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no. 239

Radon in the Helium-Bearing Natural Gas of the Texas Panhandle

Trace Elements Memorandum Report 239

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

IN REPLY REFER TO:

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON 25, D. C.

AEC-498/1

MAR 15 1951

Dr. Phillip L. Merritt, Assistant Manager
Raw Materials Operations
U. S. Atomic Energy Commission
P. O. Box 30, Ansonia Station
New York 23, New York

Dear Phil:

Transmitted herewith for your information and distribution are 8 copies of Trace Elements Memorandum Report 239, "Radon in the helium-bearing natural gas of the Texas Panhandle," by H. Faul, G. E. Manger, and A. Y. Sakakura.

Our measurements of the radon content of natural gas samples from 84 producing wells in the Texas Panhandle gas field show significant differences; furthermore, the wells with the highest radon content occur in clusters suggesting a marked variation in the distribution of the parent elements of radon, namely radium and uranium, within or near the gas reservoir. Analysis of the radon data in relation to possible source distribution suggests that rocks containing average concentrations of uranium could not supply the amount of radon observed in most of the gas wells.

Further research on the emanating power of granite and dolomite is required to determine whether the radon observed is attributable to radioactive elements in the reservoir rock or to radioactive elements outside the reservoir volume proper. The Oak Ridge National Laboratory has already initiated preliminary studies of the emanating power of the selected dolomite samples. Additional radon measurements are needed to establish the limits of the abnormal radon concentration and further delineate the possible distribution of the parent element.

Sincerely yours,

W. H. Bradley

W. H. Bradley
Chief Geologist

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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by

H. Faul, G.E. Manger, and A. Y. Sakakura

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CONTENTS

ILLUSTRATIONS

RADON IN THE HELIUM-BEARING

NATURAL GAS OF THE TEXAS PANHANDLE

by

H. Faul, G. E. Manger, and A. Y. Sakakura

ABSTRACT

The known quantity of helium in the Texas Panhandle gas reservoir is greater than could be explained by assuming normal geologic conditions. Radon content of the gas varies between about 10 and 250 micromicrocuries per liter (S. T. P.), and the more highly radioactive wells are clustered in several groups. Mathematical analysis indicates that the larger concentrations of radon could not be derived from rocks of normal radioactivity.

INTRODUCTION

In the summer of 1949, Garland B. Gott and James W. Hill of the U. S. Geological Survey observed unusual radioactive intensities at the heads of several gas wells (fig. 1) in the vicinity of the Bivins compressor station of the Canadian River Gas Company, about 30 miles north of Amarillo, Tex. A subsequent study 1/ revealed that the activity comes from radon daughter isotopes. Radon was identified in the gas by the electroscope measurements of John Rosholt and Charles

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1/ Hill, James W., Radon-bearing gas in the Amarillo helium district, Texas: U. S. Geol. Survey Trace Elements Memorandum Rept. 131, August 1950.

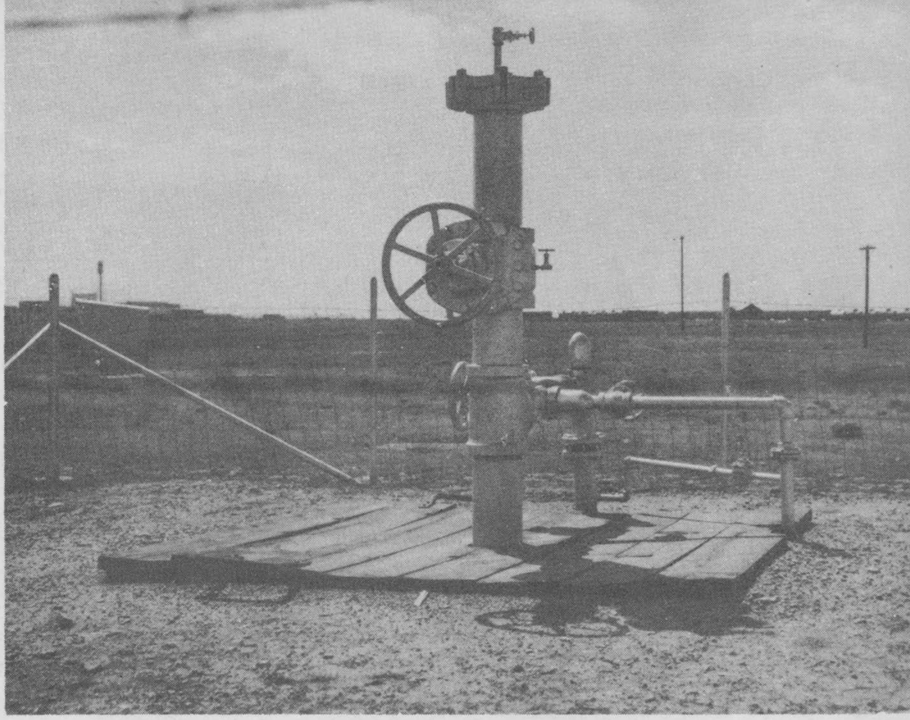
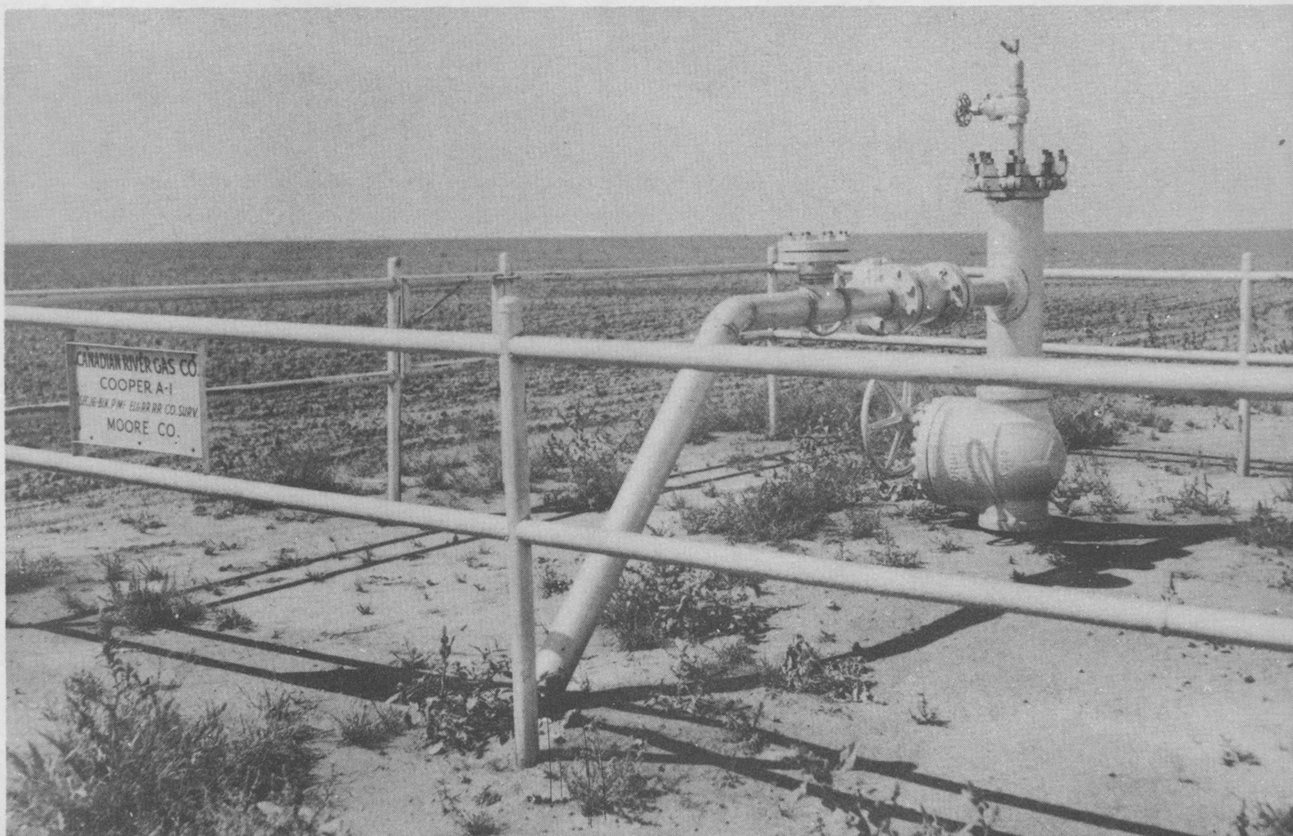


Fig. 1. Typical gas wells, Panhandle field.



Butler at the Geological Survey laboratory in Denver.

Considering the early proposal and now almost universal acceptance of the radiogenic hypothesis for the origin of helium 2/, 3/, unusual radioactivity could have been suspected in association with helium. It is surprising that the radon was not discovered during the intensive investigations of helium-bearing gases in the past two decades.

Repeated helium surveys by the U. S. Bureau of Mines have produced remarkably complete information on the helium content of all significant gas wells, and on the variation that has been observed over the years. Total reserves are also known with fair accuracy. The minimum absolute age of the Texas Panhandle reservoir can be estimated from stratigraphic evidence. The radon content of individual gas samples from 84 wells distributed over an area 16 miles wide and 40 miles long was measured during the summer of 1950. The results of these measurements are reported in the Appendix.

On the basis of all this information it is possible to make various calculations of geologic significance. For instance, one may estimate the total minimum amount of radioelements that could have produced the helium, and with the aid of the radon data, even gain some insight into their probable distribution. The more interesting aspects of these quantitative speculations are examined in this progress report.

2/ Evans, R. D., personal communication, 1950.

3/ Aldrich, L. T., and Nier, A. O., The occurrence of He^3 in natural sources of helium: Physical Review, vol. 74, 1948, pp. 1590-1594.

HELIUM CALCULATIONS

A metric ton of uranium, in equilibrium with its daughter products, evolves 0.11 cm^3 (or 3.9×10^{-6} cu. ft.) of helium per year. The equivalent figure for thorium is 0.018 cm^3 (or 4.7×10^{-7} cu. ft.). The age of the youngest reservoir rock in the area is Permian, or about 200 million years 4/, and we assume that the helium has accumulated since that time. Prior to its commercial development, the helium reserve in gas analyzing more than 0.9 percent He in the Channing district of the Panhandle field was roughly 4×10^9 cubic feet 5/or the amount that would have been generated by 4×10^8 tons of uranium since Permian time. This quantity of uranium would be found, on the average, in 2×10^{14} metric tons (2×10^4 cubic miles) of granite or 4×10^{14} metric tons (4×10^4 cubic miles) of an average limestone-dolomite complex. Corrected for the average thorium content of these rocks the values would be reduced by about 1/2 for granite and 1/3 for limestone-dolomite. We are now faced with the problem of reconciling these quantities with geologically acceptable conditions.

First, let us consider the evolution of helium in rocks. Hurley has shown 6/ that as a rule more than half of the radioactivity in outcropping granites resides on the surface of the grains, the balance being held inside the crystals of the major constituents. The helium

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4/ Marble, J. P., Report of the committee on the measurement of geologic time, 1949-1950: Nat. Research Council, 1950, p. 18.

5/ Barlow, W. H., and McCarroll, C. F., A study of the helium reserve in the Channing district of the Texas Panhandle gas field: U. S. Bur. Mines, unpublished report, 1941.

6/ Hurley, P. M., Distribution of radioactivity in granites and possible relation to helium age measurements: Geol. Soc. America Bull., vol. 61, 1950, pp. 1-8.

released within the crystals is firmly held, and does not escape in geologic time. On the other hand, the helium atoms ejected by radio-elements located on granular boundaries have a good chance of escaping because the alpha rays from which they are created do not penetrate more than 50 microns below the crystal surfaces. (Equivalent information on the locus of radioactive concentrations in limestones and dolomites is inconclusive at present.)

It follows that for granite, at least, perhaps half of the generated helium may escape. How much of the helium eventually reaches the reservoir is a matter of conjecture, but for the sake of this discussion let us assume that this fraction is also 1/2, with the balance of the helium presumably trapped along the way or escaping into the atmosphere. Allowing for all the corrections, we now have 40,000 cubic miles of granite or a possibly similar amount of the dolomite complex to dispose of.

The Channing district has an area of some 4,000 square miles (fig. 3). The true area of source rock is conjectural, and there is no basis for a guess. For the moment let us consider the 4,000 square miles to be the area of source rock. If the rock were granite, we would have to fit 40,000 cubic miles of it into an area of 4,000 square miles, yielding a hypothetical source 10 miles thick or roughly half of the total known thickness of the "granitic layer." At this point we may drop any further consideration of the limestone-dolomite complex, for the required thickness is absurdly high. If we were to

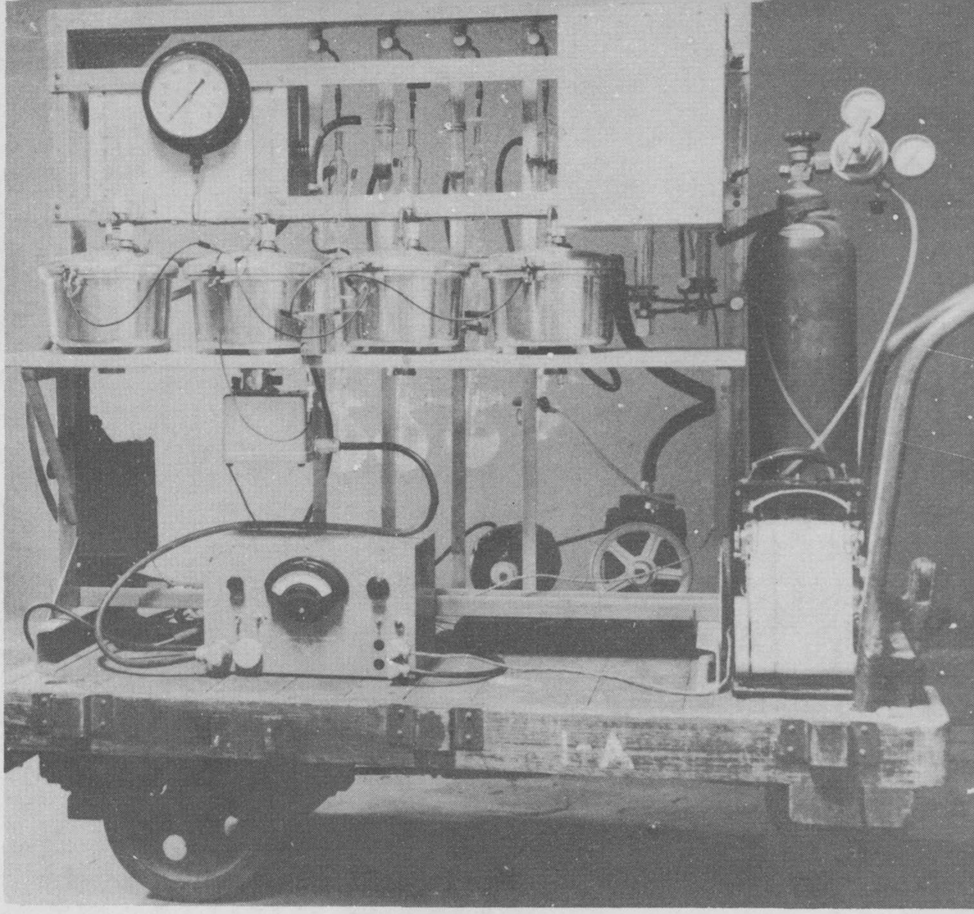
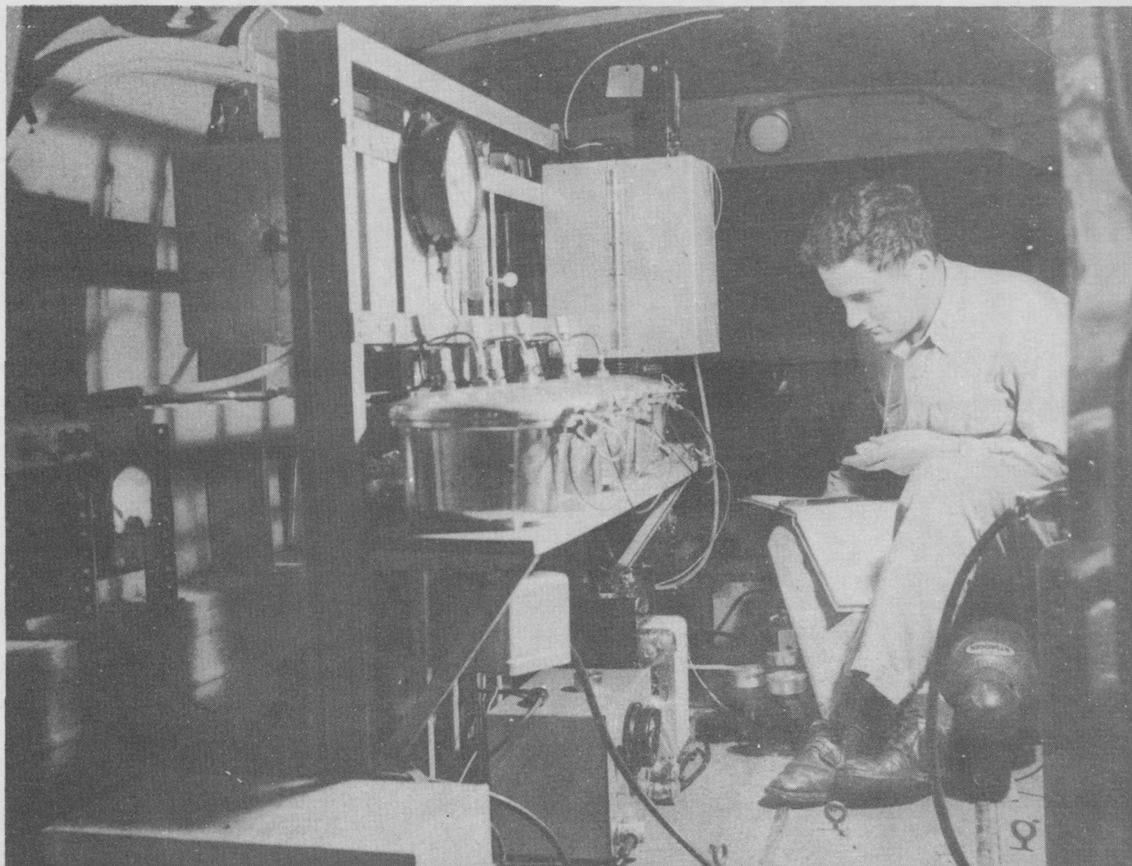


Fig. 2. Radon apparatus in the shop (above) and operating in the field at Exell, Texas.



assume a larger area of source rock, the required thickness of granite could be brought down to a fairly small figure, but we would have to postulate lateral migration for distances of the order of 100 miles. On the other hand, we could not have considered a much smaller area of source rock without piling up granite in excess of a geophysically reasonable thickness (about 20-30 miles) in addition to the general difficulty of having to evolve a mechanism for vertical helium migration through the granite for tens of miles.

From these considerations it is clear that we cannot easily account for the known amount of helium by assuming that it came from rocks of normal radioactivity (such as granite containing 0.0003 percent uranium and 0.0012 percent thorium or dolomite containing 0.0001 percent uranium). We may wish to postulate much higher concentrations of radioelements localized either in the reservoir rock or in the underlying pre-Cambrian complex. The idea is not new. Rogers 7/ wrote thirty years ago that "it might be supposed that the igneous rocks which doubtless underlie the area [of the Petrolia, Kans., field, largest helium deposit then known] at a depth of less than 2 miles contain deposits of pitchblende, and that the helium liberated by these deposits has risen and mingled with the hydrocarbon gas formed in the sediments above." On the same page he states: "There appears to be no great geologic difficulty in the way of assuming such deposits, aside, of course, from the fact that there is no direct evidence for their presence."

7/ Rogers, G. S., Helium-bearing natural gas: U. S. Geol. Survey Prof. Paper 121, 1921.

RADON MEASUREMENTS

It was in search of such evidence that a preliminary survey of radon content of the helium-bearing gas was made. The apparatus used for these measurements (fig. 2) is essentially similar to the equipment described by Evans 8/, Urry 9/, Curtiss and Davis 10/, and others, but has the distinction of being the first such device mounted in a truck and thus fully mobile.

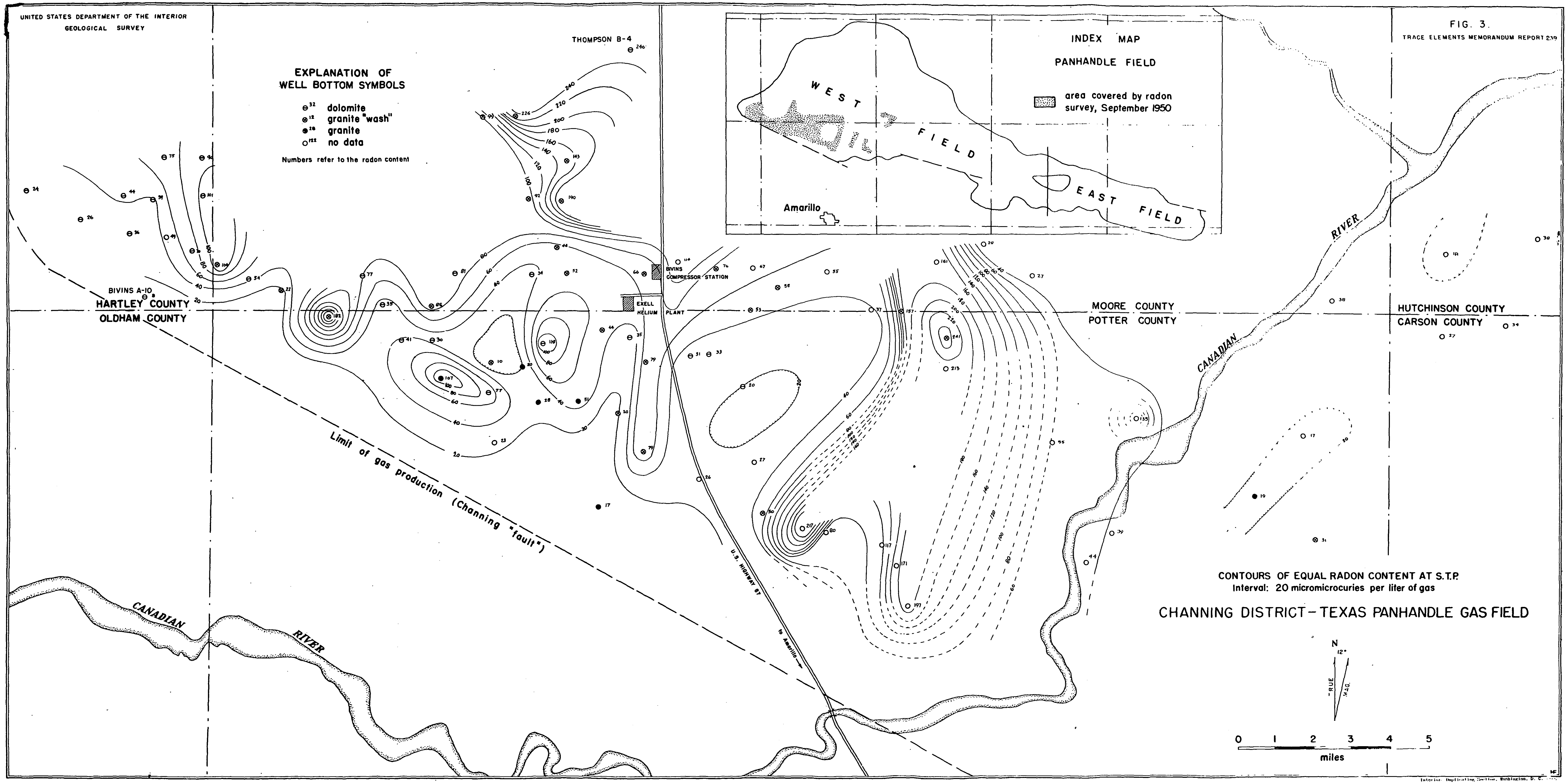
Samples from 84 wells were analyzed during September 1950. Repeat samples were taken from several wells, and it is estimated that the probable error of these determinations does not exceed ± 20 percent. The limiting sensitivity of the apparatus in its present form is roughly 3 micromicrocuries per liter of gas in the chamber.

The steel gas-sample flasks are connected to the evacuated system through a regulator, and the gas is allowed to pass through a drying column into one of four ionization chambers. The chambers are filled to atmospheric pressure. Positive ions are collected and the resulting current is measured with a vibrating-reed electrometer that records through a graphic milliammeter. The chambers are calibrated by a standard radium solution in the usual manner. Allowing for build-up and decay of the active deposit, it is possible to analyze up to 12

8/ Evans, R. D., Apparatus for the determination of minute quantities of radium, radon, and thoron in solids, liquids, and gases: Rev. Sci. Inst., vol. 6, 1935, p. 99.

9/ Urry, W. D., Determination of the radium content of rocks: Jour. Chem. Physics, vol. 4, 1935, pp. 40-48.

10/ Curtiss, L. F., and Davis, F. J., A counting method for the determination of small amounts of radium and of radon: U. S. Nat. Bur. Standards Jour. Research, Research Paper RP 1557, vol. 31, 1943, pp. 181-195.



UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
FIG. 3.
TRACE ELEMENTS MEMORANDUM REPORT 239
EXPLANATION OF WELL BOTTOM SYMBOLS
dolomite
granite "wash"
granite
no data
Numbers refer to the radon content
THOMPSON B-4
INDEX MAP
PANHANDLE FIELD
area covered by radon survey, September 1950
WEST FIELD
EAST FIELD
Amarillo
BIVINS A-10
HARTLEY COUNTY
OLDHAM COUNTY
BIVINS COMPRESSOR STATION
EXELL HELIUM PLANT
MOORE COUNTY
POTTER COUNTY
HUTCHINSON COUNTY
CARSON COUNTY
Limit of gas production (Channing "fault")
U.S. HIGHWAY 87
to Amarillo
CANADIAN RIVER
CANADIAN RIVER
CONTOURS OF EQUAL RADON CONTENT AT S.T.P.
Interval: 20 micromicrocuries per liter of gas
CHANNING DISTRICT-TEXAS PANHANDLE GAS FIELD
N
TRUE
MAG.
0 1 2 3 4 5
miles

gas samples per day with this instrument.

The measurements were made while the truck was parked near the Exell helium plant, where water and electricity connections were available. However, the truck carries a 1500-watt generator and a circulating pump to provide power and cooling water for work at remote locations.

RADON CALCULATIONS

The evolution of helium from uraniferous rock is accompanied by the release of radon, chemically similar to helium but radioactive and decaying with a half-life of 3.82 days. As the two gases travel through the rock, the amount of radon is steadily diminishing. Here we are faced with the first indeterminate parameter: How old is the radon when we detect it at the well head? Or, more indirectly, how far has it travelled? The speed of the gas in the well itself and in its immediate vicinity is very high, and the time spent in transit between the bottom of the well and the casing head is only a few minutes. However, in the reservoir itself, the velocity drops sharply as the distance from the well increases (roughly as the inverse of the distance).

We are forced to consider two possible alternatives: (1) that the radon is generated in the reservoir rock itself, or (2) that it comes from other sources, presumably below. There is no basis for a choice here, and we shall examine both possibilities in sequence.

The symbols used in the calculations are defined below:

D = Thickness of producing zone

$\Delta p^2 = p_e^2 - p_w^2$

k, $k(\vec{r})$, $k(r)$, k' = Radon atoms available per sec per unit reservoir volume, or equivalent uranium concentration, assuming complete equilibrium

λ = Decay constant of radon

M = Measured value of radon content corrected to S. T. P.

$N(\vec{r})$, $N(r)$ = Rn atoms per sweeping gas volume at point $\vec{r}$ or r

p, $p(\vec{r})$ = Fraction of rock volume open to gas (porosity)

p_e = Reservoir pressure

p_o = Atomospheric pressure

p_w = Bottom-hole pressure

r = Radius in cylindrical coordinates

$\vec{r}$ = Position vector

r_o = Radial distance from point source to well

r_e = Radius of reservoir

r_w = Radius of well

ρ = Density of reservoir rock

s = Source strength, point source

$\vec{v}(\vec{r})$ = Vector velocity of carrier gas (as a function of position)

The first alternative is essentially the problem of radon flushed from a porous medium by the movement of natural gas. A concept of this nature can be treated by well known techniques of mathematical physics; that is, an equation of continuity can be set up for a steady state:

(1) $\nabla \cdot \vec{F} = -\lambda p(\vec{r})N(\vec{r}) + k(\vec{r})$

where $\vec{F}$ is the vector flux of radon through a unit area of rock:

$$\vec{F} = \vec{v}(\vec{r})\ p^{2/3}(\vec{r})N(\vec{r})$$

and where $\lambda p(\vec{r})N(\vec{r})$ represents the decay rate of radon per unit volume of the rock. The factor $p(\vec{r})$ expresses the actual volume occupied by the gases (porosity).

The simplest case to consider is that of a point source from which other source distributions can be constructed. Then

(2)
$$k(r) = \frac{s\,\delta(r-r_0)\,\delta(\phi-\phi_0)\,\delta(z-z_0)}{r}$$

where the δ's are Dirac delta functions, and the subscript zero refers to the positions of the source of strength s in the cylindrical coordinate system. Utilizing Muskat's 11/ value of $\vec{v}(\vec{r})$ we find

(3)
$$\frac{1}{r}\frac{d}{dr}\left(-\frac{Q_0}{2\pi D}\sqrt{\frac{p_w^2}{\Delta p^2}\log\frac{r_e}{r_w}}\left\{\log\frac{r}{r_w} + \frac{p_w^2}{\Delta p^2}\log\frac{r_e}{r_w}\right\}^{-\frac{1}{2}} N(r)\right) =$$

$$= -\lambda pN(r) + k(r)$$

We denote

$$\left\{\log\frac{r}{r_w} - \frac{p_w^2}{p^2}\log\frac{r_e}{r_w}\right\}^{-\frac{1}{2}} \quad \text{by} \quad u(r)$$

11/ Muskat, Morris, Flow of homogeneous fluids through porous media, McGraw Hill, 1937.

The solution of (3) is:

$$N(r) = \frac{1}{u(r)} \exp\left[a \int^{r} \frac{r\,dr}{u(r)}\right] \left\{ u(r_w) N(r_w) \exp\left[-a \int^{r_w} \frac{r\,dr}{u(r)}\right] - \right.$$

$$\left. - \frac{as}{\lambda p} \delta(\phi - \phi_o) \delta(z - z_o) \exp\left[-a \int^{r_o} \frac{r\,dr}{u(r)}\right] st(r - r_o) \right\}$$

where the step function

$st(r-r_o) = 0$ when $r < r_o$, and $st(r-r_o) = 1$ when $r > r_o$.

Because

$N(r) = 0$ for $r > r_o$ (there is no flow backward)

$$(5) \quad N(r_w)\, u(r_w) \exp\left[-a \int^{r_w} \frac{r\,dr}{u(r)}\right] =$$

$$= \frac{as}{\lambda p} \delta(\phi - \phi_o)\, \delta(z - z_o) \exp\left[-a \int^{r_o} \frac{r\,dr}{u(r)}\right]$$

$$(6) \quad N(r_w) = \frac{a\ s}{\lambda p\ u(r_w)} \exp\left[-a \int_{r_w}^{r_o} \frac{r\,dr}{u(r)}\right] \delta(\phi - \phi_o) \delta(z - z_o)$$

where

$$a = \frac{2\pi D\ p}{Q_0} \left[\frac{p_w^2}{\Delta p^2} \log \frac{r_e}{r_w}\right]^{-\frac{1}{2}}$$

Averaging (6) over the producing zone we find, for the point source,

$$(7)\quad \bar{N}(r_w) = \frac{as}{2\pi D\lambda p\, u(r_w)} \exp\left[-a\int_{r_w}^{r_o} \frac{r\,dr}{u(r)}\right]$$

We can readily find the solution for an isotropic source by replacing s by k $st(r_o - r_w)st(r_e - r_o)$ and integrating over the source coordinates. Then, for the isotropic source:

$$(8)\quad N'(r_w) = \frac{a\,k}{p\lambda u(r_w)} \int_{r_w}^{r_e} r_o\,dr_o \exp\left[-a\int_{r_w}^{r_o} \frac{r\,dr}{u(r)}\right]$$

Performing the indicated operation for equation (7), we find

$$(9)\quad \boxed{\bar{N}(r_w) \sim \frac{s}{Q_o} \exp\left[-\frac{\pi D p}{Q_o}\left\{\left(1-\frac{1}{2\frac{p_w^2}{p^2}\log\frac{r_e}{r_w}}\right)(r_o^2-r_w^2) + \frac{r_o^2\log\frac{r_o}{r_w}}{2\frac{p_w^2}{p^2}\log\frac{r_e}{r_w}}\right\}\right]}$$

Then for the isotropic source we have

$$(10)\quad N'(r_w) \sim \frac{2\pi Dk}{Q_o}\int_{r_w}^{r_e} r_o\,dr_o\left\{\exp\left[-\frac{\pi D\lambda p}{Q_o}\left(1-\frac{1}{2\frac{p_w^2}{p^2}\log\frac{r_e}{r_w}}\right)(r_o^2-r_w^2) + \frac{r_o^2\log\frac{r_e}{r_w}}{2\frac{p_w^2}{p^2}\log\frac{r_e}{r_w}}\right]\right\}$$

The logarithmic term in the integral at its largest value will be of the order of a twentieth of the first term. Furthermore the significant contribution to the integral stems from small r. We introduce only minor error if we replace the logarithmic term by its mean, i.e.,

$$\log \frac{r_o}{r_w} \sim \frac{\int_{r_w}^{r_e} \log \frac{r_o}{r_w}\, dr_o}{r_e - r_w} = \frac{r_e}{r_e - r_w} \log \frac{r_e}{r_w} - 1$$

$$\sim \log \frac{r_e}{r_w} - 1$$

We obtain

(11)

$$N'(r_w) \sim \frac{k}{\lambda p} \; \frac{1 - \exp\left[- \frac{\pi D \lambda p}{Q_o} \left(1 - \frac{\log \frac{r_e}{r_w} - 2}{\frac{2 p_w^2}{p^2} \log \frac{r_e}{r_w}} \right) (r_e^2 - r_w^2) \right]}{1 - \frac{\log \frac{r_e}{r_w} - 2}{\frac{2 p_w^2}{p^2} \log \frac{r_e}{r_w}}}$$

The value of the exponential is small and we may write

(12)

$$\boxed{N'(r_w) \sim \frac{k}{\lambda p} \; \frac{1}{1 - \frac{\log \frac{r_e}{r_w} - 2}{\frac{2 p_w^2}{p^2} \log \frac{r_e}{r_w}}}}$$

The measured value M is related to N by

(13)

$$\boxed{\frac{p_o}{p_w} N = M}$$

Equations (9), (12), and (13) will now be applied to two actual wells, Bivins A-10 and Thompson B-4. They were selected because they have widely different radon contents yet are drilled in geologically similar strata. Both produce gas from the dolomite, and neither has reached the underlying granite "wash."

	Thompson B-4	Bivins A-10
λM	246 $\mu\mu$ c/L.	8 $\mu\mu$ c/L.
Dp^2	1.75×10^4	1.84×10^4
Q_o	3.3×10^5 ft.^{3}/d	2.24×10^5 ft.^{3}/d
p_e^2	1.3×10^5	1.1×10^5
p_w	336	311
D	~ 15	~ 15
p	$\sim .25$	$\sim .25$
r_e/r_w	$\sim 10^4$	$\sim 10^4$
ρ	2.5	2.5
k	1.77×10^{-6} g/g U	5.3×10^{-8} g/g U
s (near well)	8.33×10^5 g U	1.7×10^4 g U

However, we are now faced with the second major indeterminate parameter in this consideration: How much of the radon generated in the rock actually escapes into the pore space? It is safe to estimate the upper limit of this quantity (the gross emanating power) as 50 percent, but the lower limit may be 0.1 percent, 0.01 percent, or possibly even less. F. J. Davis of the Oak Ridge National Laboratory has proposed 5 percent as a reasonable figure 12/. Assuming for the moment that this estimate is correct we have:

	Thompson B-4	Bivins A-10
k'	3.5×10^{-5} g/g U (≈ 0.0035 percent)	10^{-6} g/g U (≈ 0.0001 percent)
s'	1.7×10^{7} g U	3.4×10^{5} g U

First let us consider k', the postulated uranium concentration in the rock. Limestones and dolomites normally contain from 0.00003 to 0.0002 percent uranium 13/, 14/. Our calculation yields 0.0001 percent uranium for the dolomite of Bivins A-10, and it seems probable that our assumptions are essentially correct that the radon of Bivins A-10 indeed originates in the dolomite surrounding the well.

The equivalent figure for Thompson B-4 is 0.0035 percent uranium or at least one order of magnitude higher than one would expect. Only a few samples of the reservoir rock are available for measurement, and gamma-ray logs have never been run on this hole. We must conclude that either the dolomite is abnormally radioactive or the radon is derived from some other source.

Assuming a point source, and neglecting any contribution from the dolomite, we must, of course, consider the distance r_0 of the

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12/ Davis, F. J., personal communication, 1950.

13/ Evans, R. D., and Goodman, Clark, Radioactivity of rocks: Geol. Soc. America Bull., vol. 52, 1941, pp. 459-490.

14/ Russell, W. L., The total gamma-ray activity of sedimentary rocks as indicated by Geiger counter determinations: Geophysics, vol. 9, 1944, pp. 180-216.

source from the bottom of the well. The variation of s as a function of r_o is given by equation (9).

For $r_o = r_w$, i.e., the source immediately at the bottom of the well we obtain 17 metric tons of uranium as the minimum source strength, assuming 5 percent radon availability, producing zone thickness $D = 15$ feet, and porosity $p = 20$ percent. The postulated source strength s plotted as a function of r_o at points outward from the well is shown in figure 4 for Thompson B-4. The source strength is expressed as a dimensionless ratio of the source strength at any point to the computed strength at the bottom of the well (17 tons, in this particular case). No allowance is made for migration other than through the dolomite radially toward the well.

These paragraphs illustrate the usefulness of the transport concept. It should be interesting to perform multiple well analyses and effectively "triangulate" for a point source, if such calculations prove to have real meaning.

SUMMARY AND CONCLUSIONS

The presence of relatively large concentrations of helium and radon in the natural gas of the Texas Panhandle is not easily explained if we assume normal geologic conditions. Some of the wells (fig. 3) contain radon in quantities that one would expect from rocks of normal radioactivity (up to about 25 micromicrocuries per liter at standard temperature and pressure). Other wells have been found to contain up to ten times that amount, and the highly radioactive wells

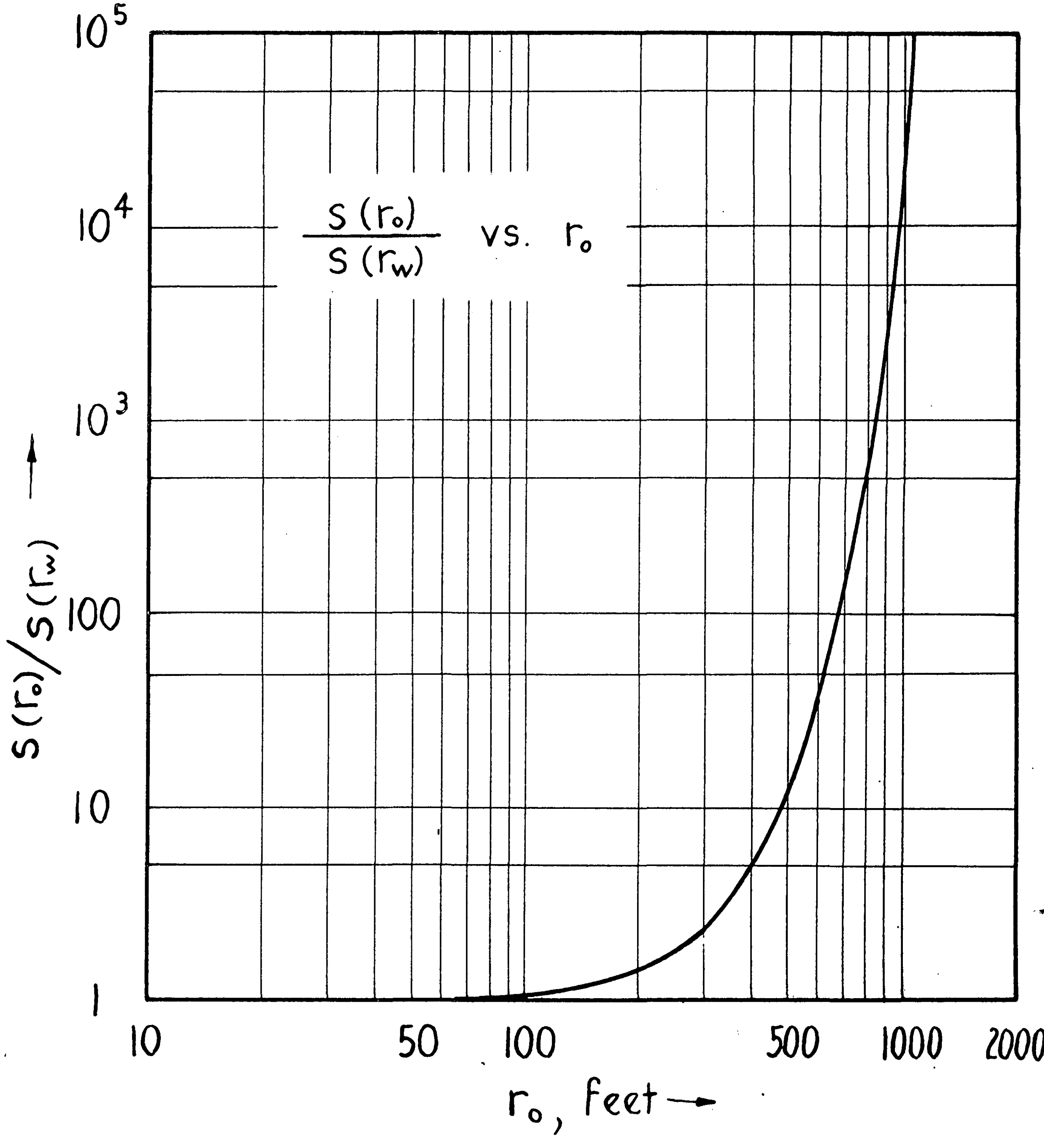

Fig. 4. Strength of a hypothetical point source as a function of r_o, the postulated distance from well Thompson B4. The strength, s, is expressed as the ratio of s at any point to s at the bottom of the well.

seem to occur in groups. Their configuration is likely to reflect broad subsurface features.

Theoretical analysis of the data indicates that the radon in some of the wells cannot originate in rocks of normal radioactivity. It is tentatively suggested that some of the radon may be derived from local concentrations of uranium or radium, but the present state of knowledge does not permit quantitative estimates of the size or grade of such concentrations. It is hoped that this question can be answered conclusively by further research discussed below.

FUTURE RESEARCH

From the map of radon content in the gas (fig. 3) it is obvious that many additional radon measurements are necessary to obtain a picture of the characteristic features of the distribution, as well as the areal extent of the radon-bearing gas. The area to the north is particularly important because of the high radon content of wells on the extreme northern edge of the region examined thus far.

One of the greatest stumbling blocks in the calculations has been the unknown emanating power of granite and dolomite. Various dolomite cores are being collected, and a general study will be made by F. J. Davis at the Oak Ridge National Laboratory to determine the limits within which the gross emanating power of dolomite may lie.

As soon as a fair collection of basement and dolomite samples is assembled, a comprehensive laboratory study will be made to establish the uranium and radium content of reservoir rocks in the helium field and their emanating power. It is expected that this study will show whether or not the radon can originate in the reservoir rock.

Bearing further on this question, it would be instructive to obtain gamma-ray logs of selected wells. Unfortunately the commercial and technological problems of such an undertaking are fairly complex. First, it would be necessary to shut down each well for several weeks to allow for the decay of transported radon. Second, it would be necessary to log the well through a "lubricator," a device that prevents loss of gas from the well while the logging cable is withdrawn. Efforts will be made to explore the possibility of gamma-ray logging some of the wells.

Theoretically, it should be possible to determine whether the radon originates in the reservoir rock by radon measurements during the transient period after complete shutdown of a producing well and before the time when dynamic equilibrium is reached. In other words, we should be able to explore the configuration of source material by measurements on a flowing well, assuming that the well was originally "at rest." Similarly we may gain useful information by measuring the radon content of a well where production is gradually increased.

However, it may be difficult to carry out dynamic measurements of this type without seriously interfering with the commercial procedures of the gas companies. Efforts will be made to obtain as much information as possible during the coming field season by coordinating our measurements with the annual helium survey conducted by the U. S. Bureau of Mines.

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APPENDIX

Radon concentrations (in micromicrocuries per liter at standard temperature and pressure) in natural gas of the Texas Panhandle fields

Channing area:

Well	Radon content ($\mu\mu$ C/L)
Baker A1	86.0
Bivins A2	43.6
Bivins (Lee) A3	19.0
Bivins A4	110.0
" A6	182.0
" A7	104.0
" A8	39.0
" A9	24.0
" A10	7.9
" A13	17.4
" A14	10.2
" A15	35.0
" A17	21.5
" A20	31.0
" A21	66.0
" A22	36.0
" A24	52.0
" A25	79.0
" A31	51.0
" A32	28.0
" A33	107.0
" A34	49.0
" A35	30.0
" A36	41.0
" A38	70.0
" A40	17.0
" A43	35.0
" A48	20.0
" A50	23.0
" A53	44.0
" A54	81.0
" A55	77.0
" A58	44.0
" A59	70.0

Well	Radon content ($\mu\mu$ C/L)
Bivins A60	101.0
" A61	90.0
" A62	75.0
" A65	26.0
" A66	54.0
" E1	77.0
" G1	39.0
" H1	38.0
Bust A1	18.0
" D1	34.0
Bradley A1	26.0
Coughlin A1	31.0
Cooper A1	34.0
Crawford B1	33.0
" D1	50.0
" D2	79.0
Johnson A1	38.0
Kilgore A1	92.0
" A2	143.0
" A3	190.0
" A5	99.0
" A6	226.0
" B1	44.0
Masterson A6	53.0
" A14	67.0
" A15	55.0
" A16	55.0
" B5	55.0
" B6	174.0
" B8	241.0
" B10	213.0
" B14	135.0
" B16	20.0
" F1	197.0
" G2	217.0
" G3	37.0
" H1	80.0
" I1	117.0
" J1	76.0
" J2	27.0
" K1	157.0
" M1	79.0
" M2	
" M3	161.0

Well	Radon content (μμ C/L)
Poling A1	27.2
Thompson B3	114.0
" B4	246.0
Cliffside field:	
(Mixture of 3 wells)	13.0