniform, porous medium.⁹

*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Atomic Energy Commission to the exclusion of others that may be suitable.

Fig. 2. Atmospheric and downhole pressures for the chimney experiment (site DH-7).

Fig. 3. Atmospheric and downhole pressures for the surface-alluvium experiment (site DH-8).

$$\frac{\partial P}{\partial t} = \alpha \frac{\partial^2 P}{\partial x^2}$$

where

P = pressure

t = time

x = distance

α = pressure diffusivity.

The pressure diffusivity is the analog of thermal diffusivity in the transient-heat-conduction equation, and is related to the permeability and porosity of the porous or fractured media by

$$\alpha = \frac{K\bar{P}}{\epsilon\mu}$$

where

K = permeability of the medium

ϵ = porosity of the medium

μ = viscosity of the gas

$\bar{P}$ = mean pressure of the gas.

As described by Carslaw and Jaeger,¹⁰ a solution to the heat-conduction equation for a semi-infinite slab with zero initial temperature and varying surface temperature can be generated from the solution for the case with constant surface temperature. The method is known as superposition.¹¹ The resulting expression for P(L,t) is

$$P_L = \sum_{n=0}^{L-1} (P_{n+1} - P_n) \times \text{ERFC} \left[\left(\frac{L^2}{4\alpha\Delta t(L-n)} \right)^{1/2} \right]$$

where

P_L = pressure at Lth time interval

L = depth in medium

Δt = time interval

A computer program,³ ERFC,* written to apply the above solution, was used with the surface-alluvium (DH-8) and chimney data (DH-7) to predict the downhole response. The

* ERFC can be run on the CDC 6600 and CDC 7600 computers of LLL's time-sharing system.

predicted and measured downhole pressure histories are plotted with the average values of the last 24-hr period matched. This averaging is done for several reasons. Some of the chimney data from previous experiments showed a small cyclic (24-hr) perturbation due possibly to temperature sensitivity of the barometric instruments. Averaging over at least 24 hr eliminates this possible bias cause. By matching the curves at some place, we avoid the need to estimate the pressure difference due to the column of gas in the sensing tube, which extends from the surface to depth in the chimney, and which has a small temperature gradient along its length. We used the end segment rather than the initial part, since initial calculated values do not match the initial conditions in the chimney.

RESULTS

Figures 4 through 6 show the computed and measured downhole response (to atmospheric-pressure change) for the chimney experiment. The sensitivity of the fit to different values of $L^2/4\alpha\Delta t$ is shown for a range of 20 to 40. The best value of 29.5 was determined by the minimum sum of squared deviations for all data points for $t \geq 500$ hr. Using values of $L = 216$ m and $\Delta t = 3600$ s, we calculate the best α as $0.11 \text{ m}^2/\text{s}$. This value represents an average through the chimney and an uncollapsed surface layer. A more detailed composite solution is possible, but beyond the scope of this analysis.

Figures 7 through 9 compare computed and measured downhole response (to atmospheric-pressure change) for the surface-alluvium experiment. The sensitivity of the fit to different values of $L^2/4\alpha\Delta t$ is significant in a range of 0.02 to 0.1, with 0.05 as the best value. Using values of $L = 9.1$ m and $\Delta t = 3600$ s, the calculated α is $0.11 \text{ m}^2/\text{s}$.

The ratio of effective permeability to porosity, K/ϵ , for the above α , using an average pressure of 85 kPa (646 mm Hg) and an air viscosity, μ , of $0.02 \text{ mPa}\cdot\text{s}$ (0.02 centipoise), is $2.6 \times 10^{-11} \text{ m}^2$ (≈ 26 D). This value agrees well with the permeability measured for alluvium over a depth of 122 m in area 10 at hole U10AM-5.^{12,13} (See Table 1.)

Table 2 gives the delay times for the response of underground pressure in percent to a step change in surface pressure.

We have further shaken down the equipment and computer software. A microwave link may be substituted for the suspect part of the telephone data line as a test in the next experiment. A local data-recording system is on-the-way to back up phone transmission or to allow testing at locations without phone service. We included a least-squares routine in the computer program to optimize curve fitting.

ACKNOWLEDGMENTS

I. Y. Borg provided most of the necessary information for the site survey and assisted in making the survey. D. G. McGuffin and K. B. Moon coordinated support to relocate and maintain the system at the test site. A. R. Denning assisted in this.

and also monitored operation and cured or headed off several problems at the site.
R. Grogan assisted in calibration and maintenance of the site instrumentation.

Fig. 4. DH-7 chimney experiment. Comparison of computed and measured downhole pressure. ($L^2/4\alpha\Delta t = 20$)

Fig. 5. DH-7 chimney experiment. Comparison of computed and measured downhole pressure. ($L^2/4\alpha\Delta t = 29.5$)

Fig. 6. DH-7 chimney experiment. Comparison of computed and measured downhole pressure. ($L^2/4\alpha\Delta t = 40$)

Fig. 7. DH-8 surface-alluvium experiment. Comparison of computed and measured downhole pressure. ($L^2/4\alpha\Delta t = 0.02$)

Fig. 8. DH-8 surface-alluvium experiment. Comparison of computed and measured downhole pressure. ($L^2/4\alpha\Delta t = 0.05$)

Fig. 9. DH-8 surface-alluvium experiment. Comparison of computed and measured downhole pressure. ($L^2/4\alpha\Delta t = 0.1$)

Table 1. Indicated in situ values of pressure diffusivity and permeability from field experiments in Yucca Flat.

Site ^a	Area	Material/region	Permeability 10 ⁻¹² m ² (D) ^b	Pressure diffusivity (m ² /s)	Test date	Remarks	Reference
U9ITS-eXY 30.5	9	Alluvium Vitric tuffs G.C. ^c ashfall tuff Undiff'd tuffs Carbonate rock	8.1 12.7 3.9 2.5 <2		July 7-14, 1971	Radial steady state. Air injection.	14
U10AM-5	10	Alluvium	8-16		July 20-21, 1971	Radial steady state. Air injection.	12
CB-1, DH-3 and 4 DH-3, recalcd.	10	Chimney in alluvium	25-99 62 ^d	1.0	May 19-25, 1972	Atmospheric-pressure method	15 3
CB-2, DH-5 DH-5, recalcd.	2	Chimney in alluvium	10 ^d 12 ^d	0.2	March and April, 1973	Atmospheric-pressure method	1 3
CB-3, DH-6 DH-6, recalcd.	2	Chimney in alluvium	33-66 56 ^d	0.5 to 1.0 1.0	Nov. 23-Dec. 22, 1973	Atmospheric-pressure method	2 3
CB-4, DH-7 and DH-8	9	Alluvium and chimmed tuff	7 ^d	0.1	Feb. and March, 1974	Atmospheric-pressure method	
	9	Surface alluvium	7 ^d	0.1		(No surface collapse)	

^aCB numbers are sequential test-site numbers. DH numbers are sequential hole numbers, one or more per test location.

^bSince 1 darcy = 0.987×10^{-12} m², the numbers in this column are essentially also in darcies.

^cG.C. signifies Grouse Canyon.

^dPorosity of 0.3 used arbitrarily to obtain these values from the pressure diffusivity.

Table 2. Calculated delay for the response of underground pressure to a step change in surface pressure.

Type of test	Pressure rise downhole (as percent of step at surface)	Time (hr)
Chimney test (216 m, $\alpha = 0.11$ m ² /s)	1	9
	25	44
	50	129
Surface-alluvium test (9.1 m, $\alpha = 0.11$ m ² /s)	1	1
	25	5
	50	14
	75	63

REFERENCES

1. D. F. Snoeberger, J. Baker, and C. J. Morris, Measurements and Correlation Analysis for Nuclear Chimney Permeability, Lawrence Livermore Laboratory, Rept. UCID-16302 (1973).
2. D. F. Snoeberger, C. J. Morris, and J. Baker, Data and Results, Nuclear Chimney Permeability-Test 3, Lawrence Livermore Laboratory, Rept. UCID-16436 (1974).
3. R. B. Rozsa, D. F. Snoeberger, and J. Baker, Chimney Permeability Data Analysis, Lawrence Livermore Laboratory, Rept. UCID-16440 (1974).
4. H. L. McKaige, Lawrence Livermore Laboratory, private communication, January 7, 1974.
5. I. Y. Borg, "Extent of Pervasive Fracturing around Underground Nuclear Explosions," J. Rock Mech. Miss. Sci. 10, 11-18 (1973).
6. J. H. Pitts and W. Kleck, Permeability and Porosity of Some Stemming Materials, Lawrence Livermore Laboratory, Rept. UCID-15876 (1971).
7. J. Z. Grens, ALPHA - An Interactive Language for the ALPHA-16 Computer, Rept. UCID-16228 (1973).
8. J. Baker, The LLL PDP-16 Data Acquisition System, Lawrence Livermore Laboratory, Rept. UCRL-75216 Preprint (1973).
9. V. Streeter, Ed., Handbook of Fluid Dynamics (McGraw Hill, New York, 1961), 15th ed., Sec. 16.
10. H. S. Carslaw and J. C. Jaeger, Conduction of Heat in Solids (Clarendon Press, Oxford, 1959), 2nd ed., p. 63.
11. C. S. Matthews and D. G. Russell, Pressure Buildup and Flow Tests in Wells (Society of Petroleum Engineers of AIME, Dallas, 1967), p. 14.
12. G. A. Morris, D. F. Snoeberger, C. J. Morris, and V. L. DuVal, Field Measurements of Permeability of NTS Alluvium in Area 10, Lawrence Livermore Laboratory, Rept. UCID-15919 (1971).
13. R. B. Rozsa, Permeability of NTS Alluvium-Numerical Simulation of Air-Injection Experiments, Lawrence Livermore Laboratory, Rept. UCID-15791 (1971).
14. D. F. Snoeberger, C. J. Morris, and G. A. Morris, Field Measurement of Permeabilities in NTS Area 9, Lawrence Livermore Laboratory, Rept. UCID-15895 (1971).
15. D. F. Snoeberger, G. A. Morris, and R. Rozsa, Chimney Permeability by Atmospheric Pressure Change - Preliminary Permeability Calculations, Lawrence Livermore Laboratory, Rept. UCID-16161 (1972).

DISTRIBUTION

LLL Internal Distribution

J. Baker	L-438	
F. Beane/R. Ide	L-7	
I. Borg	L-10	
J. Carothers	L-7	
B. K. Crowley	L-51	
R. Draper	L-777	
K. Ernst	L-404	
J. Frazer	L-404	
I. Germain	L-7	
D. Gregg	L-437	
J. Grens	L-437	
R. Heckman	L-231	2
B. Hudson	L-48	
S. Kurtz	L-48	
E. LaFranchi	L-151	
A. Maimoni	L-503	
R. Miller	L-777	
C. Morris	L-404	2
W. McKinnis	L-777	
W. Nervik	L-231	
C. W. Olsen	L-48	
R. L. Peterson	L-438	
J. Pitts	L-90	
L. Ramspott	L-44	
R. Rozsa	L-437	
A. Sherwood	L-437	
D. Snoeberger	L-437	8
D. Stephens	L-437	
A. Stripeika	L-151	
J. Thomsen	L-51	
J. Toman/R. Lessler	L-47	
G. Werth	L-13	
V. Wheeler	L-48	
TID File	L-3	30

External Distribution

T. A. Brubaker	
Colorado State University	
Fort Collins, Colorado 80521	
H. C. Carpenter	
U.S. Bureau of Mines	
Laramie, Wyoming 82070	
C. Keller	
Los Alamos Scientific Laboratory	
Los Alamos, New Mexico 87544	
J. Korver	
Teledyne Isotopes, Inc.	
Westwood, New Jersey 07675	
R. Quiring	
U.S. Dept. of Commerce	
Air Resources Lab.	
P.O. Box 14985	
Las Vegas, Nevada 89114	
B. J. McCoy	
Dept. of Chemical Engineering	
University of California	
Davis, California 95616	
Technical Information Center	2
Oak Ridge, Tennessee	

NOTICE

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately-owned rights."

CRS/1h