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# ANALYSES OF ATMOSPHERIC PRESSURE RESPONSE DATA IN HOLE U9ITSeU-29#2: NEVADA TEST SITE.

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MASTER

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## ABSTRACT

We attempted to evaluate the permeability at a deep hole (U9ITSeU-29#2: Nevada Test Site) open full length underground by using low-cost, atmospheric-pressure-response measurements. Vertical flow between the hole wall (below the sealed surface casing) and the surface dominates lateral radial flow to a second hole (U9ITSU-29, 41 m distant, and open to the atmosphere). A definitive value of permissivity (permeability/porosity) was not obtained. Packers or other means of restricting vertical flow appear to be necessary for permeability testing of horizontal strata at these holes.

## INTRODUCTION

Radioactivity was found between depths of 213 m and 244 m in device emplacement hole U-29[*] in area 9, Yucca Flat, and in a similar hole, eU-29#2,[*] one of two follow-up exploratory holes nearby. The radioactive material apparently was the product of an adjacent shot and came through a fractured or faulted region intersected by U-29 and eU-29#2. The nature of the isotopes indicates that dynamic transport of gaseous precursors occurred within a few minutes after fission. There is geologic evidence of faulting and fracturing in this area.[1,2] Fractures were observed by television examination in U-29.[3] Effective permeabilities of up to $13 \times 10^{-12}$ m$^2$ (13 darcies) were measured for the strata in this region at another hole.[4] The regions in eU-29#2 and U-29 showing radioactivity respectively bracket and nearly bracket the Grouse Canyon tuff and the contact zones with the tuffs above and below (see Fig. 1).

We are interested in measuring the effective permeabilities in the U-29 region, in particular in the Grouse Canyon tuff, so that we can better characterize the tuff strata and evaluate possible containment problems of U-29. Several methods have been considered ; these include air injection between straddle packers in eU-29#2[5] and measurement between packers of pressure responses in eU-29#2 to atmospheric pressure change[6] on the surface and in U-29. These schemes were not pursued because of their high cost. A decision was made to simply make the above pressure response measurements on eU-29#2 without packers (i.e., on the entire open length of the hole below its surface casing) and compare the measured pressure response with curves

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[*] Hole numbers in full are: U9ITSU-29 and U9ITSeU-29#2.

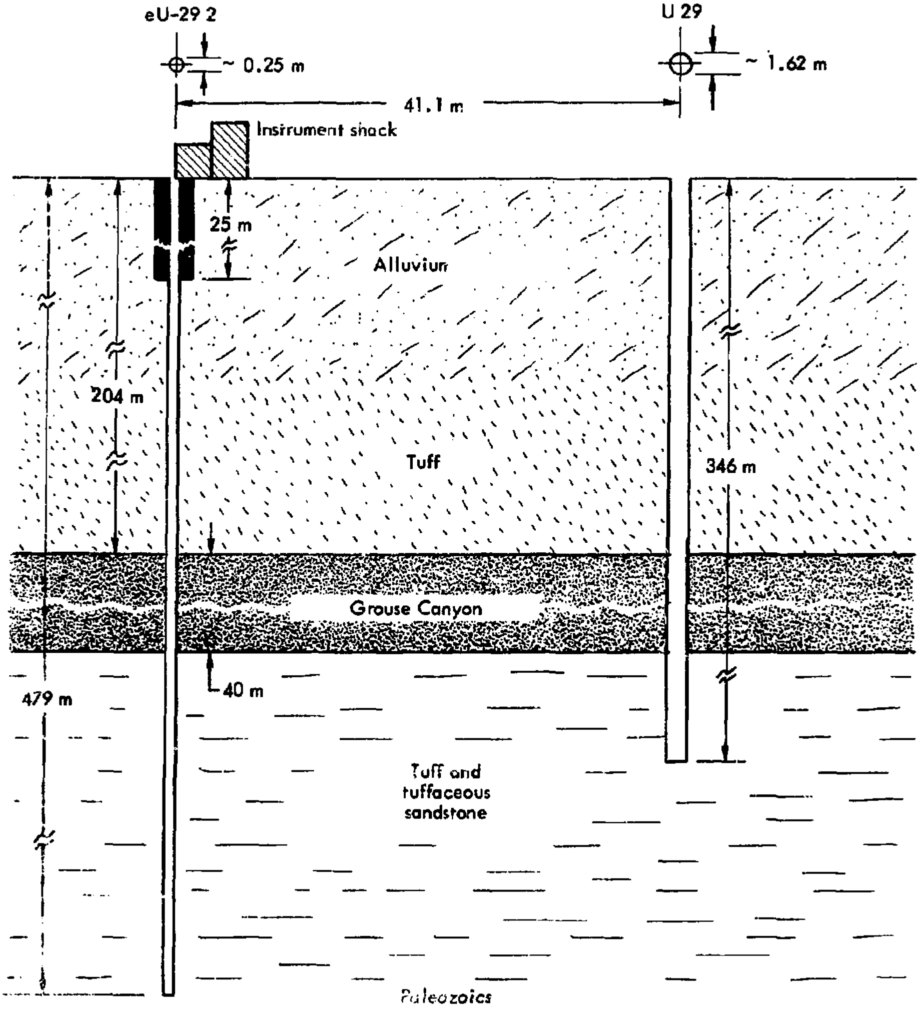

Fig. 1. Schematic diagram of the U-29 region.

computed from flow models to obtain an indication of whether the predominant escape path is radial or vertical. The instrumentation was available in standby pending the next chimney permeability assignment, and we were interested in the analysis of a radial flow problem. Results indicate dominance of vertical flow.

The U-29 site, in area 9, is in the northeast part of Yucca Flat. The immediate region consists of alluvium from the surface to a depth of approximately 110 m, and various tuff strata below to the Paleozoic limestone at approximately 400 m. Stratigraphy details are in Table 1.[*]

Hole U-29 was 346 m deep and 1.62 m in diameter. Hole U-29#2, 41 m distant, was 479 m deep with a diameter of 0.25 m. Each hole is cased to a depth of 25 m. The casings are cemented in place. Figure 1 is a schematic representation of the site.

Table 1. Stratigraphic column in holes.

| | Depth, m | |
|---|---|---|
| | U9ITSe U-29#2 | U9ITSU-29 |
| Alluvium | 113 | 110 |
| Timber mountain tuff formation Rainier Mesa member | 113-134 | 110-116 |
| Paintbrush tuff formation | 134-204 | 116-189 |
| Belted range tuff | | |
| Grouse Canyon member | 204-244 | 189-226 |
| Bedded tuffs | 244-430 | 226-346 |
| Paleozoic limestone | 430-505 | |

## INSTRUMENTATION AND DATA ACQUISITION SYSTEM

This equipment has been described in prior reports.[6] 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 circuit. Data were recorded at Livermore on punched paper tape and as teletype-writer printout. We experienced intermittent communication problems which were traced by Bell System personnel to deteriorated field wire on the site. A Bell microwave van was put in service on April 23 in order to bypass the field wire. This change eliminated all further communication problems for the remaining 9 days of the test. However, an additional software bug in the Alpha-16 was discovered and corrected the following day. Noise on the telephone circuit had been interpreted by the Alpha-16 as data. We fixed the problem by inserting a command to reinitialize the Alpha-16 data interface before each data request command.

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[*] Data was provided by H. L. McKague.

[†] 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.

A barometric pressure transducer alternately measured downhole and atmospheric pressure by means of a computer controlled solenoid valve.

Figure 2 shows measured values of atmospheric pressure and downhole pressure (eU-29#2) versus time.

Pressure measurements were recorded in volts, dc. The range of 0 to 10 V represents the pressure range of 83.99 kPa to 87.99 kPa. Output is linear. We did not convert from volts to pressure units for the analyses and curve fitting.

## FLOW MODELING

As in our earlier work we use a linearized equation describing isothermal, compressible ideal gas flow in a uniform porous medium with constant properties.[3-7] We approximated the atmospheric pressure history as a series of small step changes and obtained a solution for the transient pressure response underground by summing the responses to the step changes over the total time interval.

This solution for response pressure P can be expressed as

$$P(t) - P(0) = \sum_{i=1}^{m} (\Delta P_{sf})_i \, [F(m + 1 - i)],$$

where $(\Delta P_{sf})_i$ is the step change in atmospheric pressure (forcing function) for the $i^{th}$ time step $(\Delta t)$ and F is the response function for a unit forcing function. This superposition technique is valid for linear equations with appropriate boundary conditions.

Our initial model was for a one-dimensional, semi-infinite, radial flow geometry bounded internally by $r_0$, the radius of U-29. The linearized gas flow equation is

$$\frac{\partial P}{\partial t} = (\alpha) \frac{1}{r} \frac{\partial}{\partial r}\left(r \frac{\partial P}{\partial r}\right),$$

where

$P$ = pressure,

$t$ = time,

$r$ = distance,

and

$\alpha$ = 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 medium by

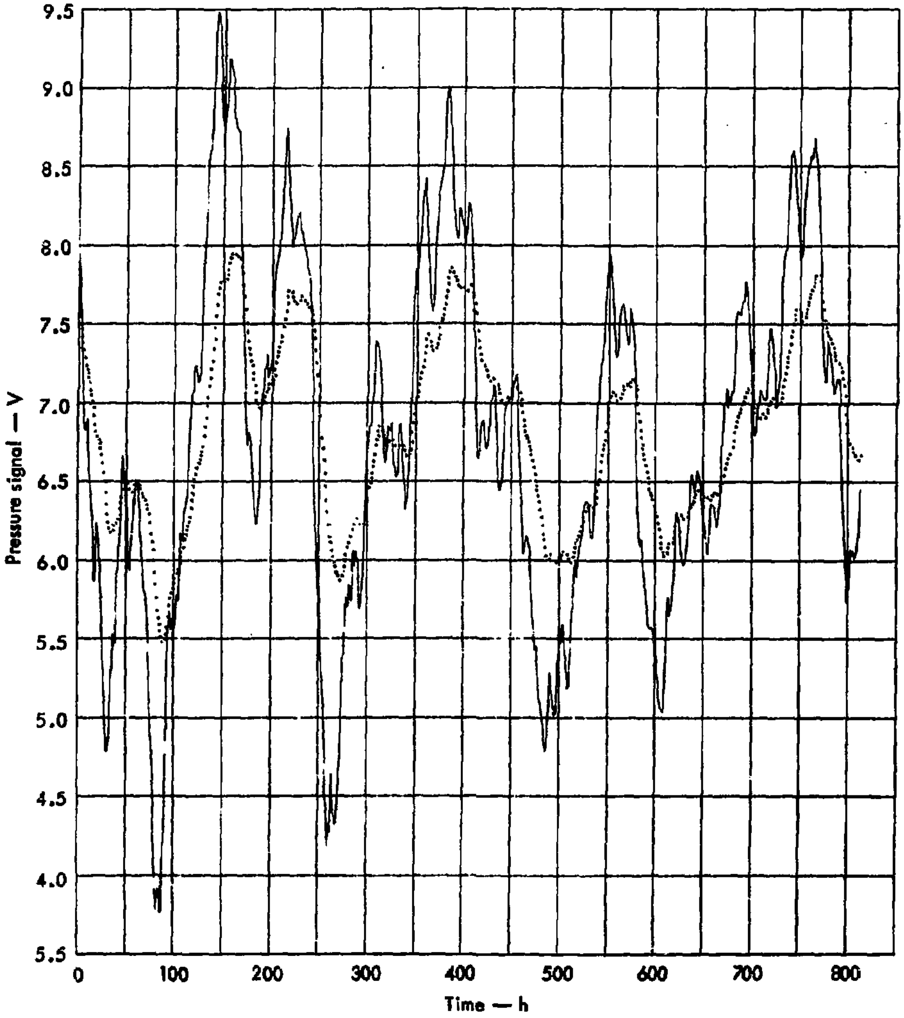

Fig. 2. Pressure versus time. The solid line indicates atmospheric pressure and the dotted line the pressure in UeU29-2.

$$\alpha = \frac{K\overline{P}}{\epsilon\mu},$$

where

$K$ = permeability,

$\epsilon$ = porosity,

$\mu$ = viscosity of gas,

and

$\overline{P}$ = mean pressure of gas.

For this geometry the step response function F is[8]

$$F\left(\frac{\alpha t}{r_0^2}, R\right) = 1 - \frac{2}{\pi}\int_0^{\infty} \exp\left(-\frac{\alpha t w^2}{r_0^2}\right)\left[\frac{J_0(w)Y_0(wR) - Y_0(w)J_0(wR)}{J_0^2(w) + Y_0^2(w)}\right]\frac{dw}{w},$$

where

$R = r/r_0$

$w$ = dummy variable of integration,

and

$J_0$ and $Y_0$ are zero order Bessel functions.

The above integral has been evaluated by numerical integration (Sherwood[9]). We generated a table of $F(\alpha t)$ versus $\alpha t$ for fixed values of $R = 50.7$ and $r_0 = 0.81$ m for use in a table-look-up subroutine.

The step response function for vertical one-dimensional flow (slab) is the error function compliment.

We used one or the other step response functions in a subroutine in the existing computer code[7] to obtain calculated pressures. In addition to use of these two models, we applied a gross-leak function and a finite-hole-volume function.

## Gross Leak Function

If a gross leak or flow path connects the atmosphere and sensing hole, dominating the flow conductance of the hole volume, the linearized equation is

$$\frac{dP_H}{dt} = \beta\,(P_s - P_H),$$

where

$P_H$ = pressure of hole,

$P_s$ = atmospheric pressure,

and

$\beta$ = coefficient related to overall conductance of leak and hose volume.

Using the above relationship and approximating the atmospheric pressure variation by a series of step changes:

$$P_H(t) - P_H(0) = \sum_{i=1}^{m} (\Delta P_s)_i \, [1 - e^{-\beta(m+1-i)\Delta t}] \, .$$

## Finite Hole

The question of whether the volume of the sensing hose and/or hole affects the pressure measurement was recognized during the beginning of the chimney experiments. The signal transmittal delay is not serious in most cases (a 300-m hose, 4 cm in diam has a time constant of about 1 s). The signal attenuation is also not serious although the measured pressure represents a larger portion of the surrounding region. This is because the time constant of the hose and/or hole is small enough to allow equilibration with the nearby porous media; the larger the hose volume, the larger the region equilibrated. In chimney experiments where a large fraction of the sensing hole is at one depth (bottom of the chimney), this averaging effect is small. In eU-29#2, which is cased to only about 25 m, the remaining 450 m depth is exposed for gas flow, meaning that any vertical pressure reading is an average over a wide depth range.

To compute this function, a finite difference code similar to TRUMP[10] was used, and the response to a step change at the surface computed. We used a two-dimensional, vertical, cylindrical geometry and simulated infinite extent in both dimensions. With these boundary conditions, the problem is linear and the calculated function may then be used in a manner similar to that of the other functions mentioned above.

## RESULTS

The computed and measured pressure histories were plotted and the curves matched for average values of all points past the first 100 h. This takes care of the pressure shift caused by density differences in the sensing hose and/or hole. The first 100 h are disregarded since the initial conditions are unknown and are significant only during this time period. The best or optimum fit is computed as that parameter resulting in the minimum of squared deviations between computed and measured data points.

The best fit of computed and measured response using the radial flow model function is shown in Fig. 3. The time lag of different peaks is correct but the amplitude variation is not very satisfactory. The best fit using the gross-leak, exponential function is shown in Fig. 4. The fit is obviously not good, missing badly in both time lag and amplitude. Figures 5 and 6 show the results using the vertical-flow, complimentary-error function and the vertical-flow, finite-hole-volume function, respectively. The fit is very good for both cases in time lag and amplitude. The finite hole function has a smaller sum of squared deviations by a factor of three, but as the two graphs show, there is not a significant visual difference. In Fig. 7 we show the comparison of these two solution functions. The finite-hole function has the same shape as a complimentary-error function at long times, but responds more quickly at early times.

We have not run a radial-flow, finite-hole-volume function. The effect would be to dampen the amplitude variation and the best fit (time lag) shown in Fig. 3 is already too dampened.

Using 0.02 mPa · s (0.02 cP) as the nominal air viscosity and 85 kPa as normal atmospheric pressure, we calculate the permissivity ($K/\epsilon$) to be $1.8 \times 10^{-10}$ $m^2$, using the finite-hole function. Using a nominal porosity of 1/3, the permeability in darcies is 60. This is the same value calculated using the complementary-error-function solution for an effective depth of 212 m. If we use an effective depth of 25 m, the depth of cased hole, the calculated permeability is about 0.8 darcies. Since previous work shows the permeability of surface alluvium to be about 8 darcies, both above values are suspect.

## CONCLUSIONS AND RECOMMENDATIONS

The best fit between computed and measured pressure response to atmospheric changes indicates that vertical flow dominates at the exploratory hole, UeU29-2. Because of the discrepancy in $K/\epsilon$ values computed from the complimentary error and finite-hole function, a definitive value of permissivity is not apparent although both functions adequately reproduce the transient pressure response.

We recommend consideration of a similar experiment in which the exploratory hole is isolated in the region of the Grouse Canyon layer to restrict the vertical flow response. In addition, tracer movement under a mild pressure gradient should also be conducted to pinpoint gross flow features, if any.

## ACKNOWLEDGMENTS

Thanks are due to A. [illegible] for programming the numerical solution of the radial function integral.

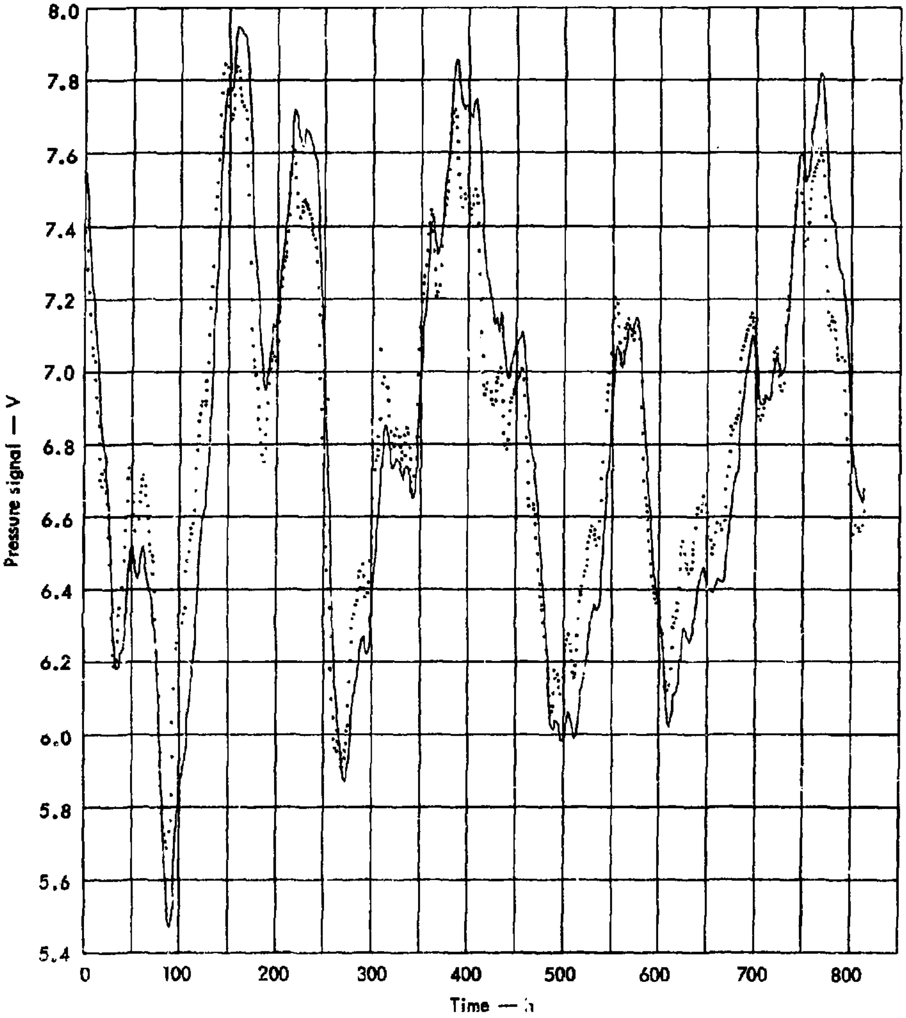

Fig. 3. Comparison of computed (dotted line) and measured (solid line) pressure response in UeU29-2 using the radial-flow function.

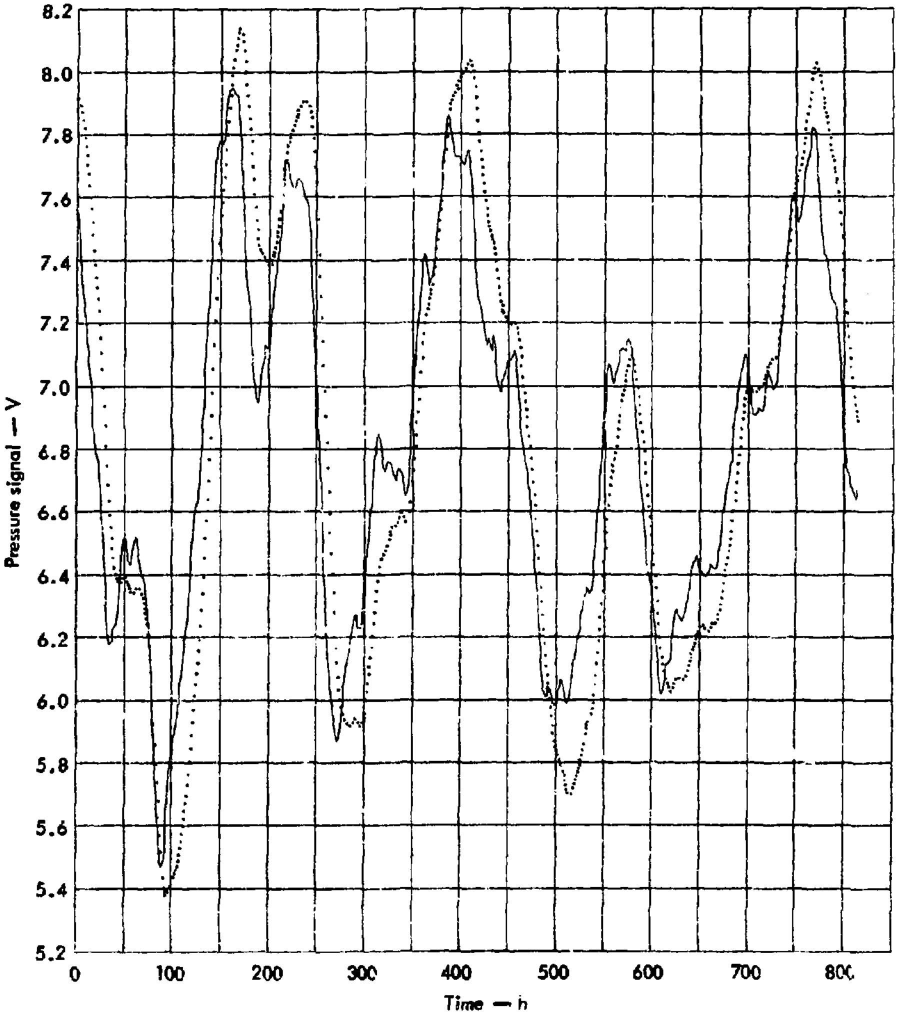

Fig. 4. Comparison of computed (dotted line) and measured (solid line) pressure response in UeU29-2 using the gross-leak function.

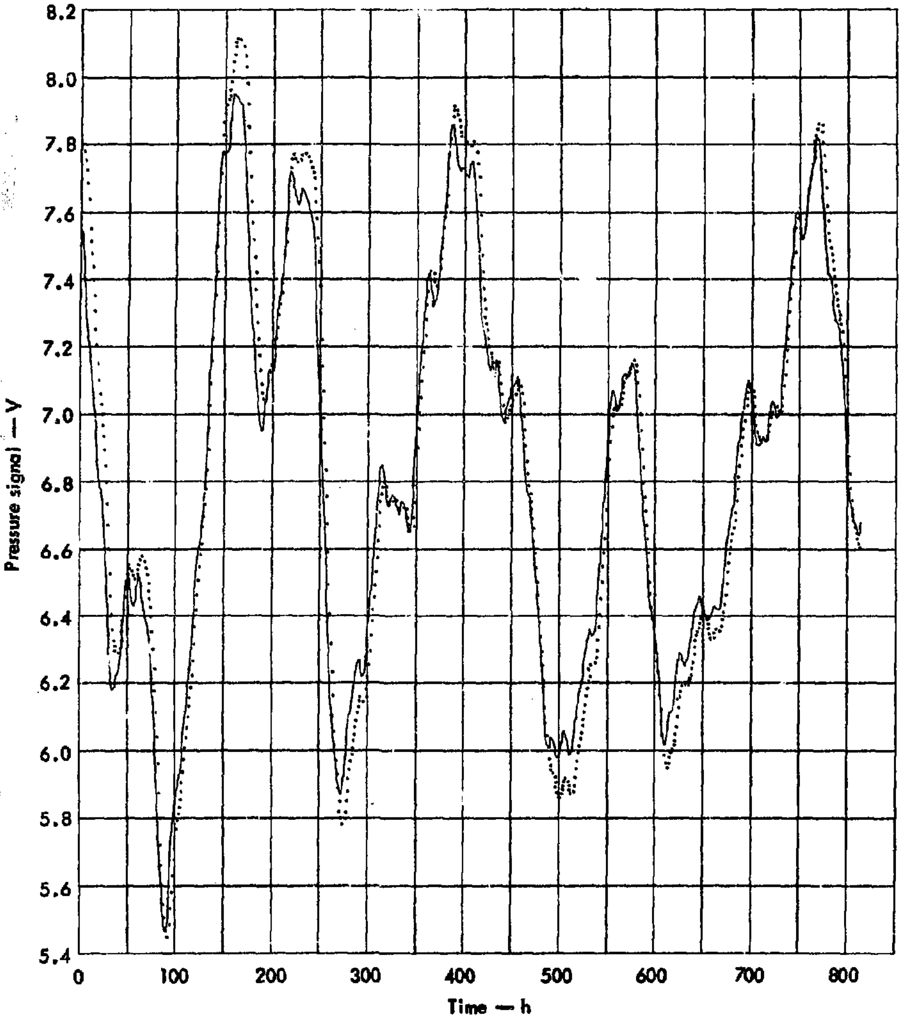

Fig. 5. Comparison of computed (dotted line) and measured (solid line) pressure response in UeU23-2 using the complementary-error function.

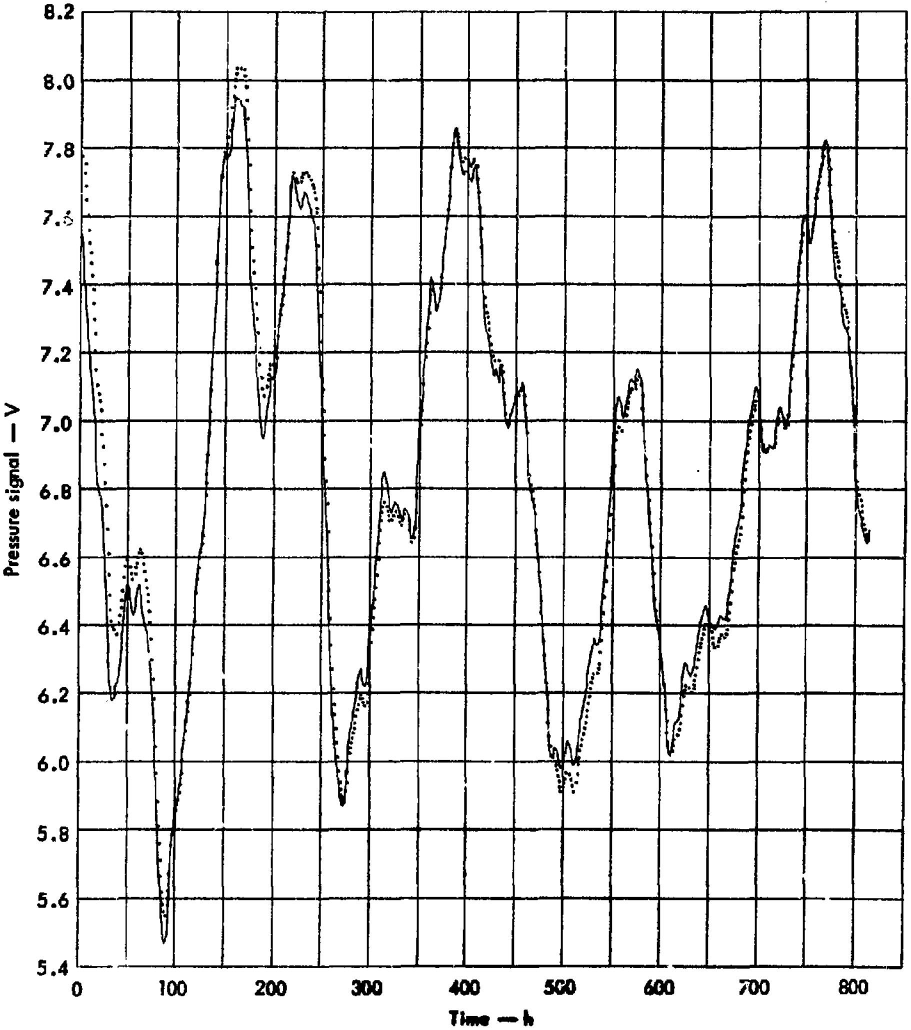

Fig. 6. Comparison of computed (dotted line) and measured (solid line) pressure response in UeU29-2 using the vertical flow, finite-hole-volume function.

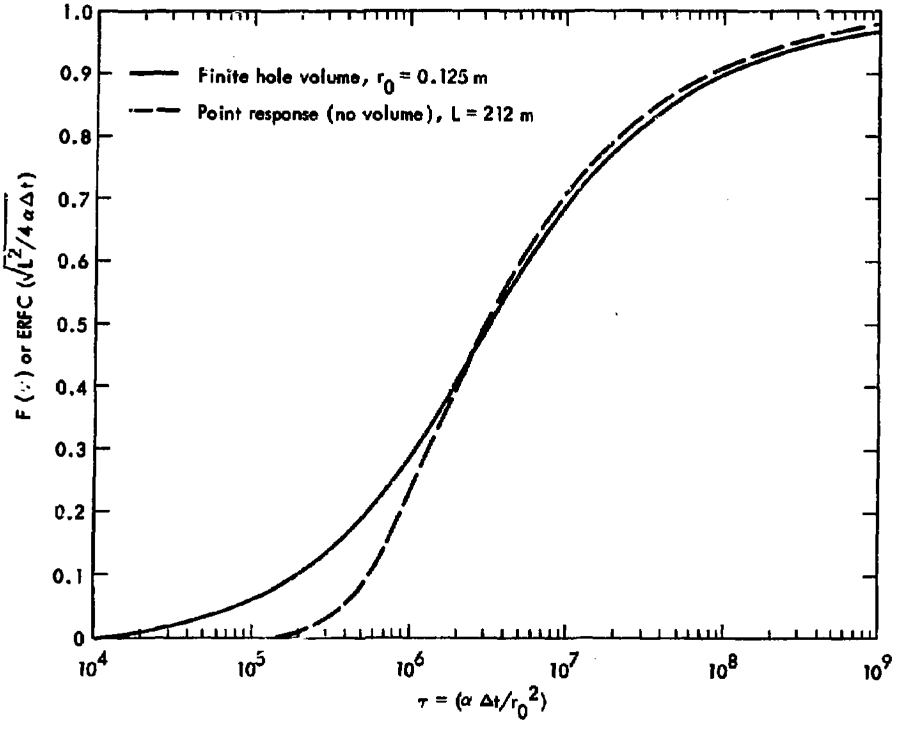

Fig. 7. Comparison of response functions for vertical flow in semi-infinite media.

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