MASTER

32795

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.) This report is not to be given additional external distribution or cited in external documents without the consent of the author or I.R.L. Technical Information Department.

UCID - 15895

Lawrence Radiation Laboratory

UNIVERSITY OF CALIFORNIA

LIVERMORE

94550

FIELD MEASUREMENT OF PERMEABILITIES IN NTS AREA 9

D. F. Snoeberger
C. J. Morris
G. A. Morris

August 23, 1971

NOTICE

This report contains information of a preliminary nature and was prepared primarily for internal use at the originating institution. It is subject to revision or correction and therefore does not represent a final report. It is passed to the recipient in confidence and should not be distributed or further disclosed without the approval of the originating institution or U.S. AEC Technical Information Center, Oak Ridge, Tennessee 37830.

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.

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

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
Attention: Distribution
Refer all requests to

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
The Experiment and Results	2
Experimental Arrangement	2
Permeability Tests	4
Tracer Tests	6
Additions and Leak Test	6
Sampling	6
Background and Atmospheric Conditions	7
Tracer Gas Determinations	9
Samples from Hole XY31 (Location 1)	9
Samples from Other Locations	9
Calculations	11
Conclusions and Discussion	12

FIELD MEASUREMENT OF PERMEABILITIES IN NTS AREA 9

ABSTRACT

We have completed a measurement of permeability to a depth of 1200 ft in an exploratory hole in Area 9 at NTS. The method consisted of successive air-injection tests on the empty hole and after each of four stages of backfilling with cement. The data include flow rate, temperature, and the buildup and decay of pressure in the hole.

Preliminary calculations showed that the average permeability of the region for the full hole is about 4 darcies, assuming a radial cylindrical model and steady-state flow. Similarly, the permeabilities of the surface alluvium, the tuff layer underlying the alluvium, and the Grouse Canyon Ashfall are all in the 2-to-12-darcy range.

Tracer gas, SF_6 , added after bringing the top of the cement to 457 ft indicated flow paths to other holes and to the ground surface within 150 ft of the hole tested.

INTRODUCTION

A field test by LLL in September 1969 at NTS hole U10am-5 indicated a permeability of 9.5 darcies for an alluvium.¹ A search of the surface with halogen leak detectors did not show surface seepage of the tracer, CCl_2F_2 , added during air injection. The threshold for detection in this work was about 500 ppm (by volume) of CCl_2F_2 in air. This permeability test was conducted to obtain steady state measurements. Some transient pressure data were taken. After analysis using the TRUMP code the transient data appeared more useful, so we planned transient measurements in our field work.

This report presents preliminary values of permeability and the results of SF_6 tracer-gas tests of the region of hole U9-ITS-eXY30.5. Permeabilities were calculated using a radial cylindrical model and assuming that selected pressurization data approximate steady state flow conditions. We will report later on transient analyses of the data.

These field measurements were made in support of the containment program.

The region penetrated by the hole, to the 1195 ft depth, includes alluvium from the surface to 180 ft, vitric tuff to 300 ft, Grouse Canyon Ashfall to 440 ft, undifferentiated tuff to 1060 ft, and paleozoic carbonates at the bottom. The permeabilities we calculated for these regions range from 2 to 12 darcies.

1. A Pasternak and E. T. McMullen, Field Measurement of the Permeability of NTS Alluvium, Lawrence Livermore Laboratory, Rept. UCID-15727 (1970).

Since a cement backfill of hole U9-ITS-eXY30.5 was required for a nearby shot, the permeability tests made with air injection to measure pressure buildups and decays could be made successively on the full hole and after each of four cement stages, which correspond approximately with the strata.

We found the tracer, SF_6 , in a nearby placement hole (U9-ITS-XY31), in a gas sampling tube in U9-ITS-Y30-PS1A, and in three places on the surface within 150 ft of U9-ITS-eXY30.5. Concentrations found were between 0.05 ppb and 30 ppm.

For brevity in the balance of the report, we will refer to the Area 9 holes in the ITS area merely by their grid designations; for example, eXY30.5.

THE EXPERIMENT AND RESULTS

Experimental Arrangement

The exploratory hole eXY30.5 used for the air injection tests was 1195 ft deep with a 10-3/4-in. casing to 79 ft. The casing was grouted in a 26-in.-diameter (bit size) hole. The bit size used to drill to 1195 ft was 9-7/8 in. The caliper log shows the hole to be uniform—approximately 10-in.-diam except for the usual enlargement at the base of the surface casing cement. The drilling fluid was air foam.

The air supply system consisted of a 6-in. pipeline with a pressure-relieving valve, a vent valve, instruments for flow, pressure, and temperature, and 10 compressors (the number in place and in use varied during the test)—each connected to the pipeline by a shutoff valve and a 3-in. line. Figure 1 is a sketch of the air system and wellhead.

Two sizes of compressors were used. Their approximate capacities, operating at site atmospheric pressure (approximately 12.7 psia) and temperature (approximately 95°F daytime), were 600 and 1000 cfm (60°F, 1 atm). Maximum total air capacity was 8000 cfm. Usable capacity was 7600 cfm—limited by the flowmeter at the line pressures realized, approximately 20 psig at the flowmeter inlet.

The flowmeter was an orifice type with changeable orifice plates. Its line bore is 6.065 in. The meter location was near the wellhead just upstream of the vent valve.

The wellhead piping was 6-in.-diam up to the 10-3/4-in. casing flange. The upper part of the wellhead, above the horizontal air inlet, was reduced in size to adapt to the well logging tool used to position the downhole pressure and temperature sensors. A 2-in.-diam manifold at the casing top was used for addition of tracer gas from six cylinders simultaneously.

The air supply piping up to the 10-3/4-in. casing was pneumatically tested at 200 psig. Working pressures downstream of the supply valve were less than 30 psig. The manifold piping was rated for a higher pressure than the compressors could deliver.

The manifold pressure upstream of the supply valve was adjusted to less than 40 psig, the maximum allowable pressure in the hole in view of the weight of the wellhead and cement, prior to testing. Air was bypassed through the relieving valve until

Fig. 1. Air system at NTS hole U9-ITS-eXY30.5 (plan view except that the vent valve and wellhead are shown rotated 90° about the pipeline axis).

the supply valve was opened to start each pressurization. After pressure buildup had nearly leveled off, the supply valve was closed to allow pressure decay in the well.

Measurements of pressure and differential pressure at the flowmeter and of pressure from the downhole transducer were recorded at the site and transmitted by telephone for simultaneous digital recording on magnetic tape by a computer at LLL. Other measurements were logged.

Two or more tests were run at each hole depth.

Figure 2 shows the stratigraphy in the region of the test. Table 1 lists the contact depths between strata, the measured depth to the top of the cement, and the probe positions in the hole for downhole measurements.

Table 1. Strata contacts, top of cement depths, and probe positions.

Strata contact	Contact depth (ft)	Top of cement (ft)	Probe depth (ft)
Alluvium/vitric tuff	180	139	100
Vitric tuff/Grouse Canyon Ashfall tuff	300	305	275
Grouse Canyon Ashfall undifferentiated tuffs	440	457	400
Undifferentiated tuffs/paleozoic carbonates	1060	1034	875

Permeability Tests

Table 2 gives the data used for the steady state calculations made for this report. Since our main interest is in the transient behavior, we allowed relatively short times—approximately 20 min, sometimes less—for pressure buildup. Atmospheric pressure during the tests was approximately 12.7 psia.

Table 2. Observed data and calculated flow rates used for steady state calculation.

Date	Hole depth (ft)	Flow rate (10 ⁶ scfd ^a)	Downhole pressure (psia)	Temp. at flowmeter (°F)	Air temperature at meter downhole (°F)
7 July	1195	5.64	18.25	109	93
	1195	6.768	18.75	109	98.5
8 July	1034	9.5	18.8	113	93
	1034	7.68	17.8	113	87
12 July	457	7.87	20.0	116	70
	457	9.50	20.5	116	71
	457	10.01	21.6	116	78
13 July	305	9.17	22.0	106	75
	305	11.76	24.0	106	75
	305	7.66	21.0	106	75
14 July	139	6.0	35.5	111	113
	139	6.72	38	111	113
	139	3.84	27	111	113

^aStandard cubic feet per day (60°F, 1 atm).

Fig. 2. Generalized stratigraphy in the region of NTS hole U9-ITS-XY31, as derived by NTS staff geologists. The upper 70-100 ft of the Carrara formation is a mixture of noncalcareous weathered mudstones, siltstones, and shales.

The calculated permeabilities (in darcies) of regions approximately matching the strata are as follows:

Alluvium	8.2
Vitric tuffs	12.9
Grouse Canyon ashfall tuff	4.0
Undifferentiated tuffs and tuffaceous sandstones	2.5

We feel that this range, 3 to 13 darcies, may be taken as an order-of-magnitude estimate for these materials as they occur in this region. We expect that values different from these may result from further calculations. The differences may be great enough to change the relative ranking of the individual strata.

We don't have a satisfactory value of permeability from the "steady-state" calculations for the paleozoic carbonates; however, the region between 1034 and 1195 ft appears to be less permeable than the other regions.

Tracer Tests

Additions and Leak Test — We made two additions of SF_6 : 618 lb at 1300 PDT on 12 July and 40 lb at 1130 PDT on 14 July; just prior to the first SF_6 addition we added about 40 lb of CCl_2F_2 to check for surface piping leaks. We started the CCl_2F_2 in as gas but soon changed to liquid addition to try to get higher partial pressure in the piping. There was no closure between the hole and the wellhead. While adding the CCl_2F_2 as gas we observed an inflow of air when we opened a 1/4-in. valve on the manifold. While transferring CCl_2F_2 liquid to the manifold, we removed a fitting upstream of the wellhead, inserted a refrigeration-type halogen leak detector probe and got a positive indication of halogen. We found no leaks. The hole depth for this test was 457 ft.

The thermistor (located at 400 ft) indicated cooling during the first addition of SF_6 but not to below 70°F. The volume of the first addition of SF_6 gas was roughly four times the hole volume. The pressure rise in the hole reached a maximum of approximately 0.4 psi 13 min after the start of addition.

Table 3 shows the amounts of air injected after the addition of SF_6 gas. Each time the gas was added first, then air was injected. It required 30 min to add the 618 lb of SF_6 . The flows listed in Table 3 were estimated from compressor ratings. The total amount of air injected after SF_6 addition was approximately 2,090,000 ft³ (60°F, 1 atm).

SF_6 is a nontoxic, relatively inert gas. Its specific gravity at 20°C relative to air is 5.11. Its solubility in water at 25°C and 1 atm SF_6 pressure is 0.0035 wt%.

Sampling — Figure 3 is a sketch of the area showing the places routinely sampled for tracer gas. All of the surface locations except No. 11 had a 1-ft or deeper hole covered by a plastic sheet about 20 × 20 ft. The edges of these sheets were held down by sandbags. Sample location 2P (Y30-PS1A) was sampled by pumping on the existing

Table 3. Air injections after SF₆ additions.

Date	Starting time	Pumping time (min)	Flow		Cumulative flow (ft ³)
			(cfm)	(ft ³)	
12 July 1971	1315	618 lb SF ₆ in			
	1348	15	700	11,000	11,000
	1420	35	4900	171,500	183,500
	1519	31	4900	151,900	335,400
	1823	24	5900	141,600	447,000
	1859	12	5900	70,800	547,800
	1943	28	5900	165,200	713,000
	2036	36	5900	212,400	925,400
13 July 1971	1203	12	5900	70,800	996,200
	1223	10	5900	59,000	1,055,200
	1247	16	7600	91,200	1,146,400
	1322	15	6900	103,500	1,249,900
	1402	10	4900	49,000	1,298,900
	1418	10	4900	49,000	1,347,900
	1457	45	5200	234,000	1,581,900
14 July 1971	1100	40 lb SF ₆ in			
	1215	11	4900	53,900	1,635,800
	1234	12	4900	58,800	1,694,600
	1307	2	3500	7,000	1,701,600
	1317	13	2800	36,400	1,738,000
	1351	11	2800	30,800	1,768,800
	1429	76	4200	319,200	2,088,000

tube, which extends to the 780-ft depth. Sample location 1 (XY31)* was sampled with a 5/8-in.-i.d. × 1000-ft hose and an approx-5-cfm pump. The hose, which weighed 650 lb, hung freely in the hole; the depth of the hose was adjusted using a truck. The hose hung from one side of the top of the hole, but at depth it may have occupied any location across the 90-in. diameter of the hole.

Samples from locations 1 and 2P were taken after pumping out approximately one hose volume. In addition to the routine sampling at locations shown in Fig. 3, we took samples randomly from the entire area during the period of testing.

All the samples were taken with a 100-ml gas syringe. Analyses were made using a portable gas chromatograph equipped with an electron capture detector. The detection limit was 1.0 ppb for CCl₂F₂ and 0.01 ppb for SF₆. The time required for each analysis was 2 min for SF₆ alone and 6 min for CCl₂F₂ and SF₆ together.

Background and Atmospheric Conditions – The atmospheric background of SF₆ was zero. Winds were out of the south and strong in the afternoons. Barometric pressure fell off during test periods in the daytime by a few tenths of an inch of mercury.

*This hole was 1000 ft deep and uncased below 77 ft.

Fig. 3. Surface near NTS hole eXY30.5 showing routine sampling locations.

Tracer Gas Determinations

Samples from Hole XY31 (Location 1) – On 12 July we sampled through the hose, which was at the 400-ft depth, at 30-min intervals beginning at noon. The first indication of tracer occurred at 2130 hours; the concentration was 4 ppb.

The next morning (at about 1045 PDT), after the cement had been raised to 305 ft and before injecting air in eXY30.5 we sampled XY31 over the 400-to-100-ft depth interval at 50-ft intervals by pulling the hose upward. We detected SF_6 at every interval in concentrations between 1 ppb and 6 ppm. The maximum concentrations, 5-6 ppm, occurred at 300-350 ft. Concentrations were above 0.1 ppm over the 200-400 ft depth interval. This interval at XY31 spans the Grouse Canyon Ashfall and includes four-fifths of the Vitric tuffs. The concentrations at 100-150 ft were about 1 ppb. After sampling each 50-ft interval, we again sampled the 400-ft level (at 1145 PDT) and found that the concentration had risen to 2.5 ppm.

On 13 July we began air injection at noon. Starting at 1430 PDT we again traversed XY31 from 100 to 900 ft. Concentrations of SF_6 at 100, 150, and 250 ft were 2, 35, and 20 ppm, respectively. Between 300 and 900 ft we found SF_6 with a concentration of less than 10 ppb. At about 1600 PDT we sampled the well top and found about 30 ppm SF_6 . Air in the hole may have risen, lifting the region of maximum concentration of SF_6 . The 100-250-ft interval spans the Vitric tuffs, including its contacts with alluvium and the Grouse Canyon Ashfall. Figure 4 is a plot of the SF_6 concentration and the sampling time vs the sample hose depth on 13 July 1971.

On 14 July 1971, at 1100 PDT, before starting air injection we traversed the region in XY31 upward from 900 to 100 ft at 50- or 100-ft intervals. The cement top was at 139 ft in eXY30.5. We found SF_6 at every interval; all concentrations were below 10 ppb. We added 40 lb of SF_6 to eXY30.5 and at noon started air injection. We traversed XY31 from the surface to 800 ft between 1400 and 1630 PDT. The concentration at the well top was 3 ppm at 1400 PDT and 10 ppm at 1630 PDT. The concentrations of SF_6 found at each level between 100 and 800 ft were all less than 15 ppb.

On 15 July 1971 at 1230 PDT a sample at the well top showed 2 ppm SF_6 .

Samples from Other Locations – On 14 July at about 1530 to 1600 PDT we observed the first indications of SF_6 at the ground surface. This was at the Y30-PS1A cellar (sampling location 2, Fig. 3). The concentration was 0.7 ppb.

Random sampling in the general test area at about 1600 PDT led to discovery of SF_6 escaping along an east-west crack about 10 ft long located approximately 150 ft south of XY31 and about 85 ft east of eXY30.5 (location 11, Fig. 3). (The SF_6 may have begun escaping before 1600 PDT.) The concentration of SF_6 throughout the length of this crack was about 1 ppm. There was no plastic cover over this location.

One other surface sampling location showed SF_6 . We found 0.05 ppb at a low spot under a plastic sheet approximately 105 ft south of eXY30.5 (location 4, Fig. 3) at about 1600 PDT.

Fig. 4. Concentration of SF_6 in hole XY31 on 13 July at the times indicated (24-hr clock, PDT).

We found tracer at the 0.3 ppb level in air pumped from the sample tube in Y30-PS1A (location 2P, Fig. 3). This tube had been placed to sample at approximately 780 ft in the chimney at Y30. The annulus outside this tube had been cemented between the surface and about 540 ft. The gas was detected at 1530-1600 PDT on 14 July 1971. Previous samples up to 1430 PDT that day had not shown SF₆.

In every other place sampled, the concentrations of SF₆ were below the limit of detectability (0.01 ppb).

We found CCl₂F₂ in each sample that contained SF₆ at a concentration greater than 1 ppm. The CCl₂F₂ concentrations varied directly with the SF₆ content.

CALCULATIONS

We calculated permeabilities using the following equation for steady state isothermal flow of compressible fluids in a radial (cylindrical) region¹:

$$Q_b = \frac{19.8 h K T_b}{\mu P_b T_h} \frac{P_h^2 - P_e^2}{\ln(r_e/r_h)} \quad (1)$$

where

Q_b = Rate of flow at P_b and T_b (ft³/day)

K = Permeability (darcies)

h = Length of uncased hole (ft)

μ = Viscosity of air at T_h (0.0185 cP)

P_b = Base pressure (14.7 psia)

T_h = Temperature of air at bottom of hole (°R)

T_b = Base temperature of air (520°R)

P_h = Pressure of air at bottom of hole (psia)

P_e = Pressure of air at radius of effect (12.4 psia)

r_h = Radius of uncased hole (0.51 ft)

r_e = Radius of effect (assumed to be 200 ft)

Rearranging the radial flow equation (1) to solve for permeability, one obtains

$$K = \frac{Q_b \mu P_b T_h}{19.8 h T_b} \frac{\ln(r_e/r_h)}{P_h^2 - P_e^2} \quad (2)$$

Equation (3),² which expresses the average permeability of a layered region as a function of the permeabilities and thicknesses of the individual layers, can be used in conjunction with Eq. (2) to determine the permeabilities of the individual strata penetrated by the test hole.

$$\bar{K} = \frac{\sum_{i=1}^n K_i l_i}{\sum_{i=1}^n l_i} \quad (3)$$

$\bar{K}$ = Average permeability of region

K_i = Permeability of ith layer

l_i = Thickness of ith layer

CONCLUSIONS AND DISCUSSION

Preliminary calculations with selected data, assumed to approximate steady state, and for a radial cylindrical model indicate a range of permeability of 2 to 13 darcies for strata in the region penetrated by hole eXY30.5. These are not final values. We hope to make revisions from further study of the results. We may obtain better estimates of radii of effect from transient calculations and otherwise improve the model. The permeability values we calculated for the individual strata may represent, for example, the particular conditions of fracturing and variation of bed geometry in this region. Measurements in these strata at several regions may narrow the uncertainties.

We found SF₆ tracer at a concentration of 4 ppb in XY31, 200 ft from eXY30.5, 7½ hr after it had been added to the test hole. By this time 925,000 ft³ of air had been injected at an approximate rate of 5000 cfm for 3 hr following tracer addition. For comparison, the transit time to XY31 at 5000 cfm, if one assumes a uniform radial volumetric displacement in interconnected voids (taken as 40%) of a 400-ft vertical cylinder, is 67 hr. The volume of air so added would be 2.0 × 10⁷ ft³. We did not detect tracer at the surface until the afternoon of 14 July. It appears that the tracer moved laterally more easily than vertically.

Judging by the concentration profiles in XY31 on 13 July and neglecting the possibility of vertical displacement of these profiles by convection, we conclude that the permeability is relatively high through the region between eXY30.5 and XY31 including the Grouse Canyon Ashfall tuff and the Vitric tuffs. The lower regions in eXY30.5 had been cemented. Air may have been flowing upward slowly in XY31 during the sampling periods, since high concentrations of SF₆ occurred at the casing top. Downflow may have

2. J. W. Amyx, D. M. Bass, Jr., and R. L. Whiting, Petroleum Reservoir Engineering (McGraw-Hill Book Co., Inc., New York, 1960), pp. 79-81.

occurred at other times. Atmospheric pressure varied over a range of about 0.4 in. of mercury during testing; it was higher early in the day and lower in the afternoons. The low concentrations found below 400 ft may represent permeation through the lower tuffs or mixing in XY31.

One of the three surface seepages we found in the afternoon of 14 July may be a crack communicating with eXY30.5. On the surface we found it was a line 10-ft long running east-west approximately 150 ft south of XY31 and 85 ft east of eXY30.5. This is within the pad area prepared for drilling these two holes. The concentration in samples from the line was much higher than from the other surface locations — 1 ppm vs 0.7 and 0.05 ppb.

SF₆ reached the Y30 chimney and apparently by convection in the chimney reached the inlet of the sampling tube in Y30-PS1A at 780 ft.

This test demonstrates the feasibility of using tracer gas methods at NTS to locate permeable zones and fractures and to aid interpretation of permeability data.

DISTRIBUTION

LLL Internal Distribution

J. Kane
J. Frazer
R. Heckman
A. Maimoni
C. Morris
G. Morris
D. Snoeberger
R. Rozsa
V. DuVal
A. Pasternak
J. Baker
P. Coyle/F. Beane
J. Pitts
L. Germain
V. Wheeler
B. Hudson
W. Nervik
J. Kury
K. Oswald/R. Miller/D. Meehan
R. McArthur
P. Smuda
TID File

30

External Distribution

J. Leisek
Teledyne Isotopes, Inc.
Las Vegas, Nevada

J. Korver
Teledyne Isotopes, Inc.
Westwood, New Jersey

C. Keller
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Division of Technical Information Extension, Oak Ridge

2

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."

RCB/lm